Centrosema: Biology, Agronomy, and Utilization
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Centroooema: Biology, Agronomy, and Utilization

Edited by R. Schultze-Kraft and R. J. Clements

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Centro Internacional de Agricultura Tropical
Centro Internacional de Agricultura Tropical
Apartado Aéreo 6713
Cali, Colombia

CIAT Publication No. 92
ISBN 958-9183-12-3
Press run: 800
Printed in Colombia
September 1990


1. *Centrosema* — Addresses, essays, lectures. I. Schultze-Kraft, Rainer. II. Clements, Robert J. III. Centro Internacional de Agricultura Tropical.
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PREFACE

Centrosema is a legume genus which, during the past ten years, has been attracting particular interest from tropical pasture scientists. To a large extent, this is because a wide range of germplasm from an increasing number of previously little-known species has become available to researchers. Ten to fifteen years ago, Centrosema meant very little else but common centro (C. pubescens); most other species were known only to taxonomists. Some of these have, in the meantime, given rise to released cultivars (C. pascuorum, C. schiedeanum, and C. acutifolium) and others are, at present, highly promising material at a final prerelease evaluation stage (C. brasilianum and C. macrocarpum). The significance of these and other new species lies in the fact that, in contrast to common centro, they are also productive under marginal ecological conditions where they are able to produce forage of a high quality similar to that of common C. pubescens on fertile soil and in high-rainfall environments.

The considerable research effort during the past decade has resulted in a large body of published and unpublished data. An authoritative review of this research was needed in order to collate the information and focus the ongoing research. This volume, consequently, attempts to present a summary of current knowledge of Centrosema and its potential for providing species for increased animal production and cover crops in plantation agriculture. Contributions from 52 authors, representing a great diversity of disciplines, are brought together in this volume. The authors work in institutions in Australia, tropical Asia and the Pacific, sub-Saharan Africa, subtropical America, and, in particular, tropical America, including the Caribbean region. This reflects the fact that Centrosema research is being conducted throughout the tropical and subtropical world. Particularly comprehensive work is being done in tropical America.

Besides summarizing present knowledge of Centrosema, critical discussion of future research priorities is another objective of this volume. This topic is addressed in each individual chapter and is summarized in the final chapter.

The taxonomy used throughout this volume is described in Chapter 1. It includes the use of the name C. pubescens which, in this volume, refers to the species traded and known agriculturally as "Centrosema
Centrosema: biology, agronomy, and utilization

...pubescens" or "common centro," although the use of this name for this material is probably incorrect (see Chapter 1, p. 8-9).

The chapters in this volume are individual and independent contributions from different authors. Therefore, there is a certain degree of overlapping of subject material in different chapters. In some respects, the overlap is advantageous to the reader interested in a specific topic, because the character of independent and comprehensive state-of-the-art reporting is maintained for the individual chapters. A detailed index at the end of the volume assists in cross-referencing between chapters.

This work was initiated at an international workshop held at the Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia, during 23-27 February 1987. The event was organized by CIAT, and was cofunded by the German Agency for Technical Cooperation (GTZ). Some financial support was also received from the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia. The workshop's Organizing Committee was composed of R. Schultze-Kraft (chairman), C. E. Lascano, J. M. Lenné, and J. M. Toledo (all at CIAT), and R. J. Clements (CSIRO). The Editorial Committee concerned with submissions to the workshop was composed of the members of the Organizing Committee and Susana Amaya (CIAT). The production editor was Elizabeth Páez.

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Chapter 1

**TAXONOMY OF *CENTROSEMA***

R. J. Williams and R. J. Clements*

**Abstract**

*Centrosema* is a member of the diverse Phaseoleae, one of the largest leguminous tribes. Together with *Clitoria, Clitoriopsis*, and *Periandra*, it forms the subtribe Cloriinae. *Centrosema brasiliyanum* and *C. virginianum* were recognized, at least by 1691, under pre-Linnaean names. Bentham recognized 25 species and listed 20 in *Flora brasiliensis* in 1859. By the end of 1986 about 104 species names had been published. After an examination of over 5000 herbarium specimens and 2000 living collections, we recognize 33 species with published names and two unpublished species. The taxonomy used is based mainly on morphological attributes, especially those of the inflorescence. Eleven groups of related species are recognized and discussed, and a key is provided for the 33 validly published species.

Living material is of great value in providing a more complete view of species characteristics and hence a better taxonomy than can be obtained from herbarium specimens alone. Research on functional variation demands living material.

Taxonomic research priorities include (1) cross-compatibility studies; (2) isozyme and other biochemical measures of affinity, especially within the *C. macrocarpum* group; (3) more complete morphological comparison of particular species (*C. acutifolium, C. grazielae*, and some

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proposed new species); (4) more thorough studies of the species in the *Centrosera macrocarpum* group, and of their interrelationships; and (5) further collection to enable (3) and (4) above.

**The Role of Taxonomy**

An understanding of the taxonomy of a group of species or varieties and of the relationships between them is essential before findings in applied botany, agriculture, or basic biology can be put into perspective. In order to extrapolate discoveries about one organism or variety to a species or group of species, and to construct optimal research strategies designed to select varieties with different response patterns, an understanding of species relationships is useful.

Taxonomy is about classification, its methods, and the resulting schema of relationships. It is not primarily aimed at providing names. It is about grouping organisms in such a way that not only are members of one group similar to each other in respect of the attributes used in the classification, but are likely to be similar for other attributes not yet measured. That is, proper circumscription of species should allow populations to be classified in a way which allows predictions to be made about attributes which are not used in the description.

Agricultural scientists are interested mainly in physiologically functional variation, which is often continuous, whereas taxonomists seek reliable, discontinuous characters for separating species or varieties, with little regard for their functional significance (Heywood, 1959). Of course, a variety which is diagnosed by apparently trivial aspects of its morphology may also possess a particular physiological adaptation which is more or less unrelated to the diagnostic criteria. A good example is the existence of races of *Centrosera macrocarpum* which show minor morphological differences but which differ markedly in adaptation to particular soils (Schultze-Kraft, 1986).

In this paper, we limit our taxonomy of *Centrosera* to classical taxonomy, mostly at the species level, with a passing perspective glance at intergeneric relationships and a sampling of the intraspecific diversity. There are many other taxonomies possible such as those based on chemical constituents, rhizobial relationships, or agronomic characteristics, either alone or contributing to a larger taxonomy. In terms of taxonomic method, we have constructed our taxa by observation and measurement, sorting and resorting thousands of
specimens, either living or from herbaria. There are, of course, methods based on computerized clustering, using formal numerical algorithms. These provide a repeatable and seemingly objective way of producing a taxonomy but still demand an arbitrary choice of attributes and measures of similarity. We accept that all these approaches to taxonomy make a contribution but limit ours to one based on morphological studies of over 5000 herbarium specimens and some agronomic knowledge of the field responses of representatives of about 2000 accessions in the *Centrosema* germplasm collections documented by Schultze-Kraft et al. (1987).

**Generic Affinities**

While the name *Centrosema* was first used in a generic sense by Bentham (1837), it had been established by de Candolle (1825) as a section within *Clitoria* to include *Clitoria brasiliana*, *C. plumieri*, and *C. virginiana*. Bentham established the genus under its current name as part of a general study of the Leguminosae which he divided into tribes and subtribes. *Centrosema* was placed in the tribe Phaseoleae and more particularly, with nine other genera, including *Clitoria*, *Periandra*, *Neurocarpum*, *Platysema*, and *Vexillaria*, in the subtribe Clitoriinae.

Bentham struggled with the integrity of this tribe as indeed do current authors. In 1865 he merged the Clitoriinae into a larger subtribe, Glycineae, a motley assemblage of not very closely related genera, which was elevated to the tribal level by Hutchinson in 1964.

Lackey (1977) moved *Clitoria*, *Centrosema*, and their allies to the Phaseolinae but subsequently (1981) reinstated Bentham’s subtribe under the name Clitoriinae with a new circumscription. He reduced it to three of the original genera, *Centrosema*, *Clitoria*, and *Periandra*, as well as a new genus described in 1954, *Clitoriopsis*.

The basic reason for this uncertainty about the membership and affinities of the subtribe was the lack of homogeneity of Bentham’s original cluster, probably brought about by a desire to maintain the core subtribe of the Phaseoloid genera, now called the Phaseolinae, as compact as possible. All this suggests that the genera are not very close to each other. Two species treated here as *Centrosema* (*C. platycarpum* and *C. triquetrum*) may be better removed to another genus, as it is clear that they do not belong with those currently recognized. Common features of the Clitoriinae are usually resupinate flowers and constant
presence of hooked hairs (Lackey, 1981). Hooked hairs, however, also occur in *Phaseolus*. The genus *Centrosema* is set apart by the following characters: the common occurrence of canavanine in *Centrosema* and its absence in the other genera of the subtribe (Bell et al., 1978); the development of a specialized functional organ (the vexillar spur); a short calyx tube; and a bracteole which is large in relation to the size of the bract. While introgression may occur between some species of *Centrosema*, it is most unlikely that it could occur between any *Centrosema* and species of other Clitoriinae.

The name *Centrosema* is a nomen conservandum under the *International Code for Botanical Nomenclature* (Voss et al., 1983). It is therefore conserved against arguments of illegitimacy and against *Steganotropis* (which is an earlier name). The type species of *Centrosema* is conserved to be *C. brasilianum* (L.) Benth.

The Discovery of Species

Linnaeus (1753) listed two species under *Clitoria* which are currently accepted as *Centrosema: Clitoria brasiliana* and *C. virginiana*. It should be noted that these species were known to Pluknet (1691) in pre-Linnaean taxonomy. While the present system of binomial nomenclature dates from 1753, it is true to say that these two species have been known to science for 300 years. By 1825, when de Candolle listed three species within his section *Centrosema*, a total of six were known which are still recognized. In addition to *Clitoria brasiliana, C. plumieri,* and *C. virginiana* which were recorded by de Candolle, *Clitoria angustifolia, C. capitata,* and *Glycine sagittata* had also been described.

Bentham (1837) listed 25 species, including two under other genera: *Vexillaria grandiflora* (syn. *C. platycarpum*) and *Platysema triquetrum*. He was apparently unaware of Richard’s publication (1792) of *Clitoria capitata*. By 1859, when he again reviewed the group for Martius’ *Flora brasiliensis*, another 18 species had to be considered, bringing the then total to 43. Bentham reduced 20 of these to synonymy, deferred consideration of *C. macrocarpum* because he knew of no Brazilian examples, ignored *Platysema triquetrum*—one of his 1837 species—and did not consider the Mexican species *Centrosema grandiflorum* (Mart. et Galeotti) Walp. which we take as conspecific with *C. schiedeanum*. As a result, he listed 20 species for Brazil.
Between 1859 and 1986, another 42 names were published. Altogether, between 1753 and 1986, there have been about 104 names which possibly refer to *Centrosea*. The most recently published comprehensive study is that for Brazil by Barbosa-Fevereiro (1977) who recognized 26 species, including *C. grazielae* which she described in 1974.

Our intention here is to summarize our view of the genus, to present a list of species with comments on their relationships, and to provide a key to the species as we see them.

Most of the 104 names are rejected because they refer to species which we consider conspecific with another whose name has priority. As a result, we recognize 33 species which have already been named. These are listed in Table 1, together with three other species whose separate identity needs further research: *C. longifolium* Benth., *C. magnificum* Malme, and *C. snethlageae* (Ducke) Fantz.

In addition to these species, we have found specimens of new species that have not yet been named and described. One of these is sufficiently well represented in our genetic resource collection to need a label for the purpose of this overall study on *Centrosea*. We therefore refer to it as “new sp. No. 4.” Another new species not yet published is *C. tetragonolobum,* found and identified by R. Schultze-Kraft. Other apparently new entities are mentioned under the species group to which they relate but we prefer not to label them until we are confident of their circumscription.

**Attributes of Taxonomic Value**

The attributes which are useful as species discriminants have particular features. Obviously, they must be variable across the genus. Furthermore, in taxa considered to be advanced in an evolutionary sense, and where canalization (in the sense of Stebbins, 1974) has occurred again and again, they may be peripheral to the real evolutionary pressures. They are likely to be those same attributes whose very presence characterizes the genus or tribe to which the species belong. In advanced genera such as *Centrosea*, the overall ground plan, within which diversity and adaptation occur, has become fixed and constrained to narrowing options even though speciation continues.
Table 1. Status, descriptive sources, and synonymy of *Centrocoma*.

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<th>Sources of best description</th>
<th>Synonyms</th>
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<td>Bentham, 1837</td>
<td><em>heteroneurum</em> Standley <em>simulans</em> Standl. &amp; Williams <em>longifolium</em> Benth.?</td>
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<tr>
<td><em>arenarium</em> Benth.</td>
<td>Barbosa-Fereiro, 1977b</td>
<td><em>floridanum</em> (Britton) Lakela</td>
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<td><em>arenicola</em> (Small) Herm.</td>
<td>Clements and Williams,</td>
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<td>Small, 1903</td>
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<td><em>bifidum</em> Benth.</td>
<td>Barbosa-Fereiro, 1977</td>
<td><em>brevilobulatum</em> Pilger</td>
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<td><em>brachypodium</em> Benth.</td>
<td>Bentham, 1839</td>
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<td><em>bracteosum</em> Benth.</td>
<td>Barbosa-Fereiro, 1977</td>
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<td><em>brasilianum</em> (L.) Benth.</td>
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<td>Belalcázar and</td>
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<td>Schultzze-Kraft, 1986</td>
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<td><em>capitatum</em> (L.C. Rich.) Amsh.</td>
<td>Amshoff, 1939;</td>
<td><em>salzmannii</em> Benth.</td>
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<td>Macbride, 1943</td>
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<td><em>carajasense</em> Cavalc.</td>
<td>Barbosa-Fereiro, 1977;</td>
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<td>Cavalcante, 1970</td>
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<td><em>coriaceum</em> Benth.</td>
<td>Barbosa-Fereiro, 1977</td>
<td><em>oblongum</em> Benth.</td>
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<td><em>dasyanthum</em> Benth.</td>
<td>Barbosa-Fereiro, 1977</td>
<td><em>glabrum</em> Benth.</td>
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<td><em>fasciculatum</em> Benth.</td>
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<td><em>grandiflorum</em> Benth.</td>
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<td><em>graziela</em> Barbosa</td>
<td>Barbosa, 1974;</td>
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<td></td>
<td>Barbosa-Fereiro, 1977</td>
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<td><em>heptaphyllum</em> Moric.</td>
<td>Moricand, 1840</td>
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<td><em>jaraguaense</em> Hoehne</td>
<td>Barbosa-Fereiro, 1977;</td>
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<td>Hoehne, 1926</td>
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<td><em>latidens</em> Killip &amp; Macbride</td>
<td>Macbride, 1943</td>
<td><em>bellum</em> Vilchez</td>
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<td><em>macrocarpum</em> Benth.</td>
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<td><em>lisboae</em> Ducke</td>
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<td>Pittier, 1944</td>
<td><em>seymourianum</em> Fantz</td>
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<td><em>pascoorum</em> Mart. ex Benth.</td>
<td>Barbosa-Fereiro, 1977;</td>
<td><em>magnificum</em> Malme?</td>
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### Taxonomy of Centrosema

#### Table 1. (Continued)

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<th>Synonyms</th>
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<td><em>plumieri</em> (Turp. ex Pers.) Benth.</td>
<td>Barbosa-Feveireiro, 1977; Pittier, 1944</td>
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<tr>
<td><em>pubescens</em> Benth.(^c)</td>
<td>Barbosa-Feveireiro, 1977; Bentham, 1859</td>
<td><em>molle</em> Mart. ex Benth.</td>
</tr>
<tr>
<td><em>rotundifolium</em> Mart. ex Benth.</td>
<td>Barbosa-Feveireiro, 1977</td>
<td></td>
</tr>
<tr>
<td><em>sagittatum</em> (H. &amp; B. ex Willd.) Malme</td>
<td>Barbosa-Feveireiro, 1977; Humboldt et al., 1824</td>
<td><em>hastatum</em> Benth.</td>
</tr>
<tr>
<td><em>schiedeanaum</em> (ined.)</td>
<td>Schlechtendal, 1838(^d)</td>
<td><em>galeottii</em> <em>galeottii</em> Fantz</td>
</tr>
<tr>
<td><em>schottii</em> (Millsp.) K. Schum.</td>
<td>Barbosa-Feveireiro, 1977, as <em>macranthum</em> Hoehne</td>
<td><em>kermesi</em> Burkart</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Burkart, 1937, as <em>kermesi</em>;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pittier, 1944, as <em>plumieri</em></td>
</tr>
<tr>
<td><em>tapirapoanense</em> Hoehne</td>
<td>Barbosa-Feveireiro, 1977; Hoehne, 1922</td>
<td><em>prehensile</em> Ducke</td>
</tr>
<tr>
<td><em>triquetrum</em> (Hoffm. ex Benth.) Benth. &amp; Hook</td>
<td>Barbosa-Feveireiro, 1977; Ducke, 1922, as <em>latissimum</em></td>
<td><em>latissimum</em> Ducke</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>venosum</em> Mart. ex Benth.</td>
<td>Barbosa-Feveireiro, 1977</td>
<td></td>
</tr>
<tr>
<td><em>vetulum</em> Mart. ex Benth.</td>
<td>Barbosa-Feveireiro, 1977</td>
<td></td>
</tr>
<tr>
<td><em>vexillatum</em> Benth.</td>
<td>Barbosa-Feveireiro, 1977</td>
<td></td>
</tr>
<tr>
<td><em>virginianum</em> Benth.</td>
<td>Barbosa-Feveireiro, 1977; Burkart, 1937; Clements and Williams, in preparation; Correll and Correll, 1982, as <em>angustifolium</em></td>
<td><em>biflorum</em> Mart. ex Benth.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>decumbens</em> Mart. ex Benth.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DOUBTFUL SPECIES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>longifolium</em> Benth.</td>
<td>Bentham, 1837</td>
<td>part of *angustifolium?</td>
</tr>
<tr>
<td><em>magnificum</em> Malme</td>
<td>Malme, 1931</td>
<td>part of *macracarpum?</td>
</tr>
<tr>
<td><em>snethlageae</em> (Ducke) Fantz</td>
<td>Ducke, 1922</td>
<td>near <em>dasyanthus</em></td>
</tr>
</tbody>
</table>

\(^a\) But includes *C. brasilianum* var. *angustifolium*.

\(^b\) But includes *C. brachypodum*.

\(^c\) As applied by Bentham (1859) and here.

\(^d\) As *Clitoria schiedeana*.
The morphological features which characterize species may be functional only in a limited way, frequently with respect to reproductive biology. They may relate to ecological adaptation in no other way than as part of a coadapted and coevolving character complex which hopefully includes physiological attributes of interest to plant breeders and agronomists. In this sense, morphological attributes merely flag the boundaries of a set of populations which have responded to selection pressures in a common way. Within such species and varieties we should be able to extrapolate from information about one population to another, providing we can discover the rules of the pattern of variation.

The attributes which have been found to be useful in delineating Centrosera spp. and in determining individual specimens or populations are listed in Table 2. As discussed above, these relate to the key marker attributes of the tribe or subtribe and genus.

Recognized Species

The key presented in the Appendix of the chapter depends heavily on the characteristics listed in Table 2. It was not possible to delineate even one species on one character alone; instead, character complexes are involved.

Table 1 lists in alphabetical order the 33 species that we recognize but, in the following discussion, the species are grouped into related sets in about the same order as in the key. Illustrations of the species are presented in color plates I to X in Appendix I of the book. The natural distribution of the species is discussed by Schultze-Kraft et al. (see Chapter 2).

We distinguish the species referred to in this paper as Centrosera schiedeanum (comb. ined., syn. Clitoria schiedeana Schlecht.) from that commonly distributed and referred to by recent authors as Centrosera pubescens Benth. ("centro"). We include in C. schiedeanum the Mexican material referred to under this name by Schultze-Kraft et al. (1987) and most other herbarium material distributed under this name or as Clitoria schiedeana, as well as the cultivar "Belalto." We continue to refer to the other species as Centrosera pubescens, the name under which it is known agriculturally. We do this even though our studies have shown that the type material of C. pubescens is distinct from the species commonly known under that name and indeed is conspecific with what we call C. schiedeanum. However, until a correct name can
**Taxonomy of Centrosema**

Table 2. Attributes of taxonomic value in *Centrosema*.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Species fidelity 1 to 5 (low to high)</th>
<th>Environmental stability 1 to 5 (low to high)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant habit</td>
<td>4</td>
<td>3</td>
<td>Small range of forms</td>
</tr>
<tr>
<td>Stem diameter</td>
<td>3</td>
<td>3</td>
<td>Too variable mostly</td>
</tr>
<tr>
<td>Stipule shape</td>
<td>4</td>
<td>4</td>
<td>Useful only for a few species</td>
</tr>
<tr>
<td>Stipule size</td>
<td>2</td>
<td>3</td>
<td>Useful only for a few species</td>
</tr>
<tr>
<td>Leaf type</td>
<td>5</td>
<td>4</td>
<td>Only 4-5 categories</td>
</tr>
<tr>
<td>Leaflet shape</td>
<td>4</td>
<td>3</td>
<td>Difficult to define</td>
</tr>
<tr>
<td>Leaflet size</td>
<td>2</td>
<td>2</td>
<td>Usually too variable</td>
</tr>
<tr>
<td>Leaflet venation</td>
<td>5</td>
<td>4</td>
<td>Complex to describe</td>
</tr>
<tr>
<td>Leaflet texture</td>
<td>3</td>
<td>3</td>
<td>No standard descriptions of categories</td>
</tr>
<tr>
<td>Leaflet pubescence</td>
<td>3</td>
<td>3</td>
<td>Too variable</td>
</tr>
<tr>
<td>Inflorescence type</td>
<td>3</td>
<td>3</td>
<td>Useful in extremes</td>
</tr>
<tr>
<td>Peduncle length</td>
<td>3</td>
<td>2</td>
<td>Useful in extremes</td>
</tr>
<tr>
<td>Peduncle to petiole ratio</td>
<td>4</td>
<td>4</td>
<td>Only 2-3 categories</td>
</tr>
<tr>
<td>No. of flowers per peduncle</td>
<td>5</td>
<td>4</td>
<td>Categories not linear; i.e., 1-2, 2-10, 8-40 flowers</td>
</tr>
<tr>
<td>Pedicel bract shape</td>
<td>4</td>
<td>4</td>
<td>Only 3-4 categories</td>
</tr>
<tr>
<td>Pedicel bract size</td>
<td>3</td>
<td>4</td>
<td>Only 3-4 categories</td>
</tr>
<tr>
<td>Bracteole shape</td>
<td>5</td>
<td>4</td>
<td>About 6 categories</td>
</tr>
<tr>
<td>Bracteole size</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Ratio of bracteole length to calyx tube length</td>
<td>4</td>
<td>4</td>
<td>Only 2-3 categories used</td>
</tr>
<tr>
<td>Calyx teeth</td>
<td>4</td>
<td>4</td>
<td>Various relations</td>
</tr>
<tr>
<td>Color of standard</td>
<td>2</td>
<td>4</td>
<td>Pattern is more reliable</td>
</tr>
<tr>
<td>Color of keel and wings</td>
<td>4</td>
<td>4</td>
<td>Not very discriminatory</td>
</tr>
<tr>
<td>Spur character</td>
<td>5</td>
<td>5</td>
<td>Only 3 categories</td>
</tr>
<tr>
<td>Style and stigma form</td>
<td>5</td>
<td>5</td>
<td>Requires careful dissection</td>
</tr>
<tr>
<td>Pod characters</td>
<td>4</td>
<td>4</td>
<td>Reliable but discriminatory for only a few species</td>
</tr>
<tr>
<td>Seed characters</td>
<td>3</td>
<td>4</td>
<td>Reliable but discriminatory for only a few species</td>
</tr>
</tbody>
</table>

be found for the species known agriculturally as *Centrosema pubescens,* we will continue to use that name for that species and the later synonym *Centrosema schiedeanum* for the species first discussed above.

**The Species Groups**

Some species are more closely related to each other than they are to others. The species therefore are examined as a number of groups, each
group containing two or more species. These groups may well correspond to taxonomic categories such as "series" and "subseries," but we do not propose to accord them this status here. The groups are:

Group 1: *Centrosera dasyanthum*, *C. latidens*, *C. jaragualaense*, *C. vetulum*

Group 2: *C. arenicola*, *C. pascuorum*, *C. virginianum*

Group 3: *C. acutifolium*, *C. capitatum*, *C. grandiflorum*, *C. grazielae*, *C. macrocarpum*, *C. pubescens*, *C. schiedeanum*, *C. new sp. No. 4* (ined.)

Group 4: *C. bracteosum*, *C. venosum*

Group 5: *C. rotundifolium*, *C. heptaphyllum*

Group 6: *C. arenarium*, *C. brachypodium*, *C. coriaceum*

Group 7: *C. angustifolium*, *C. bifidum*, *C. brasiliannum*, *C. "tetragonolobum"* (ined.)

Group 8: *C. tapirapoenense*, *C. vexillatum*

Group 9: *C. carajasense*, *C. fasciculatum*, *C. sagittatum*

Group 10: *C. plumieri*, *C. schottii*

Group 11: *C. platycarpum*, *C. triquetrum*

**Group 1: Centrosera dasyanthum, C. latidens, C. jaragualaense, and C. vetulum**

From an evolutionary viewpoint this group seems less specialized than the rest of the genus. The spur is incompletely developed; the calyx segments are more or less equal sized and broad, and the veins semireticulate; and the inflorescence is sometimes racemose. *Centrosera snethlageae* (Ducke) Fantz may well belong to this group. We have taken *C. belkum* Vilchez to be a synonym for *C. latidens*.

As accepted here, *C. dasyanthum* is somewhat more variable than either the type description or that of Barbosa-Fevereiro (1977). Some specimens from Minas Gerais, Brazil, have long, lanceolate, glabrescent calyx teeth; almost glabrous, semioriaceous, lanceolate bracteoles; and leaves similar to those of *C. latidens* but less pubescent beneath.

The group is poorly represented in collections, especially *C. latidens*. 10
**Group 2: Centrosema arenicola, C. pascuorum, and C. virginianum**

Because of their long narrow calyx teeth, these three species are easily keyed together. Nevertheless, the distinctive leaf venation, stipules, and pod of *C. pascuorum*, together with its chromosome number of $2n=22$ compared with 18 for the others, suggest that this group is not really homogeneous. *Centrosema virginianum* is a widely distributed and extremely variable species, with a multitude of races and several botanical varieties (see p. 17-19). It is distributed from about latitude 41° N on the east coast of USA, through Mexico, Central America, and the Caribbean islands, and all tropical South American countries, to about latitude 36° S in Argentina. *Centrosema arenicola* is, by contrast, uniform and restricted to a small area in Florida, USA. The two species are separated genetically by a reproductive barrier (R. J. Clements, unpublished data). Although *C. pascuorum* and *C. virginianum* have been confused for more than a hundred years because of the similarity of their flowers in pressed specimens, the two species are distinct and not closely related.

**Group 3: Centrosema acutifolium, C. capitatum, C. grandiflorum, C. grazielae, C. macrocarpum, C. pubescens, C. schiedeanum, and Centrosema new sp. No. 4 (ined.)**

Because of the central position of *C. macrocarpum* (see below), this group is also referred to as the *C. macrocarpum* group.

Apart from the nomenclatural problems of *C. pubescens* and *C. schiedeanum* discussed above, the real difficulty with this group is the blurring of the species boundaries. One solution would be to take the whole set as one large polymorphic species—a coenospecies or species complex. Reduction of the current species to the level of varieties does not overcome the problem of merging boundaries; it simply changes the nomenclature. The argument that because they are potentially intercrossable or in fact do intercross, when brought together in experiments or occasionally in the field, is irrelevant. The real test of the independence of these species is whether they are, on the whole, morphologically distinct and isolated from each other in nature by genetic, geographic, or ecological isolation, or by other aspects of reproductive biology such as the nature of the breeding system or the specificity of pollinators.
Most forms of *C. macrocarpum* show specialized pollen-vector guide patterns on the standard and there is evidence of obligate cross-fertilization in this species. In *C. pubescens*, cleistogamy is common and, in the living material known to us, cross-fertilization, if it occurs, is not obligate. Even though such species may be crossed and show high cross-compatibility, in nature they are effectively isolated by differences in reproductive biology, supported by differences in habitat, and other isolating factors. Effective isolation, although not leading to intergroup barriers, will lead to isolation of the species in terms of the various gene complexes important for adaptation.

Whether the *C. macrocarpum* group is a single species or a group of related but distinct species affects more than our nomenclature. Both the agronomist and the biologist are interested in relating patterns of variation to adaptation to the environment. It is important to know where the species boundary and, therefore, the “boundary of like responses” lies. For the breeder, it is important to know if species are close to each other, even so close that introgression occurs. In such proximities lie the possibility of interspecific breeding and the construction of novel character combinations.

Considering the nature of the calyx, growth habit, woodiness, size, and floral color patterns, a likely evolutionary relationship is suggested in Figure 1. The implication here is that *C. macrocarpum* is the archetype of the group derived from some “pre-Centrosema”

![Diagram of probable evolutionary relationships of *Centrosema macrocarpum* and allied species.](image)

**Figure 1.** Probable evolutionary relationships of *Centrosema macrocarpum* and allied species.
germplasm. *Centrosea macrocarpum* has the largest leaves, calyx tube and teeth, and pods. It has complex nectar-guide color patterns on the standard. Together with more lignified stems and a deep root system, all these characters suggest that it is probably close to the archetype from which other members of the group have evolved. The considerable variation which exists has been classified and described by Schultz-Kraft (1986). In addition to this variation, we include in *C. macrocarpum* the very large *C. lisboa* and probably *C. magnificum*, as did Barbosa-Fevereiro (1977). The latter species, with its very large calyx teeth and distinctive, very large, ovate but attenuate leaflets seems distinct, but it has only been collected once. Because it was collected in the same location as *C. tapirapoanense*, it is possible that it is a hybrid between the latter and *C. macrocarpum*.

In the Guianas, Tobago, and the tropical latitudes of Brazil and Peru, *C. capitatum* occurs, distinguished from *C. macrocarpum* by smaller, more ovate, but mostly acuminate, leaflets, and very long, narrow, falcate bracteoles within pseudocapitate peduncles. The pods are usually strongly falcate and thickened toward the sutures, although some collections made in Mato Grosso and Goiás, Brazil, lack the falcate pod. Numerous collections of this species were once distributed under its synonym, *C. salzmannii*.

*Centrosea pubescens* is the most widespread member of the group and represents a usually smaller leaved form with calyx teeth smaller than *C. macrocarpum*. It is usually prolific in seed production, facilitated by its frequently cleistogamous self-compatability. Some introgression apparently occurs between this species and *C. macrocarpum*, *C. schiedeanum*, and *C. acutifolium*.

In subtropical eastern Brazil, south of latitude 15° S, *C. grandiflorum* occurs. Although its leaves are frequently as large as those of *C. macrocarpum*, the undersurfaces are usually strongly pubescent and frequently tomentose. It is also distinguished from *C. macrocarpum* by its slightly smaller pods and blue-violet flowers. There is some evidence of introgression with *C. macrocarpum* in the region near Brasília.

In the northern hemisphere, toward the subtropics, or in the submontane tropics, *C. schiedeanum* occurs, occasionally introgressing with *C. macrocarpum*. Although in some ways it is the northern equivalent of *C. grandiflorum*, this species is distinct and usually smaller leaved, but still larger than *C. pubescens* with which it is occasionally contiguous or even sympatric.
We take *C. grandiflorum* (Mart. et Galeotti) Walp.—not that of Bentham—to be synonymous with *C. schiedeanum*, although Fantz (1979) either felt that it was sufficiently different to name it separately as *C. galeottii* or was unaware of *C. schiedeanum*. In Mexico, there appears to be introgression between *C. schiedeanum* and *C. macrocarpum*. Fantz (1979) has erected a separate species, *C. seymourianum*, for a large-leaved *Centrosema* from Nicaragua which we take as conspecific with *C. macrocarpum*. Because Central American and Mexican forms seem to continuously intergrade through Colombian to Brazilian forms, more evidence is needed before they can be segregated into distinct species.

*Centrosema acutifolium* clearly belongs to this group, although it has strongly reduced dorsal and lateral calyx teeth. The species has been neglected by recent authors, probably because of the inadequate quality of the type material. However, the intensive germplasm collections made for forage plant programs have resulted in the recognition of this distinct species. Some Colombian samples may be outside the range of *C. acutifolium* and need to be studied further.

*Centrosema grazielae* has even more strongly reduced dorsal and lateral calyx teeth, with the lateral teeth more remote from the lower tooth than in *C. acutifolium*, from which it is readily distinguished by its torulose pods, more elliptical leaflets, and occasional amphicarpy. While the holotype specimen has lobed leaflets, these have not been seen in other specimens and indeed, do not occur in some isotypes seen.

Possibly five other taxa have been identified that relate to this group, the mostly widely collected being one temporarily referred to as new sp. No. 4 in the genetic resource collections from central Brazil.

**Group 4: Centrosema bracteosum and C. venosum**

These two species may have affinities with the large *C. macrocarpum* group discussed above. They also share with *C. rotundifolium* and *C. heptaphyllum* similar calyx and bracteole proportions, a prostrate slender growth habit, amphicarpy, and thickened falcate pods.

**Group 5: Centrosema rotundifolium and C. heptaphyllum**

These two species are probably the most closely related of all 33 species which have been accepted here. *Centrosema rotundifolium* is
most commonly found with the pinnate trifoliolate leaves typical of the genus. It is prostrate with strong amphicarpy. *Centrosera heptaphyllum*, however, has a 5-7 pinnate leaf with leaflets of a different shape; narrower bracts, bracteoles, and stipules; a semierect growth habit; and a swollen taproot. Further collection is needed to establish whether we are really dealing with two distinct species or a continuum.

**Group 6: Centrosera arenarium, C. brachypodum, and C. coriaceous**

These three species have a similar calyx type; the dorsal and lateral teeth are reduced, the latter being triangular. The peduncles are many-flowered and vary in size; the smallest are reduced to almost axillary fascicles, while the largest are obvious peduncles that are as long as 60 mm. They have pods thickened toward the sutures without becoming torulose as in *C. brasiliense*.

*Centrosera coriaceous* is distinct because of its usually oblong-elliptical leaflets which are set at an obvious acute angle to the rachis, are coriaceous, and almost glabrous. *Centrosera arenarium* is distinguished by being thick-stemmed and having a semierect habit when young. Subsequently, it may develop an open twining habit, with young branches and leaves tomentose or at least pubescent. *Centrosera brachypodum* has sparsely hirtellous to glabrous, ovate-acuminate leaflets, with narrower stipules and obliquely acuminate ovate bracteoles. The three species have contiguous and complementary, rather than overlapping, geographical ranges in eastern to northeastern Brazil.

**Group 7: Centrosera angustifolium, C. bifidum, C. brasiliense, and C. “tetragonolobum” (ined.)**

This group (*C. brasiliense* group) shows a leaflet shape which is usually elliptical-oblong to lanceolate, occasionally becoming ovate. In *C. angustifolium* it becomes narrow to linear. The bracteoles are large and completely enclose the calyx until full corolla development occurs when the bracteole may be shorter than the lower (ventral) tooth. The flowers tend to be violet-purple and the pods torulose or, as in *C. angustifolium*, at least convex.

Within *C. brasiliense* we recognize var. *angustifolium* Amsh., a variety distinct from the separate species *C. angustifolium*. Although
there is continuing confusion between these two taxa such as by Barbosa-Fereverio (1977), the species are distinct, with *C. brasilianum* having the larger distribution range in South America, and *C. angustifolium* extending into Central America where it has been also described under the synonyms *C. heteroneurum* and *C. simulans*.

*Centrosema bifidum* is clearly distinct and recognizable by its large, rigid, and coriaceous bracteoles and large lanceolate leaflets.

Another species closely allied to *C. brasilianum* has been collected by R. Schultze-Kraft and is referred to as "*C. tetragonolobum."* This species differs from the former mainly by having the pod sutures considerably enlarged into four obvious wings.

**Group 8: *Centrosema tapirapoanense* and *C. vexillatum***

These two species both have the typical remote but reduced triangular lateral calyx teeth and the large bracteoles of the *C. brasilianum* group. They differ from that group by having even larger papery bracteoles and flattened, slightly convex, broad pods with barely thickened sutures and abruptly acuminate apices. The two species are usually distinguished from each other by their leaflet shape and texture and bracteole shape.

**Group 9: *C. carajasense*, *C. fasciculatum*, and *C. sagittatum***

These three species are unifoliolate with the petiole strongly winged. *Centrosema carajasense* is clearly distinguished from the others by the shape and texture of the leaflet. Although we have separated *C. sagittatum* and *C. fasciculatum* mainly on the basis of the length of the lower calyx tooth, neither this character nor others are consistently related, as was suggested by Barbosa-Fereverio (1977), to the incision of the upper calyx lobe. Separation of these two species is therefore questionable.

**Group 10: *Centrosema plumieri* and *C. schottii***

Although remarkably similar in stem, leaf, bracteole, and calyx characters, these species are easily distinguished from each other: *C. schottii* has a torulose to quadrangular pod, whereas *C. plumieri* has a broad, flattened, convex pod with raised lateral nerves 2-3 mm from 16
Taxonomy of Centrosema

each suture. The lower calyx tooth in both is short and triangular, while the other teeth are almost obsolete, visible only as undulations on the large campanulate calyx. *Centrosema schottii* has been reported under various names. Apart from *C. macranthum* (Brazil), it has been referred to as *C. haitiense* (Haiti), *C. kermesi* (Argentina), and *C. lobatum* (Cuba).

Group 11: *Centrosema platycarpum* and *C. triquetrum*

These two species differ from all others treated here by the reduction of the spur to a gibbous suture at the junction of the vexillum and its sinuous claw. The corolla is large, and may be half as broad again as long, with crested wings. The pods of the two species are very large but distinct from each other. Those of *C. triquetrum* range from 60-180 mm long and 30-50 mm wide, with wings on each suture. *Centrosema platycarpum* has woody pods which are compressed but not flat, falcate to semisinuate, with two wings on the vexillary suture, bare on the carinal suture, but with a thickened central nerve. The style and stigma differ from other *Centrosema* species as do the orbicular stem-clasping stipules. Although they have been treated as *Centrosema* here, we believe that these two species should be removed from *Centrosema*. Both species were originally referred to distinct genera: *C. platycarpum* to Vexillaria and *C. triquetrum* to Platysema. *Centrosema triquetrum* has been referred to under other synonyms (Table 1).

Intraspecific Variation

Varieties have been named in the following species: *C. arenarium*, *C. brasilianum*, *C. coriaceum*, *C. pascuorum*, *C. rotundifolium*, and *C. virginianum*. We believe that varieties of two of these species (*C. coriaceum* and *C. pascuorum*) cannot be justified. However, there are several other variable species which could be classified into intraspecific taxa, while some of the species listed in Table 1 may eventually prove to be mere varieties.

*Centrosema virginianum* is by far the most variable and widely distributed species. It has 25 synonyms and 12 named varieties. Our attempts to classify this intraspecific variation will be considered here in some detail, because they illustrate the problems that complicate any exercise of this kind. In many respects, the same problems occur in the classification of species within the *C. macrocarpum* group.
The varieties of *C. virginianum* we recognize are as follows:

*C. virginianum* (L.) Benth. var. *virginianum*

var. *angustifolium* (DC.) Grisebach
var. *decumbens* (Mart. ex Benth.)
Clements & Williams (ined.)
var. *unifoliatum* (Rose) Clements & Williams (ined.)
var. *simplicifolium* A. Rich.
var. *cubanum* Clements & Williams (ined.)

These varieties are useful in classifying the most obvious morphological variants of *C. virginianum*, but much of the morphological variation in the species is more or less continuous and is therefore difficult to describe by traditional taxonomic methods. A significant amount of variation is regionally coherent (that is, one can easily recognize plants from different regions). An attempt has been made to describe this regional variation, by defining 15 geographical and climatic regions and characterizing the plants within each region (R. J. Clements and R. J. Williams, unpublished data). The following four generalizations can be made:

A center of morphological diversity of *C. virginianum* is found in the Caribbean region and nearby parts of Central America and Florida. More than half of the 53 geographical races (and five of the six taxonomic varieties) occur in this area. Material from Cuba is particularly variable with respect to leaflet number, shape, and pubescence. Unifoliolate varieties occur in both Cuba and Central America (Mexico and Guatemala). The small, yellow seeds which are characteristic of all Cuban accessions contrast strikingly with those from most other islands (especially the Bahamas) and mainland USA.

Some combinations of characters occur in more than one region. For example, a “maritime” or mesic influence can be seen in specimens from the Brazilian southeastern seaboard, the Caribbean islands, and parts of the USA coastline. These specimens are characterized by rather large, thin leaflets and thin calyx teeth. These features do not always reflect underlying genetic adaptations; the distinctions that are so obvious in herbarium specimens frequently vanish when living collections from the same locations are transferred to less favorable environments. Other features such as narrow leaflets, are more strongly genetically controlled, but occur in diverse habitats and
probably represent common genetic adaptations to a range of environmental stimuli.

In general, specimens of *C. virginianum* from a particular geographic region resemble most closely the material from an adjacent region. Specimens from the Uruguayan and coastal Rio Grande do Sul region and from the semi-arid region of northeastern Brazil are least closely similar to material from other regions, at least for those characters used for the analysis.

Despite the wide morphological variation within *C. virginianum* and the enormous geographical range of the species (about 8000 km from north to south), there is little evidence of reproductive barriers between varieties or regional races (R. J. Clements, unpublished data). Only one cross produced near-sterile F₁ progeny.

What has been gained from examining variation within *C. virginianum*? In terms of description, a great deal of progress has been made, but in terms of useful classification, the results have been disappointing. The botanical varieties distinguish only a few extreme morphological variants. The concept of geographical regions is helpful in understanding patterns of morphological variation but, in general, the variation in each region overlaps with that in other regions.

**The Value of Living Collections**

Living collections permit experimental studies of the environmental responses of different populations. Given the difficulties in understanding variation at the infraspecific level, the development of a genetic resources database containing passport and performance data may provide an alternative and more direct way of selecting populations for particular plant-breeding goals. Familiarity with living collections can also point to errors in classification derived from herbarium material. For example, we believe that incorrect determinations such as those for some specimens incorrectly determined as *C. pascuorum* and cited in *Flora brasiliensis*, arose through unfamiliarity with the key differences which stand out in living material.

Another example of the value of living collections is the separation of *C. arenicola* from *C. virginianum*. *Centrosera arenicola* plants have a swollen taproot which develops commonly from trailing aboveground stems; we have not seen this organ on any herbarium specimen of this species.
In addition to their value in allowing us to see morphological characters which cannot be appreciated from herbarium specimens, living plants are essential for cytology, for studies on breeding systems and on genetic barriers between species (for example, on cross-compatibility within the *C. macrocarpum* group of species), for many chemotaxonomic studies (for example, analysis of species relationships, using isozyme characterization), and for studies on the genetics of plant form and on the stability of form in relation to the environment. In general, research on functional variation relies heavily on living material. Thus, a combination of taxonomy, genetics, agronomy, and other disciplines can provide a much clearer understanding of genetic diversity within *Centrosema* than any one discipline can do (Clements and Williams, 1980).

**Priorities for Future Taxonomic Research**

A monographic review of *Centrosema* is proposed by the current authors, based on all material available to us until the end of 1986. Subsequent continual collection and research are likely to add further species to the genus and may modify the taxonomy and circumscription of those we currently recognize. Our current taxonomy represents a view of our knowledge now.

The priorities for research as we see them are:

Further experimental study of cross-compatibility, by controlled crossing and by biochemical studies, including isozyme analyses of the taxa within the *C. macrocarpum* group.

More complete morphological comparison of certain species such as *C. acutifolium* and *C. grazielae*, and comparisons between *C. schiedeanum* from Mexico and Costa Rica, on the one hand, and collections with apparent affinities to *C. schiedeanum* from Colombia on the other. These comparisons will require further collection, detailed morphological comparison, and experimentation with living material.

A more detailed study of variation within *C. pubescens*, especially of the collection represented in germplasm collections.

Further field collections in Mexico and Central America are needed to understand the range and interspecific relationships of what are possibly two or three new species.

Further collection in Ecuador, Peru, and northern Bolivia is needed because of the paucity of collections from these areas.
References


and. n.d. Taxonomy and biogeography of *Centrosema virginianum*, *C. arenicola* and *C. pascuorum*. (In preparation.)


———; Williams, R. J.; Coradin, L.; Kretschmer, Jr., A. E.; and Lazier, J. R. 1989. 1989 World catalog of Centrosema germplasm; Catálogo mundial 1989 de germoplasma de Centrosema. Centro Internacional de Agricultura Tropical (CIAT) and International Board for Plant Genetic Resources (IBPGR), Cali, Colombia. 322 p.


Appendix: Key to the Species of Centrosema

1a. Lower (median) calyx tooth longer than or equalling tube, or if less than tube, then leaf unifoliolate with winged petioles .............................................. 2

2a. Leaves with 3-7 leaflets, or if unifoliolate, then not winged ....................... 3

3a. Upper calyx lobe also longer than or equalling tube, or if slightly shorter, then lateral teeth falcate and near the lower tooth ........................................... 4
4a. All calyx teeth similar in length and shape ................................. 5

5a. Calyx teeth broad, ovate-obtuse to lanceolate, 5-15 mm long, 2.5-4.5 mm wide, upper two mostly united; inflorescence ferruginous-hirsute-tomentose; spur reduced to a transverse pouch; leaflets chartaceous .......................... 6

6a. Bracteoles and calyx teeth lanceolate-attenuate; long-hirsute teeth 8-14 mm long, 2.5-4 mm wide; inflorescence and young branches long-hirsute-tomentose ........................................... C. vetulum

6b. Bracteoles and calyx teeth ovate-obtuse, or if lanceolate, then not long-hirsute ........................................ 7

7a. Leaflets oblong-obtuse, shortly acuminate to emarginate, dorsal veins ferruginous-hirsute; calyx tube and teeth 5-8 mm long .............................. C. jaraguaense

7b. Leaflets ovate-acuminate to elliptical or lanceolate-attenuate; calyx tube 8-12 mm long ........................................... 8

8a. Leaflets usually elliptical-lanceolate, not densely tomentose beneath .................. C. dasyanthum

8b. Leaflets broad ovate to elliptical, acuminate, densely tomentose beneath .......... ........................................ C. latidens

5b. Calyx teeth narrow lanceolate, 5-18 mm long, 1-3 mm wide, upper two usually free, sometimes united to 2/3 length; inflorescence not tomentose; spur obvious; leaflets membranous to thinly chartaceous ........................................ 9

9a. Stipules lanceolate, 4-9 mm long; leaflets lanceolate to narrow elliptical, base attenuate to acute; pods torulose, slightly falcate; flowers crimson violaceous ........................................... C. pascuorum

9b. Stipules triangular to short lanceolate, 0.5-5 mm long; leaflets various, base obtuse to cordate, sometimes acute; pods terete to compressed; flowers lilac, pink, medium violet, sometimes white but not crimson violaceous ......................... 10

10a. Stipules 0.5-2 mm long; upper calyx teeth slightly shorter to slightly longer than tube, often partly united; pods compressed, 4.5-7 mm wide ........ C. arenicola

10b. Stipules 2-5 mm long; upper calyx teeth slightly shorter to much longer than tube, if united then longer; pods terete, 3-45 mm wide (rarely wider) ... C. virginianum

4b. Calyx teeth clearly different in length, lower tooth usually at least one and a half times as long as the rest .................................................. 11

11a. Leaflets 3-7, clearly pinnate, with rachis longer than 10 mm; lateral calyx teeth shorter than to equalling the tube ...................................... 12

12a. Leaves trifoliolate ................................................... 13

13a. Leaflets ovate to broad lanceolate, obtuse, acute to attenuate; plants twining and climbing .................................................. 14

14a. Leaflets large, 40-150 mm long, 20-80 mm wide; upper and lateral teeth longer than tube; pods large, 115-275 mm long, 8-11 mm wide ......................... 15

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Taxonomy of Centrosema

15a. Bracteoles chartaceous, ovate to oblong-apiculate, 8-15 mm long, 7-8 mm wide; leaflets membranous to chartaceous, hirsute to tomentose beneath; flowers blue or violet; pods usually terete ............................... *C. grandiflorum*

15b. Bracteoles coriaceous, ovate to lanceolate, acuminate, sometimes falcate, 10-22 mm long, 6-8 mm wide; leaflets mostly membranous, glabrous but occasionally tomentose beneath; flowers cream to pink with marked color pattern on standard; pods usually compressed ....................... *C. macrocarpum*

14b. Leaflets and pods smaller than (14a); upper and lateral calyx teeth scarcely longer than the tube; lateral teeth oblique-lanceolate; pods 65-150 mm long, 6-9 mm wide ................................................. 16

16a. Inflorescence pseudocapitate; bracteoles thin, papyraceous, long-falcate, 10-18 mm long; leaflets ovate, acuminate; pods thickened near sutures, straight to strongly falcate; flowers cream flushed with violet ................................. *C. capitatum*

16b. Flowers toward apex of raceme; bracteoles rigid-membranous, not prominent, ovate-falcate, 4-12 mm long; leaflets ovate, acute to obtuse; pods straight to slightly falcate .................................................. 17

17a. Bracteoles 8-12 mm long; bracteoles, calyx tube, and teeth strigose to sericeous; leaflets ovate-acute, occasionally acuminate; pods straight, pale to medium brown without dark submarginal band; flowers violet .................. *C. schiedeananum*

17b. Bracteoles 4-9 mm long; bracteoles and calyx tube glabrous to puberulous ... 18

18a. Tube 3-4 mm long, lateral teeth more or less equalling tube; pods with distinct submarginal dark band; flowers lilac or white .......................... *C. pubescens*

18b. Calyx small, tube 2.5-3 mm long; lateral and dorsal teeth often shorter than tube; pod without submarginal band; flowers lilac, violet, rarely white .................. 19

13b. Leaflets orbicular to obovate, emarginate to apiculate, chartaceous to rigid membranous, strigose to tomentose; calyx tube and upper lobe to 4 mm long, other teeth longer; prostrate, decumbent, or ascending; often amphiocarpic; aerial pods short-falcate, 25-60 mm long ............................. *C. acutifolium*

12b. Leaflets 5-7, pinnate, oblong to oblanceolate, mucronate, obtuse or emarginate; plants ascending; strong taproot ................................. *C. heptaphyllum*

11b. Leaflets 3-7, digitate, or if pinnate, rachis not more than twice as long as petiolule; lateral teeth longer than tube, lower tooth 7-22 mm long, 3-4 times as long as tube .................................................. 19

19a. Leaves mostly pinnately trifoliolate to 5-digitate, obovate, elliptical, or lanceolate; plants rhizomatous, branches fulvous, pilose; pods 70-120 mm long, more or less falcate ........................................... *C. bracteosum*

19b. Leaflets 3-7, digitate, narrow lanceolate to linear; plants rhizomatous, mostly amphiocarpic; pods 35-65 mm long, subfalcate to straight ............... *C. venosum*

3b. Only the lower calyx tooth longer than the tube; lateral teeth triangular or obsolete, equidistant from upper and lower teeth; bracteoles longer than entire calyx ... 20
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20a. Tube small, 2.5-4 mm long, upper lobe and lateral teeth 1-2 mm long, lower tooth 4-5 mm long; leaflets ovate-obtuse to elliptical, sometimes lobed; pods torulose; often amphicarpic .................................................. C. graziellae

20b. Tube 4-6 mm long, upper lobe 2-4 mm long, lower tooth 6-13 mm long; pods various .......................................................... 21

21a. Racemes 1-2 flowered .............................................................. 22

22a. Bracteoles valvate, papyraceous to chartaceous, broad ovate .... C. brasilianum

22b. Bracteoles imbricate, rigid-coriaceous, lanceolate to oblong ........... 23

23a. Bracteoles ovate to oblong, 9-18 mm long; leaflets ovate to ovate-lanceolate, acuminate, 35-140 mm long, 15-48 mm wide ...................... C. bifidum

23b. Bracteoles narrow ovate to lanceolate, falcate, 5-10 mm long; leaf with rachis only twice as long as petiolule, or subdigitate; leaflets narrow lanceolate to linear, acute to obtuse; pods straight .............................................. C. angustifolium

21b. Racemes 2-7 flowered. .............................................................. 24

24a. Bracteoles chartaceous to coriaceous, scarcely longer than entire calyx, 8-15 mm long ........................................................................ 25

25a. Leaflets membranous or chartaceous .......................................... 26

26a. Leaflets chartaceous, pubescent beneath, at least on veins, oblong, obovate or ovate, obtuse to emarginate .................................. C. arenarium

26b. Leaflets membranous to papyraceous, glabrous to sparsely puberulous or strigose, ovate, lanceolate or elliptical, acute to just obtuse .......... C. brachypodium

25b. Leaflets coriaceous, elliptical, oblong or obovate, mostly glabrous, at acute angle to the rachis ............................................... C. coriaceum

24b. Bracteoles papyraceous, large, about twice as long as calyx (tube + teeth), 15-30 mm long .......................................................... 27

27a. Bracteoles ovate-acute or briefly acuminate; leaflets ovate-elliptical, lanceolate or oblong, obtuse to emarginate, rarely acute, thin coriaceous ...... C. vexillatum

27b. Bracteoles ovate, long acuminate; leaflets ovate-acuminate, membranous ................................................................. C. tapiropoanense

2b. Leaves unifoliolate, petiole winged ............................................... 28

28a. Leaflets chartaceous to coriaceous, oblong-cordate to ovate-sagittate, acuminate; calyx teeth triangular ........................................ C. carajasense

28b. Leaflets membranous to papyraceous, ovate-sagittate to hastate or deltoid; calyx teeth lanceolate ...................................................... 29

29a. Lower calyx tooth 10-14 mm long ................................................ C. fasciculatum

29b. Lower calyx tooth 6-8 mm long ................................................ C. sagittatum

1b. Calyx teeth all shorter than the tube; leaves trifoliolate; stipules large .......... 30

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Taxonomy of Centrosema

30a. Calyx teeth almost obsolete, dorsal and lateral teeth reduced to a shallow convex lobe; vexillary spur present; stipules triangular to lanceolate, prominent but separate; stems coarse, angular but not thickened or winged at corners ........ 31

31a. Leaflets ovate to rhomboid, base acute to obtuse, laterals ovate; peduncles shorter than petioles; flowers 2-10, white with violet patch; pods compressed, mostly convex with a 2-4 mm wide subsutural thickening .................. C. plumieri

31b. Leaflets ovate, more or less lobate to subrhomboid, base obtuse to truncate; peduncles longer than petioles; flowers 1-3, violet; pods quadrangular-torulose ........................................ C. schottii

30b. Lower teeth short, triangular; vexillary spur absent, reduced to a small gibbous area; stipules orbicular, wider than long and encircling node; stems coarse, angular, and thickened or winged at corners ............................. 32

32a. Upper calyx lobe slightly bifid or folded; pod flat, winged at sutures, 70-200 mm long, 30-60 mm wide; stems winged ....................... C. triquetrum

32b. Upper calyx lobe entire, truncate; pod compressed and woody, valves convex, two-winged on vexillary suture, the other bare, with a median wing, to 170 mm long, 40 mm wide .................................................. C. platycarpum
Chapter 2

BIOGEOGRAPHY OF CENTROSEMA

R. Schultze-Kraft, R. J. Williams, and L. Coradin

Abstract

The natural distribution of 35 Centrosema species is presented. Centrosema virginianum has the widest distribution and is followed by C. plumieri, C. pubescens, C. sagittatum, and C. schottii. A group of five species (C. arenicola, C. dasyanthum, C. jaraguaense, C. "tetragonolobum," and C. vetulum) has the narrowest natural distribution. Three species occur north of the equator only: C. arenicola, C. schiedeanum, and C. "tetragonolobum"; whereas 15 species are native exclusively to the southern hemisphere. Thirty-one of the 35 species occur in tropical Brazil, the most important center of species diversification of Centrosema.

According to habitat information from the collection sites, Centrosema includes species with potential adaptation to diverse habitats such as the dry tropics, high-altitude tropics, subtropics, poorly drained and/or seasonally flooded conditions, and acid, low-fertility soils.

Further germplasm collection has been identified as of high research priority, particularly for those so far poorly collected, but, potentially, agronomically valuable, species such as C. arenarium, C. brachypodum,
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*C. capitatum*, *C. grandiflorum*, *C. rotundifolium*, *C. vexillatum*, and *Centroselecta* new sp. No. 4. The highest regional priority for germplasm collection is accorded to southeast Brazil.

**Introduction**

Until now no major attempt has been made to collate biogeographical data on the genus *Centroselecta* as a whole. Barbosa-Fereiro (1977) presents in her *Centroselecta* treatment valuable information on species distribution in Brazil. Useful information is also included in regional floras such as those for Argentina (Burkart, 1943), Suriname (Amshoff, 1939), Peru (Macbride, 1943), Venezuela (Pittier, 1944), Guatemala (Standley and Steyermark, 1946), and Panama (D'Arce, 1980). Caution is needed when using the data of these regional floras because of uncrirical use of species names. The biogeography of *C. virginianum*, *C. arenicola*, and *C. pascuorum* has been comprehensively studied by R. J. Clements and R. J. Williams (unpublished data), and the natural distribution of *C. macrocarpum* by Schultzze-Kraft (1986). For *C. brasiliannum* and *C. acutifolium*, the biogeography of the collected living material (germplasm) has also been studied by Schultzze-Kraft and Bealcazar (1988) and Schultzze-Kraft et al. (1987), respectively.

In this review of geographical and ecological information, a considerable portion of the data is from germplasm collections held by CSIRO, EMBRAPA-CENARGEN, and CIAT. The major part of the distribution information, however, is based on studies of collections, held at the world's major herbaria, by R. J. Williams (one of the authors) and R. J. Clements, both of CSIRO.

The value of a biogeographical treatment has been outlined by Williams et al. (1984) in their discussion of the natural distribution of another forage legume, *Stylosanthes*. The value lies basically in providing a perspective for the understanding of differential adaptations of the species to ecological stresses; assisting in the taxonomic resolution of a genus, both among and within species; and, in conjunction with other information, assisting in focusing attention on particular populations and areas that are likely sources of specific adaptations, with subsequent definition of new collecting targets. The present study, therefore, also aims to identify germplasm collection gaps by briefly discussing the existing collections versus the known distribution based on herbarium information.
Any biogeographical information is of limited value unless there is a consensus on the taxonomy and the species names used. As has been pointed out in the previous chapter, there are still some uncertainties in the taxonomy of *Centrosema*. Therefore, in order to avoid confusion and aid communication, the present chapter refers only to unambiguous species and species names that are recognized by Williams and Clements (this volume).

### Geographical Distribution and Environmental Adaptation

#### Overview and information limitations

*Centrosema* is a New World genus. Thus, the present review of biogeographical information does not consider data from non-American regions with naturalized populations such as *C. pubescens* and *C. plumieri* in Southeast Asia. Although there are reports from the Philippines (de la Viña and Engle, 1985) and Indonesia (K. L. Mehra, unpublished information discussed by Humphreys et al., this volume) of considerable variation in local *C. pubescens* populations regarding morphological characters and collection site ecology, there is a general consensus that the genetic variability is low (personal communications from A. de la Viña and K. L. Mehra, September 1986). These populations are derived from early introductions of commercial cultivars or other narrowly based collections.

In this review, the 35 *Centrosema* species as recognized by Williams and Clements (this volume) are considered. They include two new, not yet validly named, species, that is *C. tetragonolobum* in the *C. brasiliannum* group, and *C*. new sp. No. 4 in the *C. macrocarpum* group. While the description of the former awaits publication (Schultz-Kraft and Williams, n.d.), no attempt has as yet been made to describe *C*. new sp. No. 4.

Table 1 presents, for each species considered, a summary of geographical and ecological data. While the latitude ranges are based on both germplasm and herbarium information, most of the other information is from collectors’ notes of germplasm material only. Table 1 also lists the number of germplasm accessions available for each species. The figures are extracted from a world catalog (Schultz-Kraft et al., 1989) which is based on collections held by CSIRO, EMBRAPA,
<table>
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<tr>
<th>Species</th>
<th>Latitude range</th>
<th>Altitude range (m.a.s.l.)</th>
<th>Rainfall mm/year</th>
<th>No. of dry months&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Habitat</th>
<th>Soil&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Map&lt;sup&gt;c&lt;/sup&gt; no.</th>
<th>No. of germplasm accessions&lt;sup&gt;d&lt;/sup&gt;</th>
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<td>acutifolium</td>
<td>22° S-06° N</td>
<td>90-540</td>
<td>1300-2200</td>
<td>3-5</td>
<td>Savanna scrub; forest scrub</td>
<td>Acid, medium to low fertility</td>
<td>4</td>
<td>36</td>
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<td>angustifolium</td>
<td>30° S-09° N</td>
<td>120-1210</td>
<td>1120-3030</td>
<td>0-5</td>
<td>Savanna scrub; forest scrub</td>
<td>Acid, medium to low fertility</td>
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<td></td>
<td></td>
<td>(often poorly drained)</td>
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<tr>
<td>arenarium</td>
<td>20° S-02° S</td>
<td>700-900</td>
<td>750-830</td>
<td>5-6</td>
<td>Caatinga; savanna scrub;</td>
<td>Acid, medium to low fertility</td>
<td>12</td>
<td>2</td>
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<td>forest scrub</td>
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<td>arenicola</td>
<td>28° N-30° N</td>
<td>10-200</td>
<td>1000-1600</td>
<td>2-3</td>
<td>Forest scrub</td>
<td>Acid, sandy</td>
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<td>220-900</td>
<td>1130-1630</td>
<td>4-5</td>
<td>Savanna</td>
<td>Acid, low fertility</td>
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<td>500-1200</td>
<td>780-1680</td>
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<td>Savanna scrub; forest scrub</td>
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<td>26° S-12° S</td>
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<td>23° S-18° S</td>
<td>10-800</td>
<td>370-2920</td>
<td>0-8</td>
<td>Caatinga; savanna scrub;</td>
<td>Acid, medium to low fertility</td>
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<td>16° S-11° N</td>
<td>230-400</td>
<td>1620-2840</td>
<td>2-5</td>
<td>Savanna scrub; forest scrub</td>
<td>Acid, medium to low fertility</td>
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<td>3</td>
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<td>carajasense</td>
<td>14° S-05° S</td>
<td>260-450</td>
<td>1560-2740</td>
<td>3-5</td>
<td>Forest scrub</td>
<td>Acid, medium fertility</td>
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<td>coriaceum</td>
<td>22° S-10° S</td>
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<td>900-1110</td>
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<td>Savanna scrub</td>
<td>Acid, low fertility</td>
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<td>5</td>
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<td>dasyanthum</td>
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<td>19° S-07° S</td>
<td>390-530</td>
<td>1500-1610</td>
<td>5</td>
<td>Forest scrub</td>
<td>Medium fertility</td>
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<td>25° S-15° S</td>
<td>800-1070</td>
<td>1290-1580</td>
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<td>Savanna scrub</td>
<td>Medium fertility</td>
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<td>grazielae</td>
<td>23° S-08° N</td>
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<td>1130-3180</td>
<td>0-5</td>
<td>Savanna scrub; forest scrub</td>
<td>Acid, medium to low fertility</td>
<td>7</td>
<td>48</td>
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<td>heptaphyllum</td>
<td>16° S-09° S</td>
<td>500-600</td>
<td>700-1000</td>
<td>6-7</td>
<td>Savanna; woodlands</td>
<td>Sandy</td>
<td>11</td>
<td>—</td>
</tr>
<tr>
<td>jaraguense</td>
<td>24° S-22° S</td>
<td>1100</td>
<td>1240-1530</td>
<td>3-5</td>
<td>Forest scrub</td>
<td>Acid, sandy</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>latidens</td>
<td>04° S-05° S</td>
<td>120-580</td>
<td>1540-2580</td>
<td>0-2</td>
<td>Forest scrub</td>
<td>Acid, medium to low fertility</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>macrocarpum</td>
<td>19° S-19° N</td>
<td>10-2050</td>
<td>430-3940</td>
<td>0-10</td>
<td>Savanna scrub; forest scrub</td>
<td>Acid, medium to low fertility</td>
<td>6</td>
<td>319</td>
</tr>
<tr>
<td>pascuorum</td>
<td>19° S-17° N</td>
<td>20-1000</td>
<td>370-1760</td>
<td>4-10</td>
<td>Caatinga; savanna scrub;</td>
<td>Medium to high fertility</td>
<td>2</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>forest scrub</td>
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</tbody>
</table>

(Continued)
Table 1. (Continued).

<table>
<thead>
<tr>
<th>Species</th>
<th>Latitude range</th>
<th>Altitude range (m.a.s.l.)</th>
<th>Rainfall mm/year</th>
<th>No. of dry months (^a)</th>
<th>Habitat</th>
<th>Soil(^b)</th>
<th>Map no.</th>
<th>No. of germplasm accessions (^d)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>platycarpum</em></td>
<td>15° S-04° S</td>
<td>300-750</td>
<td>1570-1690</td>
<td>4-5</td>
<td>Savanna scrub; forest scrub</td>
<td>Acid, medium fertility</td>
<td>22</td>
<td>2</td>
</tr>
<tr>
<td><em>plumeri</em></td>
<td>26° S-23° N</td>
<td>20-1540</td>
<td>530-3940</td>
<td>0-8</td>
<td>Forest scrub</td>
<td>Medium to high fertility</td>
<td>20</td>
<td>269</td>
</tr>
<tr>
<td><em>pubescens</em></td>
<td>23° S-23° N</td>
<td>10-1600</td>
<td>500-4160</td>
<td>0-8</td>
<td>Forest scrub</td>
<td>Medium to high fertility</td>
<td>8</td>
<td>1173</td>
</tr>
<tr>
<td><em>rotundifolium</em></td>
<td>19° S-04° S</td>
<td>120-370</td>
<td>430-1160</td>
<td>5-8</td>
<td>Caatinga</td>
<td>Very sandy</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td><em>sagittatum</em></td>
<td>28° S-21° N</td>
<td>30-1200</td>
<td>640-3230</td>
<td>2-8</td>
<td>Forest scrub</td>
<td>Medium to high fertility</td>
<td>19</td>
<td>49</td>
</tr>
<tr>
<td><em>schiedeanum</em></td>
<td>03° N-22° N</td>
<td>150-2000</td>
<td>850-4260</td>
<td>0-6</td>
<td>Forest scrub</td>
<td>Medium to high fertility</td>
<td>5</td>
<td>36</td>
</tr>
<tr>
<td><em>schottii</em></td>
<td>26° S-23° N</td>
<td>10-860</td>
<td>600-1600</td>
<td>3-8</td>
<td>Forest scrub</td>
<td>Calcareous, medium to high fertility</td>
<td>21</td>
<td>100</td>
</tr>
<tr>
<td><em>tapirapoanense</em></td>
<td>15° S-08° N</td>
<td>100-300</td>
<td>1600-2800</td>
<td>1-5</td>
<td>Seasonally flooded forest scrub</td>
<td>Acid, medium fertility</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td><em>tetragonolobum</em>(^*)</td>
<td>04° N-06° N</td>
<td>70-150</td>
<td>2060-2500</td>
<td>3-4</td>
<td>Savanna scrub</td>
<td>Acid, medium to low fertility</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td><em>triquetrum</em></td>
<td>10° S-10° N</td>
<td>100-720</td>
<td>1150-2630</td>
<td>0-3</td>
<td>Forest scrub</td>
<td>Medium fertility</td>
<td>22</td>
<td>4</td>
</tr>
<tr>
<td><em>venosum</em></td>
<td>23° S-09° N</td>
<td>40-1200</td>
<td>970-2130</td>
<td>3-5</td>
<td>Savanna</td>
<td>Acid, low fertility, very sandy</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td><em>vetulum</em></td>
<td>20° S-18° S</td>
<td>1150</td>
<td>1540</td>
<td>5</td>
<td>Forest scrub</td>
<td>Acid, sandy</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td><em>vexillatum</em></td>
<td>22° S-08° N</td>
<td>100-250</td>
<td>1240-3070</td>
<td>1-5</td>
<td>Seasonally flooded forest edges</td>
<td>Alluvial, also acid, medium to low fertility</td>
<td>17</td>
<td>7</td>
</tr>
<tr>
<td><em>virginianum</em></td>
<td>36° S-40° N</td>
<td>10-2200</td>
<td>350-2200</td>
<td>0-8</td>
<td>Woodlands; caatinga; forest scrub</td>
<td>Low to high fertility</td>
<td>3</td>
<td>381</td>
</tr>
<tr>
<td>new sp. No. 4</td>
<td>16° S-08° S</td>
<td>310-400</td>
<td>1590-1660</td>
<td>4-5</td>
<td>Savanna scrub; forest scrub</td>
<td>Medium to low fertility</td>
<td>9</td>
<td>6</td>
</tr>
</tbody>
</table>

\(^a\) Dry month = month with \(\leq 60\) mm rainfall.

\(^b\) Acid soil = a soil whose acidity may have agronomic implications (pH \(\leq 6\)).

\(^c\) See Appendix to this chapter.

\(^d\) Extracted from a world catalog as of 1 February 1987 (Editor's note: now published as Schultze-Kraft et al., 1989).
the Agricultural Research and Educational Center at Fort Pierce (ARECFP) of the University of Florida, the International Livestock Centre for Africa (ILCA), and CIAT. Table 2 summarizes these five collections which total more than 3000 distinct accessions. The only species which, as yet, have no available germplasm are *C. dasyanthum*, *C. heptaphyllum*, *C. jaraguaense*, and *C. vetulum*.

Maps showing the geographical distribution of the species are in the Appendix to this chapter. On these maps, a distinction is made between locations from which only herbarium specimens are available and collection sites of germplasm samples. This facilitates the rapid identification of germplasm collection gaps. A collection gap exists when a population, known to exist in a geographical area from herbarium specimens, is not represented in the germplasm collection, regardless of whether information on new genetic variation is available. The identification of collection gaps is thus based on the assumption that geographical distance is linked with genetic variation.

In this context, it is necessary to point out some limitations of the information presented:

In contrast to germplasm collection (that is, the collection of living plant material) which began only 20-30 years ago, *Centrocoma* herbarium specimens have been collected for as long as two centuries. On the one hand, this explains the relative abundance of herbarium material for some species. On the other hand, many of the older collection sites are so poorly identified that they could not be included in the distribution maps (Appendix to this chapter). It should be remembered, however, that information from both herbarium and germplasm collections reflects only the intensity of collection activities and not necessarily the real natural frequency and distribution of the species.

Just how well ecological information from collection sites used for Table 1 reflects the habitat preference of a given species depends on the number of collections and the adequacy of the data supplied.

The descriptions of collection sites, particularly in relation to soil and vegetation, have to be carefully interpreted. The soil or vegetation type reported by the collector often refers to the generalized description of a region rather than to the habitat where a particular plant population was actually growing. One example of possible misinterpretation is to infer that material collected on “Latosols” in a “savanna” vegetation type is fire-and-drought resistant and well
Biogeography of Centrosema

Table 2. The major collections of *Centrosema* germplasm (no. of accessions as of 1 February 1987).

<table>
<thead>
<tr>
<th>Speciesa</th>
<th>CIAT</th>
<th>CSIRO</th>
<th>EMBRAPA</th>
<th>ARECFPb</th>
<th>ILCAc</th>
<th>Reconciled totald</th>
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<tbody>
<tr>
<td>acutifolium</td>
<td>36</td>
<td>11</td>
<td>30</td>
<td>1</td>
<td>5</td>
<td>36</td>
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<tr>
<td>angustifolium</td>
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<td>7</td>
<td>8</td>
<td>2</td>
<td>—</td>
<td>28</td>
</tr>
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<td>arenarium</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>—</td>
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<td>2</td>
</tr>
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<td>arenicola</td>
<td>1</td>
<td>2</td>
<td>—</td>
<td>2</td>
<td>—</td>
<td>2</td>
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<td>bifidum</td>
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<td>2</td>
<td>8</td>
<td>—</td>
<td>—</td>
<td>10</td>
</tr>
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<td>brachypodium</td>
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<td>10</td>
<td>1</td>
<td>—</td>
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</tr>
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<td>bracteosum</td>
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<td>1</td>
<td>1</td>
<td>—</td>
<td>—</td>
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</tr>
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<td>brasilianum</td>
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<td>53</td>
<td>193</td>
<td>5</td>
<td>48</td>
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<td>capitatum</td>
<td>3</td>
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<td>1</td>
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<td>—</td>
<td>3</td>
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<td>6</td>
<td>—</td>
<td>—</td>
<td>6</td>
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<td>—</td>
<td>—</td>
<td>5</td>
</tr>
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<td>dasyanthum</td>
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<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
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<td>fasciculatum</td>
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<td>1</td>
<td>2</td>
<td>—</td>
<td>—</td>
<td>2</td>
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<td>grandiflorum</td>
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<td>—</td>
<td>5</td>
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<td>grazielae</td>
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<td>14</td>
<td>20</td>
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<td>2</td>
<td>48</td>
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<td>heptaphyllum</td>
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<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>jaraguense</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>latidens</td>
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<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>macrocarpum</td>
<td>312</td>
<td>32</td>
<td>208</td>
<td>2</td>
<td>28</td>
<td>319</td>
</tr>
<tr>
<td>pascuorum</td>
<td>67</td>
<td>69</td>
<td>41</td>
<td>11</td>
<td>15</td>
<td>87</td>
</tr>
<tr>
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<td>1</td>
<td>1</td>
<td>—</td>
<td>—</td>
<td>2</td>
</tr>
<tr>
<td>plumieri</td>
<td>138</td>
<td>83</td>
<td>38</td>
<td>39</td>
<td>43</td>
<td>269</td>
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<tr>
<td>pubescens</td>
<td>704</td>
<td>498</td>
<td>219</td>
<td>113</td>
<td>120</td>
<td>1173</td>
</tr>
<tr>
<td>rotundifolium</td>
<td>4</td>
<td>11</td>
<td>6</td>
<td>3</td>
<td>—</td>
<td>15</td>
</tr>
<tr>
<td>sagittatum</td>
<td>34</td>
<td>18</td>
<td>10</td>
<td>5</td>
<td>—</td>
<td>49</td>
</tr>
<tr>
<td>schiedeanum</td>
<td>35</td>
<td>13</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>36</td>
</tr>
<tr>
<td>schottii</td>
<td>50</td>
<td>56</td>
<td>19</td>
<td>33</td>
<td>24</td>
<td>100</td>
</tr>
<tr>
<td>tapirapoanense</td>
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<td>—</td>
<td>1</td>
<td>—</td>
<td>—</td>
<td>1</td>
</tr>
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<td>“tetragonolobum”</td>
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<td>—</td>
<td>—</td>
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</tr>
<tr>
<td>triquetrum</td>
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<td>—</td>
<td>1</td>
<td>—</td>
<td>—</td>
<td>4</td>
</tr>
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<td>venosum</td>
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<td>1</td>
<td>6</td>
<td>1</td>
<td>—</td>
<td>10</td>
</tr>
<tr>
<td>vetulm</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>vexillatum</td>
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<td>1</td>
<td>5</td>
<td>1</td>
<td>—</td>
<td>7</td>
</tr>
<tr>
<td>virginianum</td>
<td>152</td>
<td>209</td>
<td>111</td>
<td>94</td>
<td>18</td>
<td>381</td>
</tr>
<tr>
<td>new sp. No. 4</td>
<td>6</td>
<td>2</td>
<td>5</td>
<td>—</td>
<td>—</td>
<td>6</td>
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<td>Unidentified spp.</td>
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<td>13</td>
<td>90</td>
<td>16</td>
<td>1</td>
<td>119</td>
</tr>
<tr>
<td>Artificial interspecific hybrids</td>
<td>38</td>
<td>40</td>
<td>10</td>
<td>4</td>
<td>6</td>
<td>41</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1925</strong></td>
<td><strong>1147</strong></td>
<td><strong>1073</strong></td>
<td><strong>339</strong></td>
<td><strong>312</strong></td>
<td><strong>3020</strong></td>
</tr>
</tbody>
</table>

a. Including natural interspecific hybrids.

b. Information from A. E. Kretschmer, Jr., University of Florida, Agricultural Research and Educational Center, Fort Pierce (ARECFP), USA.

c. Information from J. R. Lazier, International Livestock Centre for Africa (ILCA), Addis Ababa, Ethiopia.

d. Total of accessions accepted as distinct after eliminating duplications.
adapted to acid, infertile soils. However, particularly in the case of
climbing Centrosema species, plants were often collected in habitats
that are protected from fire and overgrazing such as gallery forest
grounds. Here the water table during the dry season is usually higher
and the soil is somewhat more fertile than in the prevailing savanna
ecosystem to which the collection site may belong.

In the following sections, 35 Centrosema species are briefly discussed
according to their distribution and environmental adaptation. They are
ordered into 11 groups of species that have close relationships as
proposed by Williams and Clements (this volume).

Species group 1: C. dasyanthum, C. latidens,
C. jaraguaense, C. vetulum (map 1)

The four species in this group are in every respect little known.
Although it has been collected at only three locations in Colombia and
Peru, C. latidens appears to have the widest distribution. The
distribution of C. dasyanthum, C. jaraguaense, and C. vetulum is even
narrower and is confined to an area some degrees north of the Tropic of
Capricorn in the Brazilian states of São Paulo, Rio de Janeiro, and
southeast Minas Gerais. These species are known only from scarce
locations such as those mentioned by Barbosa-Fevereiro (1977), and as
yet no germplasm has been collected. For C. latidens one Colombian
accession is available.

Species group 2: C. arenicola, C. pascuorum,
C. virginianum

Centrosema arenicola (map 2). This is the only Centrosema species
which is exclusively subtropical. Its distribution is restricted to Florida,
USA, where it has been collected between 28° N and 30° N. There it
falls into the wide distribution of the closely related C. virginianum
which is very common in Florida. Centrosema arenicola is found in
undisturbed communities on well-drained, acid, sandy soils, flowering
mainly on forest edges or openings but extending vegetatively into
semishaded forests. Very few living collections have been made, but C.
arenicola is a very uniform species and the present germplasm is
representative (R. J. Clements, personal communication).

Centrosema pascuorum (map 2). Ranging from latitude 19° S to
17° N, the distribution of this annual species is remarkably disjunct and

difficult to understand. Being a truly tropical lowland species, there are six distribution pockets: northeast Brazil, the Pantanal, coastal Ecuador, Guyana, north Venezuela, and Central America and Mexico. Only in northeast Brazil and north Venezuela can the species be considered as frequent. *Centroselectum pascoorum* occurs in seasonally arid environments with very low to medium rainfall (370-1760 mm/yr) and a marked dry season lasting 4 to 10 months. In the Pantanal and occasionally in Venezuela, it has been found at locations with seasonal flooding stress. Soils at collection sites are characterized by medium to high fertility.

There are about 90 *C. pascoorum* germplasm accessions available. It is probable that they adequately represent the species distribution. More material from coastal Ecuador, Central America and Mexico, Guyana, and coastal Pará and the Pantanal in Brazil is desirable.

*Centroselectum virginianum* (map 3). The distribution of this species has been comprehensively studied by R. J. Clements and R. J. Williams (unpublished data). Extending from latitude 35° S to latitude 40° N, *C. virginianum* is by far the most widely distributed species of *Centroselectum*. Its total latitudinal range of 75 degrees is almost the same as that of the genus *Stylosanthes* as a whole (Williams et al., 1984). In the southern hemisphere, it is particularly frequent (or particularly well collected?) between latitudes 15° and 30°, and north of 15° S in Bahia, northeast Brazil. North of the equator, the major concentration of collection sites is in coastal and subcoastal USA and Mexico, including the Yucatán Peninsula, and the Caribbean. The accumulation of locations in Colombia is mainly a consequence of CIAT’s intensive germplasm collection activities in that country.

The climatic range is correspondingly wide and includes tropical, subtropical, and maritime temperate conditions. R. J. Clements and R. J. Williams (unpublished data) classify the *C. virginianum* distribution into 15 regions, recognizing varieties and geographical races. In some of these regions, frosts are common and can be severe. The altitudinal variation (ten to 2200 m) is also wider for this species than for other *Centroselectum* spp. Rainfall and vegetation conditions range from semiarid caatinga in northeast Brazil which has an annual rainfall of only 350 mm to forest edges that receive 2000 mm a year in the humid tropics of Bahia, Brazil. With few exceptions, a distinct dry or cold season lasting as long as 8 months is characteristic. Soils are usually well drained and of low to high fertility.
There are at present about 380 germplasm accessions available. Compared with the distribution of herbarium material, some poorly collected regions in terms of germplasm are evident such as the southern zone of distribution, including northeast Argentina, Uruguay and Paraguay, and Peru. South Brazil and Bolivia also merit further plant exploration. Collecting in the Central American region is also desirable in order to close the distribution gap between Mexico and Colombia. There may be, however, a real scarcity of material in the region.

**Species group 3: C. acutifolium, C. capitatum, C. grazielae, C. macrocarpum, C. grandiflorum**, C. pubescens, C. schiedeanum, **Centrosema new sp. No. 4.**

*Centrosema acutifolium (map 4).* The distribution of *C. acutifolium* is disjunct and not well understood. There is a small distribution pocket between latitudes 4° and 6° N at both sides of the Orinoco River, and a considerably more extended distribution in Brazil, particularly in the central west region. Preliminary herbarium studies (R. J. Williams, unpublished data) indicate the possibility of the species extending farther into Colombia (Andes region and north coastal plains). Since these specimens are not positively confirmed as *C. acutifolium*, they were not taken into consideration for this review. Based on the disjunct distribution and on morphological and marked agronomic differences, it has recently been suggested that they be considered as two different taxa at the botanical variety level (var. “orinocense” and var. “matogrossense”) (Schultze-Kraft et al., 1987).

Based on the germplasm material collected so far, *C. acutifolium* comes from truly tropical lowland sites in savanna and forest-edge environments with medium to high rainfall (1300-2200 mm/yr) and 3 to 5 dry months. Most collections have been made on acid, low-fertility soils. The present germplasm collection comprises about 40 accessions. Future collection activities should concentrate in the southern fringe of the distribution (particularly in the state of Minas Gerais from where additional variability in the form of less tropical germplasm is expected) and in the Amazon region of Brazil. Specific attempts to broaden the germplasm range of Colombian and Venezuelan material have not been successful. Variety “orinocense” so far has shown a very restricted distribution limited to the Orinoco region between latitudes 4° and 6° N.
**Biogeography of Centrosea**

*Centrosea capitatum* (map 5). This species extends from Tobago (latitude 11° N) across the Guianas into the Amazon River mouth region and appears again between latitudes 13° and 16° S in central west Brazil and coastal Bahia. Furthermore, several specimens are known from the Iquitos area in northeast Peru, and one germplasm collection was made in Colombia. Although this patchy distribution is not well understood, the locations have a low altitude and medium (central west Brazil) to high rainfall (all other sites) in common. The only three available germplasm collections were made in forest-edge environments on acid soils of low fertility. This narrow genetic base must be broadened by germplasm collecting throughout the known *C. capitatum* distribution.

*Centrosea macrocarpum* (map 6). The distribution of this species ranges from 19° N to 19° S. In the southern hemisphere, locations of *C. macrocarpum* are scattered and slightly overlap the distribution of *C. grandiflorum*, whereas in the northern hemisphere, it is particularly frequent in northern South America, Central America, and Mexico. In Mexico, its distribution overlaps that of the coarse Mexican forms of *C. schiedeanum* and, morphologically, both species seem to intergrade (Williams and Clements, this volume). *Centrosea macrocarpum* has been found in regions with an annual rainfall as low as 430 mm and as high as 4000 mm (Santa Marta in Colombia and Soná in Panama, respectively). Most collections, however, are from subhumid environments with an annual rainfall of 1100-1800 mm and 2-6 dry months. Being a tropical species, *C. macrocarpum* also occurs at higher altitudes (as high as 2000 m). Most collections have been made on acid, low-fertility soils and in scrub vegetation of gallery forest edges in savanna ecosystems.

Combining biogeographical, morphological, and agronomic information, *C. macrocarpum* was classified into five distinct groups (Schultze-Kraft, 1986): Central American material; the particularly promising group of low-altitude accessions from northern South America; the large-seeded Colombian high-altitude accessions (var. *“andinum”*); the erect forms from south of the equator; and the Brazilian blue-flowered material from south of latitude 15° S. Later, the Brazilian group has been identified as *C. grandiflorum* (Williams and Clements, this volume) and is considered separately below.

The present *C. macrocarpum* collection comprises about 320 accessions. Further germplasm collecting is justified in Bolivia, Ecuador, Trinidad and Tobago, and in Central America except Panama. Brazil south of latitude 17° S, northeast Brazil, and Mexico
west of longitude 95° W should also be targeted for collection to better understand the species' distribution boundaries.

Centroserma grandiflorum (map 6). This species extends between latitudes 15° and 25° S in subtropical southern Brazil. It overlaps the southern distribution fringe of the closely related C. macrocarpum. The species is not particularly common and at present only five germplasm accessions are available. They were collected on medium-fertility soils in environments with an annual rainfall of 1300-1600 mm and 5 dry months. Further collecting in southeast and south Brazil will most likely broaden the still rather narrow genetic base.

Centroserma grazielae (map 7). The distribution of C. grazielae extends from close to the Tropic of Capricorn in Rio de Janeiro State, Brazil, to latitude 8° N and overlaps with that of C. pubescens. It appears that C. grazielae replaces C. pubescens in those regions where the latter does not occur for edaphic reasons such as acid, low-fertility soils. In one eastern Venezuelan location, the collected germplasm sample was obviously a natural hybrid between C. pubescens and C. grazielae. As map 7 shows, there are two major distribution areas where the species occurs with a moderate frequency: central west and southeast Brazil, and the Colombian Eastern Plains (Llanos Orientales). Isolated pockets are eastern Venezuela and the grassland areas of the Amazon River mouth region. According to recent studies of herbarium specimens from Central America and the Caribbean (R. J. Williams, unpublished data), a Centroserma form similar to C. grazielae occurs in that region. Because their identity is still doubtful, none of the examined specimens have been considered for map 7.

Centroserma grazielae is a lowland species, native to regions with medium to high rainfall (1130-3180 mm/yr) and a dry season that lasts as long as 5 months. Soils at collection sites are well drained, acid, and of low to medium fertility. Centroserma grazielae is the only twining Centroserma species in which amphicarpy has been observed. This suggests its potential adaptation to burning and overgrazing.

As shown in map 7, C. grazielae has been well collected as germplasm material, but is not well represented as herbarium specimens. At present, there are about 50 accessions available. Future collecting targets for increased variability are southeast Brazil (Minas Gerais and Rio de Janeiro) and the Amazon mouth region.

Centroserma pubescens (map 8). The distribution of this common species extends from close to the Tropic of Cancer in Cuba, through the
tropical belt, to the Tropic of Capricorn. *Centrosema pubescens* is particularly frequent in northern South America, Central America, and the Caribbean. The altitudinal range is ten to 1600 m, the latter figure representing locations in the Colombian coffee zone. *Centrosema pubescens* is usually a high-rainfall species although a series of accessions, particularly from northeast Brazil, Colombia, Venezuela, and Mexico, have been collected in dry environments with annual rainfall as low as 500 mm. Soil fertility at collection sites is usually intermediate to high.

It is noteworthy that the distribution of *C. pubescens* overlaps with that of the other *Centrosema* spp. which are considered to be closely related to *C. pubescens*, that is, *C. acutifolium*, *C. capitatum*, *C. grandiflorum*, *C. grazielles*, *C. macrocarpum*, and *C. schiedeanum*.

The present *C. pubescens* collection comprises almost 1200 accessions which adequately represent the known geographical range of the species. Nevertheless, there are poorly sampled regions which warrant further germplasm collection such as Paraguay, Bolivia, northeast Brazil, Central America north of Costa Rica, and the Caribbean except Cuba.

*Centrosema schiedeanum* (map 5). This is one of the three *Centrosema* species with a distribution restricted to the northern hemisphere. There appear to be three distinct plant forms from three regions: a coarse Mexican form which is morphologically similar to *C. macrocarpum*, and which occurs at higher altitudes between latitudes 16°-22° N and longitudes 92°-105° W; from Costa Rica and Panama a highly stoloniferous form of the cv. Belalto type, similar to *C. pubescens*, and found at low to high altitudes; and from the Colombian Llanos another form that is also close to *C. pubescens* and is found at low altitudes. Although some of the Mexican accessions have been collected in environments with annual rainfall of a little less than 1000 mm and with as many as 6 dry months, all other material is from high-rainfall areas that have as much as 4260 mm/yr. Soils at the Mexican sites are characterized by almost neutral pH and medium to high fertility. In Costa Rica, Panama, and, particularly, the Colombian Llanos, they are acid and of medium to low fertility.

There are at present about 40 germplasm accessions available which broadly cover the natural distribution of the species as is currently known. However, germplasm collection should continue in Central America between Panama and Mexico, particularly in the Pacific coastal region. In tropical Mexico, more collecting should be done west of longitude 95° W.
**Centrosema new sp. No. 4 (map 9).** This refers to a new, as yet undescribed, *Centrosema* species which is taxonomically close to *C. pubescens* and has a very restricted distribution between latitudes 8° S and 16° S in central west Brazil. The species is not frequent and has only occasionally been collected at gallery forest edges in the Cerrados. Sites are at low altitudes (300-400 m), with a high rainfall (1600-1700 mm/yr), and a marked dry season typical of the Cerrados (4-5 months). Soils at collection sites are acid and of medium to low fertility. The six available germplasm accessions outnumber the known herbarium specimens; hence, future collection activities in the Cerrados should give attention to this species.

**Species group 4: C. venosum and C. bracteosum**

*Centrosema venosum* (map 10). This species is one of the few typical grassland savanna species of *Centrosema* for which an exclusively creeping habit, amphicarpy, tuberous roots, and leathery leaves are characteristic features. *Centrosema venosum* occurs in the northern hemisphere in the Colombian and Venezuelan Llanos, south of the equator in savanna islands in the Brazilian Amazon, and in the Campos and Cerrados of central west and southeast Brazil as far south as latitude 18° S. Soils are always very sandy, acid, and infertile. South of latitude 12° S, the distribution of *C. venosum* overlaps with that of the very similar *C. bracteosum*.

Only a few germplasm samples are as yet available (10 accessions), necessitating the collection of additional material. Germplasm multiplication, and thus conservation, however, is still an unresolved problem, because it has not yet been possible to grow *C. venosum* under the artificial conditions of the greenhouse or plant nursery.

*Centrosema bracteosum* (map 10). This species is restricted to open savanna regions in Brazil. It is a creeper and produces underground seed in addition to normal aerial pods, and/or has tuberous roots. It has, therefore, several escape and regeneration mechanisms which allow it to survive burning or overgrazing. In its distribution, *C. bracteosum* overlaps with the very similar *C. venosum*, but it is less tropical and reaches into subtropical Brazil to about latitude 25° S. The only two available germplasm accessions are from the Planaltina area in the Distrito Federal (altitude 1000 m, annual rainfall 1600 mm, with 5 dry months). Further collections are necessary, but, as for *C. venosum*, there are germplasm multiplication problems because it has not been possible to raise plants under greenhouse or plant nursery conditions.
Species group 5: *C. rotundifolium* and *C. heptaphyllum*

*Centrosema rotundifolium* (map 11). This tropical northeast Brazilian species spreads into Minas Gerais. There are 3-leaflet and 5-leaflet forms of which the latter are sometimes confused with *C. heptaphyllum*. Both forms are creepers, show amphiachary, and occur on very sandy soils in caatinga vegetation with very low to medium rainfall (430-1160 mm/yr) and a long dry season (5-8 months). In the present *C. rotundifolium* germplasm collection, no more than 15 accessions are available. Further collection efforts in northeast Brazil and Minas Gerais are, therefore, necessary.

*Centrosema heptaphyllum* (map 11). This is an amphiachary, taprooted, dryland and savanna species, also native to Brazil, with a distribution apparently restricted to the states of Bahia and northern Minas Gerais. Only a very few herbarium specimens are known and, as yet, no germplasm has been collected. It is important to obtain collections of this species, particularly in order to elucidate its affinity with *C. rotundifolium*.

Species group 6: *C. arenarium*, *C. brachypodum*, *C. coriaceous*

*Centrosema arenarium* (map 12). In terms of germplasm, *C. arenarium* has been poorly collected and is subsequently very poorly documented with respect to ecological information. It is a northeastern Brazilian dryland (750-830 mm rainfall/yr) species but also extends into more humid environments such as those of Pará state and coastal Bahia. Its distribution overlaps with that of the closely related *C. brachypodum*; herbarium specimens from south of latitude 10° S are similar to those of *C. brachypodum*.

The presently available *C. arenarium* collection consists of only two accessions. Therefore, every effort to broaden this narrow genetic base is justified.

*Centrosema brachypodum* (map 12). This species is restricted to the southern hemisphere between latitudes 7° and 26° S. There appear to be three distribution areas, giving origin to an equal number of distinct *C. brachypodum* groups. The first area is northeast Brazil, where the species overlaps with the closely related *C. arenarium* and where low rainfall (820-1100 mm/yr, 5-6 dry months) and medium to high soil
fertility are characteristic for *C. brachypodum* germplasm collection sites. The second area is tropical to subtropical southeast and south Brazil (Minas Gerais, Espírito Santo, Rio de Janeiro, São Paulo, and Paraná) with somewhat higher rainfall (1100-1650 mm/yr, 4-5 dry months) and acid soils of medium to low fertility. *Centrosema brachypodum* is particularly frequent in this region. The third area is subtropical Paraguay from where only a few specimens are known and which, however, may not belong to *C. brachypodum* (R. J. Williams, unpublished data).

Only 11 germplasm accessions are so far available. Consequently, all three distribution regions warrant further collection efforts.

*Centrosema coriaceum* (map 13). This tropical Brazilian savanna species is typical of the “campo rupestre” vegetation in Bahia and Minas Gerais where it grows on well-drained, sandy, and acid soils of low fertility. The environment is somewhat drier (900-1000 mm/yr) with a dry season of 6 months. Only five germplasm accessions are as yet available. More collections, principally in Minas Gerais, are therefore necessary.

**Species group 7: C. brasilianum, C. angustifolium, C. bifidum, C. “tetragonolobum”**

*Centrosema brasilianum* (map 14). The distribution of *C. brasilianum* extends south almost to the Tropic of Capricorn. In the north, however, it does not extend beyond latitude 12° N. The species is particularly frequent in northeast Brazil and in Venezuela.

*Centrosema brasilianum* is a tropical lowland species. The rainfall conditions at the collection sites were classified into six groups according to total annual rainfall and rainfall distribution (Schultze-Kraft and Belalcázar, 1987). These groups showed that 69% of the collection originates from subhumid environments with an annual rainfall range between 890 and 1680 mm with as many as 8 dry months. Thirteen percent were collected under very dry caatinga conditions in northeast Brazil with less than 890 mm/yr. The remaining 18% were collected in the humid tropics characterized by high rainfall (1700-2900 mm/yr) such as in the Brazilian Amazon and the Ilhéus-Itabuna region of Bahia, Brazil. Soils at the collection sites are of medium to low fertility and always well drained. The occurrence of the species in the Pantanal, however, suggests some adaptation to less well-drained conditions.
The present *C. brasiliurnum* collection comprises about 230
germplasm accessions. There are several collection gaps south of
latitude 15° S, where further efforts should be undertaken in Bolivia,
Paraguay, the adjacent Pantanal in Brazil, Minas Gerais, and Rio de
Janeiro. More collecting is needed in the equatorial region of Brazil
(Amazon), as well as in the Guianas.

*Centrosetna angustifolium* (map 15). Although north of the equator
this species does not occur farther north than latitude 10° N, south of
the equator its distribution extends to subtropical coastal Brazil as far
as latitude 30° S. *Centrosetna angustifolium* is more frequent in central
west and southeast Brazil and in Colombia than in other regions where
collection sites are scattered. Its absence in northeast Brazil suggests
that this species is not adapted to low rainfall conditions. Germplasm
collection sites are characterized by medium to high rainfall (1100-3000
mm/yr, 0-5 dry months). Many of the Colombian accessions have been
collected on poorly drained, seasonally flooded sites in savanna and
forest-edge environments.

There are about 30 germplasm accessions available, but only in
Colombia do their collection locations adequately represent the known
natural distribution. In order to broaden the genetic base, germplasm
must be collected in Paraguay, subtropical Brazil, central west and
southeast Brazil, the Amazon region, northern South America (except
Colombia), and Central America.

*Centrosetna bifidum* (map 16). This tropical species is characteristic
of the Brazilian Cerrados where it occurs on well-drained, acid, and
infertile soils. Its distribution is restricted to the central west region
between latitudes 13° and 18° S. The annual rainfall range at the
collection sites is 1300-1600 mm with the typical Cerrados dry season of
4-5 months. A few locations are known from Minas Gerais at about
latitude 20° S.

The present germplasm collection comprises 10 accessions which
adequately represent the known distribution of *C. bifidum* in central
west Brazil. Future collection in Minas Gerais may add new variation to
the existing collection.

*Centrosetna “tetragonolobum”* (map 16). This is not yet a validly
named species and is, at present, being described (Schultze-Kraft and
Williams, n.d.). It is closely related to *C. brasiliurnum*. Its distribution is
restricted to latitudes 40°-60° N on both the Colombian and Venezuelan
sides of the Orinoco River and is almost identical with that of *C.*
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*acutifolium var. "orinocense."* Rainfall is high (2100-2500 mm/yr), with the dry season lasting 3 to 4 months. The general vegetation in the region is savanna, but *C. "tetragonolobum"* was collected at gallery forest edges on acid soils of medium to low fertility. At present, 12 germplasm accessions are available and further collection must be made to broaden this narrow genetic base.

**Species group 8: C. vexillatum and C. tapirapoaense**

*Centrosema vexillatum* (map 17). This truly tropical lowland species has a distribution from latitude 22° S to 8° N. As yet, only seven germplasm accessions are available. With one exception, they were collected in medium to high rainfall environments on seasonally flooded river banks. More material of this species is required, and collection efforts should concentrate on the Pantanal, Brazil; El Beni Department, Bolivia; along the Amazon River, Brazil; and Guyana.

*Centrosema tapirapoaense* (map 17). This species has a similarly wide distribution but is a less frequent species. There exist three distribution pockets: Mato Grosso, Brazil, close to latitude 15° S; along the Amazon River, close to longitude 70° W (Peru, Brazil); and north of the equator, close to the Caribbean coast, in Colombia, near 11° N. Only one germplasm accession is available; it originates from a seasonally flooded forest edges close to the Areões River, Mato Grosso. More collections are highly desirable.

**Species group 9: C. carajasense, C. fasciculatum, C. sagittatum**

*Centrosema carajasense* (map 18). This is a truly tropical Brazilian species with a narrow distribution ranging from latitude 5° to 14° S. Germplasm collections (six) outnumber herbarium specimens. They were collected in Mato Grosso and Pará at forest edges, with medium to high rainfall (1600-2700 mm/yr) and as many as 5 dry months, and on acid, medium-fertility soils. As do the closely related *C. fasciculatum* and *C. sagittatum*, *C. carajasense*, in its native habitat, grows under shady conditions. The germplasm base of this species should also be widened through further collections.

*Centrosema fasciculatum* (map 18). This species is another unifoliolate species that is closely related to *C. sagittatum* and *C. carajasense*. In comparison with *C. carajasense*, its distribution extends
somewhat farther south (120°-190° S). A location for a herbarium speci-
men is known from latitude 70° S in Peru. The little ecological in-
formation available for C. fasciculatum suggests that this species has a
habitat similar to that of C. carajasense. Only two germplasm accessions
are so far available.

Centrosema sagittatum (map 19). The distribution of this species
extends from 21° N to south of the Tropic of Capricorn where a series
of subtropical herbarium specimens are known from southern Brazil,
Paraguay, and Argentina. Although it has a wide distribution, C.
sagittatum is not a common species; only south of latitude 15° S can a
somewhat higher frequency be observed. It is a lowland species which
usually prefers low-rainfall environments with a well-defined dry season.
In Panama and Mexico, however, collections have been made in areas
with annual rainfall as high as 3200 mm, yet with a dry season of 2-3
months. Soils are usually of medium to high fertility. A remarkable
feature of C. sagittatum in its native habitat is its shade tolerance.

At present there are about 50 accessions available which, however,
represent only inadequately the natural distribution of the species.
Regions warranting germplasm collection are the southern subtropics,
southern and northeast Brazil, Bolivia, Peru, and Ecuador, Central
America between Panama and Mexico, and Hispaniola.

Species group 10: C. plumieri and C. schottii

Centrosema plumieri (map 20). The distribution of this species is, in
most features, very similar to that of C. pubescens. Unlike C. pubescens,
however, C. plumieri extends farther into the subtropics (26° S in
southern Paraguay). Unlike in the southern hemisphere where locations
are scattered, C. plumieri is more frequent in Colombia, Venezuela,
Panama, tropical Mexico, and the Greater Antilles. The altitude range
is practically the same as for C. pubescens (20-1500 m). In general, C.
plumieri is a species from high-rainfall areas. There are, however,
exceptions such as accessions from Mexico and Colombia which were
collected in low-rainfall environments (550-900 mm/yr) with as many as
8 dry months. It is usually found in soils with intermediate to high
fertility.

The present C. plumieri collection comprises 270 accessions. No
germplasm is, as yet, available from the southern fringe of distribution
beyond 18° S. Germplasm collection efforts should be concentrated
there, particularly in the subtropical zone. Further collecting in Bolivia,
Peru, Ecuador, and Central America is also necessary. Germplasm adapted to particularly dry conditions may be expected from further plant collection in northeast Brazil.

_Centrosema schottii_ (map 21). This is a species with a disjunct distribution limited by both Tropics; only one herbarium specimen is known from a subtropical environment (northeast Argentina). Being one of the least common of the widely distributed _Centrosema_ species, _C. schottii_ occurs frequently in the Yucatán Peninsula, Mexico. Other frequency patches are the Greater Antilles, northern Venezuela, coastal Ecuador, and northeast Brazil. Features characteristic of the native habitats of _C. schottii_ are low to medium rainfall, a distinct dry season of 3-8 months, and calcareous soils of medium to high fertility.

Collecting germplasm in the southern fringe of distribution as well as in northeast Brazil and the Greater Antilles (with the exception of Cuba), may well broaden the presently available genetic base which consists of about 100 accessions.

**Species group 11: C. platycarpum and C. triquetrum**

_Centrosema platycarpum_ (map 22). This Brazilian species is principally known from collections made along the Brasília-Belém transect. The only two germplasm accessions also originate there. The collection locations are characterized by a subhumid climate (1630 mm rainfall/yr with 4-5 dry months), soil of medium fertility, and savanna and forest scrub.

_Centrosema triquetrum_ (map 22). This closely related species has a considerably wider distribution and has been collected between latitudes 10° S and 10° N and over a longitudinal range from 45° to almost 80° W. Collections have been made at forest edges in humid environments, on soils of intermediate fertility which are sometimes poorly drained. Only four germplasm accessions are available; they come from Venezuela, Brazil, and Peru.

**Distribution Pattern**

Based on the latitudinal ranges presented in Table 1 and outlined in the previous section, the 35 species under consideration can be clustered into six distribution groups (Table 3). It is noteworthy that 46% of the species (that is, 16) have a “narrow” to “very narrow” distribution. This
**Biogeography of Centrosema**

Table 3. Natural distribution of *Centrosema* species according to categories of latitudinal ranges\(^a\) of collection sites.

<table>
<thead>
<tr>
<th>Latitudinal range</th>
<th>Virginianum</th>
<th>Plumieri</th>
<th>Pubescens</th>
<th>Sagittatum</th>
<th>Schottii</th>
<th>Angustifolium</th>
<th>Arenarium</th>
<th>Brachypodium</th>
<th>Capitatum</th>
<th>Schiedeanum</th>
<th>Tapirapoanense</th>
<th>Triquetrum</th>
<th>Vexillatum</th>
<th>Bifidum</th>
<th>Bracteosum</th>
<th>Carajasense</th>
<th>Coriaceum</th>
<th>Fusciaclatum</th>
<th>Grandiflorum</th>
<th>Heptaphyllum</th>
<th>Latidens</th>
<th>Platycarpum</th>
<th>Rotundifolium</th>
<th>Vetulum</th>
<th>New sp. No. 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very wide ((&gt; 60))</td>
<td><strong>(\geq 60)</strong></td>
<td><strong>45-60</strong></td>
<td><strong>31-44</strong></td>
<td></td>
<td></td>
<td><strong>angustifolium</strong></td>
<td><strong>arenarium</strong></td>
<td><strong>brachypodium</strong></td>
<td><strong>capitatum</strong></td>
<td><strong>schiedeanum</strong></td>
<td><strong>tapirapoanense</strong></td>
<td><strong>triquetrum</strong></td>
<td><strong>vexillatum</strong></td>
<td><strong>bifidum</strong></td>
<td><strong>bracteosum</strong></td>
<td><strong>carajasense</strong></td>
<td><strong>coriaceum</strong></td>
<td><strong>fusciaclatum</strong></td>
<td><strong>grandiflorum</strong></td>
<td><strong>heptaphyllum</strong></td>
<td><strong>latidens</strong></td>
<td><strong>platycarpum</strong></td>
<td><strong>rotundifolium</strong></td>
<td><strong>vetulum</strong></td>
<td><strong>new sp. No. 4</strong></td>
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<tr>
<td>Wide</td>
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<td><strong>brasilianum</strong></td>
<td><strong>brachypodium</strong></td>
<td><strong>capitatum</strong></td>
<td><strong>schiedeanum</strong></td>
<td><strong>tapirapoanense</strong></td>
<td><strong>triquetrum</strong></td>
<td><strong>vexillatum</strong></td>
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<td>Intermediate to wide (31-44)</td>
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<td></td>
<td><strong>angustifolium</strong></td>
<td><strong>arenarium</strong></td>
<td><strong>brachypodium</strong></td>
<td><strong>capitatum</strong></td>
<td><strong>schiedeanum</strong></td>
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<td><strong>heptaphyllum</strong></td>
<td><strong>latidens</strong></td>
<td><strong>platycarpum</strong></td>
<td><strong>rotundifolium</strong></td>
<td><strong>vetulum</strong></td>
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<tr>
<td>Narrow to intermediate (16-30)</td>
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<td><strong>acutifolium</strong></td>
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<td><strong>capitatum</strong></td>
<td><strong>schiedeanum</strong></td>
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<td><strong>latidens</strong></td>
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<td><strong>rotundifolium</strong></td>
<td><strong>vetulum</strong></td>
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<tr>
<td>Narrow</td>
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<td></td>
<td><strong>acutifolium</strong></td>
<td><strong>arenarium</strong></td>
<td><strong>brachypodium</strong></td>
<td><strong>capitatum</strong></td>
<td><strong>schiedeanum</strong></td>
<td><strong>tapirapoanense</strong></td>
<td><strong>triquetrum</strong></td>
<td><strong>vexillatum</strong></td>
<td><strong>bifidum</strong></td>
<td><strong>bracteosum</strong></td>
<td><strong>carajasense</strong></td>
<td><strong>coriaceum</strong></td>
<td><strong>fusciaclatum</strong></td>
<td><strong>grandiflorum</strong></td>
<td><strong>heptaphyllum</strong></td>
<td><strong>latidens</strong></td>
<td><strong>platycarpum</strong></td>
<td><strong>rotundifolium</strong></td>
<td><strong>vetulum</strong></td>
<td></td>
</tr>
<tr>
<td>Very narrow ((&lt; 5))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>acutifolium</strong></td>
<td><strong>arenarium</strong></td>
<td><strong>brachypodium</strong></td>
<td><strong>capitatum</strong></td>
<td><strong>schiedeanum</strong></td>
<td><strong>tapirapoanense</strong></td>
<td><strong>triquetrum</strong></td>
<td><strong>vexillatum</strong></td>
<td><strong>bifidum</strong></td>
<td><strong>bracteosum</strong></td>
<td><strong>carajasense</strong></td>
<td><strong>coriaceum</strong></td>
<td><strong>fusciaclatum</strong></td>
<td><strong>grandiflorum</strong></td>
<td><strong>heptaphyllum</strong></td>
<td><strong>latidens</strong></td>
<td><strong>platycarpum</strong></td>
<td><strong>rotundifolium</strong></td>
<td><strong>vetulum</strong></td>
<td></td>
</tr>
</tbody>
</table>

\(a\) Latitudinal range is expressed as the total number of degrees (in parentheses) between southernmost and northernmost collection sites.

probably suggests a specialized adaptation to particular ecological niches of these species and, therefore, a limited potential for adaptability to different environments. It may also suggest, however, that some species are still in an early stage of evolutionary development and have not yet spread.

In Table 4, the distribution of *Centrosema* species in the major regions of the Americas is summarized. Thirty-one of the 35 species under consideration occur in tropical Brazil; 19 in northern South America; 16 in Ecuador, Peru, Bolivia, and tropical Paraguay; 11 in Mexico, Central America, and the Caribbean; 9 in subtropical South America; and 2 in USA. Accordingly, tropical Brazil can be considered as the major center of species diversification of *Centrosema*. Ten species occur exclusively in this region: *C. arenarium*, *C. bifidum*, *C. carajasense*, *C. coriaceum*, *C. dasyanthum*, *C. heptaphyllum*, *C. platycarpum*, *C. rotundifolium*, *C. vetulum*, and *Centrosema* new sp. No. 4. The only other regions with a distribution exclusiveness are USA and northern South America, each with one species (*C. arenicola* and *C. "tetragonolobum," respectively). In contrast to a previous suggestion by Clements and Williams (1980), Central America is not an outstanding center of *Centrosema* diversity.
Table 4. Distribution of *Centrosea* species in the major regions of the Americas.

<table>
<thead>
<tr>
<th>Species</th>
<th>USA</th>
<th>Mexico, C. America, Caribbean</th>
<th>Northern South America&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Ecuador, Peru, Bolivia, trop. Paraguay</th>
<th>Tropical Brazil</th>
<th>Subtropical South America&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
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<td>X</td>
<td></td>
<td>X</td>
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<tr>
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<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>arenarium</td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>arenicola</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bifidum</td>
<td></td>
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<td></td>
<td></td>
<td>X</td>
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</tr>
<tr>
<td>brachypodium</td>
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<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
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<td>X</td>
<td>X</td>
<td>X</td>
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</tr>
<tr>
<td>capitatum</td>
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<td></td>
<td>X&lt;sup&gt;c&lt;/sup&gt;</td>
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<td></td>
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<tr>
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<td>fasciculatum</td>
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</tr>
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</tr>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>latidens</td>
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</tr>
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</tr>
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<td>X</td>
<td>X</td>
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</tr>
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</tr>
<tr>
<td>sagittatum</td>
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<td>X</td>
<td>X</td>
<td>X</td>
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</tr>
<tr>
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<td></td>
<td>X</td>
<td>X</td>
<td></td>
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</tr>
<tr>
<td>schottii</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
</tr>
<tr>
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<td>&quot;tetragonolobum&quot;</td>
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<tr>
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</tr>
<tr>
<td>venosum</td>
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<td></td>
</tr>
<tr>
<td>vetulkum</td>
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<td></td>
</tr>
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</tr>
<tr>
<td>virginianum</td>
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<td>X</td>
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<td>X</td>
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<td>X</td>
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<td>new sp. No. 4</td>
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<td></td>
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</tr>
</tbody>
</table>

Total no. of species 2 11 19 16 31 9

No. of species restricted to the respective region 1 0 1 0 10 0

---

<sup>a</sup> Colombia, Venezuela, Guianas.
<sup>b</sup> South of the Tropic of Capricorn.
<sup>c</sup> Trinidad only.
Taxonomic Implications

Summarizing the comments of the previous sections, there may be sufficient biogeographical reasons, to recognize distinct taxa at the variety level, at least, for *C. acutifolium*, *C. macrocarpum*, *C. schiedeleanum*, and *C. virginianum*. The existence of disjunct distributions or altitudinal ecotypes does not always lead to recognizable varieties; for example, there are no obvious varieties of *C. pascuorum* or *C. pubescens*. But if biogeographical differences are associated with consistent differences in morphological features and traits of agronomic importance, there may be good cause for taxonomic reconsideration.

When more locations and biogeographical information on *C. brachypodum* and *C. capitatum* become available, it may be necessary to examine the taxonomic status of these two species.

Agronomic Implications

The present study suggests that particular *Centrosea* species may be a source of adapted germplasm for certain environmental conditions:

- Dry tropics.
  - *C. arenarium*, *C. brachypodum*, *C. brasilianum*, *C. macrocarpum*, *C. pascuorum*, *C. plumieri*, *C. pubescens*, *C. rotundifolium*, *C. sagittatum*, *C. schottii*, *C. virginianum*.

- High altitudes and subtropics.
  - *C. angustifolium*, *C. arenicola*, *C. brachypodum*, *C. bracteosum*, *C. grandiflorum*, *C. macrocarpum*, *C. plumieri*, *C. pubescens*, *C. sagittatum*, *C. schiedeleanum*, *C. schottii*, *C. virginianum*.

- Poorly drained, seasonally flooded areas.
  - *C. angustifolium*, *C. pascuorum*, *C. triquetrum*, *C. tapiropoanense*, *C. vexillatum*.

- Acid, low-fertility soils.
  - *C. acutifolium*, *C. angustifolium*, *C. arenarium*, *C. bifidum*, *C. brachypodum*, *C. bracteosum*, *C. brasilianum*, *C. capitatum*, *C. carajasense*, *C. coriaceum*, *C. graziela*, *C. macrocarpum*, *C. schiedeleanum*, *C. "tetragnolobum"*, *C. venosum*, *Centrosea* new sp. No. 4.
Research Priorities

The collection of germplasm should receive high priority. This refers principally to the very poorly collected but, potentially, agronomically valuable species, that is, *C. arenarium*, *C. brachypodium*, *C. capitatum*, *C. grandiflorum*, *C. rotundifolium*, *C. vexillatum*, and *Centrosea* new sp. No. 4. Other species which possibly do not have a high agronomic potential but are not well enough known because of insufficient representation in the major *Centrosea* germplasm collections, and which, therefore, warrant further collection, are *C. bifidum*, *C. bracteosum*, *C. carajasense*, *C. coriaceum*, *C. fasciculatum*, and *C. venosum*. Another group of species with completely unknown potential comprises *C. dasyanthum*, *C. jaraguaense*, *C. latidens*, *C. vetulum*, *C. heptaphyllum*, and *C. tapirapoaense*. For these species there is no germplasm material, or only one as yet unstudied accession, available. This group, therefore, also merits high collection priority.

The highest regional priority is accorded to southeast Brazil, particularly the state of Minas Gerais. Material of most of the above-mentioned species are expected to be found during a proposed collecting mission in this region. Such findings would, furthermore, fill important gaps in the knowledge of species distribution in southeast Brazil. Another important mission, aiming less at collecting material of underrepresented species and more at filling important distribution gaps, is projected for Central America, between Panama and Mexico. Paraguay and Bolivia, where several species have been collected, but inadequately, also merit more attention.

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———; Coradin, L.; Kretschmer, Jr., A. E.; and Lazier, J. R. 1989. 1989 World catalog of *Centrosema* germplasm; Catálogo mundial 1989 de germoplasma de *Centrosema*. Centro Internacional de Agricultura Tropical (CIAT) and International Board for Plant Genetic Resources (IBPGR), Cali, Colombia. 322 p.


Appendix: Maps Showing the Natural Distribution of *Centrocoma* spp.

Contents

Map 1. *C. latidens, C. dasyanthum, C. jaraguaense, C. vetulum*
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Map 14. *C. brasilianum*
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Map 18. *C. carajasense, C. fasciculatum*
Map 19. *C. sagittatum*
Map 20. *C. plumieri*
Map 21. *C. schottii*
Map 22. *C. triquetrum, C. platycarpum*

Note:

Solid symbols refer to sites from where germplasm (living plants) is available. Open symbols refer to collection sites of herbarium specimens. When germplasm and herbarium material are available from the one location, priority is given to the germplasm symbol. A single symbol can also refer to more than one germplasm accession and/or herbarium specimen if the respective collection sites are sufficiently close.
Map 3. Natural distribution of *Centrosema virginianum*. 
Map 9. Natural distribution of *Centrosema* new sp. No. 4.
Map 12. Natural distribution of *Centroselecta brachypodum* and *C. arenarium*. 
Map 15. Natural distribution of Centroserna angustifolium.
Chapter 3

CENTROSEMA SPECIES FOR SEMIARID AND SUBTROPICAL REGIONS

R. J. Clements*

Abstract

At least six Centrosema species occur naturally in the semiarid tropics. Their adaptive features are described. Two cultivars of C. pascuorum have been developed for commercial use in pastures. One was bred for semiarid tropical regions that have a dry season lasting 5 to 8 months. The other is a late-flowering cultivar suited to wet-dry tropical regions which are seasonally flooded for long periods of time. Both cultivars provide valuable dry-season grazing for cattle. Centrosema pascuorum is also being evaluated as a leguminous ley in cropping systems.

One Centrosema species, C. arenicola, is restricted to the subtropics. Another, C. virginianum, extends to much higher latitudes and possesses frost-avoidance mechanisms which are described in some detail. At least eight species extend into the South American subtropics, and some species and ecotypes are found in elevated tropical (coffee zone) regions. Attempts to develop C. virginianum for subtropical pastures in Australia are described. Bred lines have persisted for 8 years when grazed at a stocking rate of 1.5 steers/ha.

Introduction

The natural distribution of Centrosema species on the American landmass is an immediate guide to their climatic adaptation. The

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starting point for this review is therefore the biogeography of *Centroserma* in America, with emphasis on semiarid and subtropical regions (Schultze-Kraft et al., this volume). Present knowledge of the adaptive features of *Centroserma* species from these regions will then be reviewed, and attempts to develop and commercialize these species will be summarized.

One of the difficulties in discussing adaptation to environmental stress is to relate cause and effect unambiguously. This is because a particular adaptation can enable a plant to resist several different kinds of stress, while a single stress can be countered by many different adaptations (Clements et al., 1983a). Also, many adaptations are still not well understood. For example, leaf pubescence is common in *Centroserma* species both in semiarid and high-altitude tropical environments. Is pubescence mainly a reflectance mechanism to counter the high levels of solar radiation that occur in both kinds of environment? Is it an adaptation to low temperatures on high tropical mountains, acting by increasing leaf boundary layer resistance to heat transfer? Is it primarily a means of reducing water loss by transpiration in semiarid environments? Do different kinds of pubescence have different functions? The answers to all these questions are unclear, and this uncertainty should be kept in mind in any discussion of adaptation, even when answers appear obvious.

**Climates and Species**

The term “semiarid tropics” has no precise meaning. In this chapter, the climatic categories V3 and V4 of Troll and Paffen (Troll, 1966) are taken to define the semiarid tropics. V3 climates (wet-and-dry tropical climates) have 4 to 7 humid months, while V4 climates (tropical dry climates) have 2 to 4 humid months. A humid month is defined as one in which the mean rainfall exceeds potential evaporation.

Seven American regions are specifically included in the semiarid tropics under this definition: most of subcoastal northeastern Brazil; a narrow belt of land on the Pacific coast of Ecuador and Peru; the southern plains of Guyana; several parts of Venezuela within 200 km of the Caribbean coast and the Gulf of Venezuela (including some offshore islands); the Guajira Peninsula and other parts of northern Colombia; pockets in several Central American countries, notably Guatemala, Honduras, and El Salvador; and parts of southern Mexico. There are also two significant semiarid subtropical regions in America: the
Centrosema species for semiarid and subtropical regions

Paraguayan and Argentine Chaco; and northern Mexico, including Baja California. Semiarid tropical and subtropical climates occur widely in other parts of the world, particularly in Africa, India, and Australia.

The following Centrosema species occur naturally in semiarid American tropical regions: C. arenarium, C. brasilianum, C. pascuorum, C. rotundifolium, C. schottii, and C. virginianum. Two of these species, C. pascuorum and C. rotundifolium, are found more commonly in the semiarid tropics than elsewhere, while the remainder are less narrowly adapted climatically. Another group of species is adapted primarily to higher rainfall environments but includes rare accessions from the semiarid tropics. This group includes C. macrocarpum, C. plumieri, C. pubescens, C. sagittatum, and C. brachypodium.

The term "subtropics" literally includes only those regions bordering on the tropics, in which frost is a significant environmental limitation. However, there are also regions within tropical latitudes which are elevated and therefore have highland tropical climates and are in many ways comparable with the subtropical zone. Near the equator, mean temperature declines by approximately 6 °C for each 1000-meter increase in altitude, so that highland tropical conditions occur at altitudes between 1000 and 2000 m (Johnson, 1976; Snow, 1976). At such latitudes, frosts do not occur and the zone is called "tierra templada" or "coffee zone" and is characterized by low night temperatures (8-18 °C mean minimum in the coolest month) (Papadakis, 1966). At higher latitudes, highland tropical conditions are reached at lower elevations and frosts occur during the winter.

Brazilian climatologists such as Ratisbona (1976), use a mean temperature of less than 18 °C in the coldest month to distinguish subtropical from tropical climates. On this basis, most of the southern part of the Brazilian shield, extending northward to about 18° S in Minas Gerais and 21° S in Mato Grosso do Sul, could be called subtropical. Although this area now experiences on average only 0-10 frosts per year (Ratisbona, 1976), mean temperatures may have been 5-6 °C lower during the recent ice age, that is, as recently as 14,000 years ago. This point is worth considering, because the Brazilian central plateau is an important center of species diversity for Centrosema, containing more than half of the species (Clements and Williams, 1980). Another region of species diversity in Central America and Mexico also contains significant areas of elevated coffee zone land.
Only one species, *C. arenicola*, is restricted to the subtropics (central Florida, USA). However, *C. virginianum*, which has by far the widest natural distribution of the *Centrosea* species, extends to much higher latitudes than *C. arenicola* (40° N on the Atlantic coastal plains of the USA and 35° S in Argentina and Uruguay). These are the only two species which extend north of the Tropic of Cancer in North America.

The following species have distributions that extend south of the Tropic of Capricorn in South America: *C. virginianum, C. plumieri, C. angustifolium, C. grandiflorum, C. schottii, C. brachypodum, C. bracteosum, C. sagittatum*, and perhaps *C. acutifolium*. Also, as previously noted, many species are found in those parts of Minas Gerais which have a strong subtropical influence. These include several species already mentioned and a small group of poorly collected taxa (*C. coriaceum, C. dasystachyum*, and *C. vetulum*) which are more or less restricted to this region.

Finally, there are species and ecotypes which occur in highland tropical microclimates. For example, ecotypes of *C. macrocarpum* (Schultze-Kraft, 1986), *C. virginianum*, and *C. pubescens* have been collected in highland tropical climates. *Centrosea schiedeanum* is a coffee zone plant in Mexico and Central America, but is also found in lowland climates of Colombia. However, it does not occur in the latitudinal subtropics.

**Adaptations to Semi-arid Environments**

The critical environmental limitations in the semi-arid tropics include drought stress during the long dry season, high temperatures, high radiation levels, fire, and low levels of mineral nutrients. Several kinds of character combinations have been observed in *Centrosea* species from these environments.

One pattern is exhibited by *C. pascuorum*: an annual life cycle, rapid growth rate, twining or creeping runners which produce adventitious roots, flowering time closely matched to the environment (Figure 1), self-pollination, massive flowering and seed production (Figure 1), tolerance of extremely low leaf-water potentials (Table 1), leaf movements which reduce light interception, narrow leaflets to reduce radiation load and increase heat loss, and a high level of hard-seededness coupled with a rate of softening which varies between accessions and is probably correlated with the environment. One other
Centrosema species for semiarid and subtropical regions

![Flowering date (days after 31 December)](image)

Figure 1. Variation in flowering date of 71 accessions (66 introductions and 5 breeding lines) of *Centrosema pascuorum* grown at Katherine, Northern Territory, Australia. Flowering dates of the two commercial cultivars, Cavalcade and Bundey, are shown by arrows. Mean seed yields of accessions in each flowering class are shown by dots. Rows consisted of 10 plants at 0.5 m spacing. (Taken from Thomson et al., n.d.)

<table>
<thead>
<tr>
<th>Species</th>
<th>Water-stress tolerance (MPa)</th>
<th>Leaf-water potential at zero conductance (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>M. atropurpureum</em></td>
<td>-2.4</td>
<td>-1.9</td>
</tr>
<tr>
<td><em>C. pubescens</em></td>
<td>-8.0</td>
<td>-5.9</td>
</tr>
<tr>
<td><em>C. brasili-anum</em></td>
<td>-8.3</td>
<td>-4.2</td>
</tr>
<tr>
<td><em>C. pascuorum</em></td>
<td>-12.1</td>
<td>-8.0</td>
</tr>
</tbody>
</table>

a. Water-stress tolerance is the leaf-water potential measured just before the last leaf died on drought-stricken plants.

SOURCE: Ludlow et al., 1983.

species, *C. schottii*, is also an annual but differs from *C. pascuorum* in several respects (for example, it has broad leaflets). A third species, *C. virginianum*, is a perennial over most of its range but may function as an annual in the semiarid tropics. Some accessions collected in
northeastern Brazil behave as annuals, even when grown in humid environments (Clements, 1977 and 1983a; Schultzze-Kraft and Keller-Grein, 1985), while most others have no obvious adaptations to aridity and are probably short lived. In fact, many of the kinds of adaptations one might expect to find in the semiarid tropics such as leaf pubescence, narrow leaflets, or underground buds, are found in *C. virginianum* accessions from other environments, illustrating once again the problem of determining cause and effect.

A contrasting combination of characters is seen in *C. rotundifolium*: a perennial life cycle, slow growth rate, extensive underground storage organs, underground buds, a prostrate (nontwining) growth habit, amphicarpy (production of seeds both above and below the ground surface), sparse seed production, and broad thickened leaflets. This species has been poorly collected and, because of its poor seed production in Australia, has been little studied. However, in terms of adaptive strategies as defined by MacArthur and Wilson (1967), it seems to be a K-selected species in contrast to the r-selected *C. pascuorum*.1

*Centrosema brasiliianum* has moisture-stress avoidance or tolerance mechanisms which are poorly understood but which appear to differ from those described for *C. pascuorum* and *C. rotundifolium*. *Centrosema brasiliianum* is able to remain green and even grow slowly during droughts. This can be explained partly by its stronger stomatal control of water loss than some other *Centrosema* species (Table I), which probably prolongs the life of individual leaves. However, its tolerance of leaf-water deficits is lower than that of *C. pascuorum* and no greater than that of *C. pubescens*, while its stomatal control of water loss is lower than that of siratro (*Macroptilium atropurpureum*). It seems likely, therefore, that *C. brasiliianum* may have a deep root system which is able to reach soil moisture inaccessible to other species.

Leaflet morphology of *C. brasiliianum* in the semiarid tropics does not seem to have adaptive significance. *Centrosema brasiliianum* is predominantly a species that has narrow leaflets, although rarely as narrow of those of *C. pascuorum*. Forms with broad leaflets also occur alongside forms with narrow leaflets in the semiarid tropics (Schultzze-Kraft and Belalcázar, 1988). *Centrosema brasiliianum* leaflets are not pubescent or thickened, nor is there much evidence of leaf movements

1. K and r refer to fitness in crowded and uncrowded environments, respectively. Where favorable and unfavorable conditions alternate, r-selection will lead to rapid population growth and extravagant use of resources, whereas K-selection will lead to conservative replacement strategies and efficient use of resources during stress periods.
Centrosema species for semiarid and subtropical regions

to reduce radiation load. Also, accessions from the semiarid tropics vary greatly in seed production (Clements et al., 1984), suggesting that rapid population turnover may not be a critical drought-escape mechanism.

Very little is known about the adaptive features of *C. arenarium* and *C. schottii* in the semiarid tropics. In fact, the natural distribution of both species is poorly understood. It is possible that both species are adapted to particular soils. *Centrosema schottii* appears to have particularly hard seeds—-is this a factor contributing to its success in the semiarid tropics?

Amphicarpy is common in *Centrosema* and indeed in the Phaseoleae tribe; *C. rotundifolium*, *C. grazielae*, *C. venosum*, and *C. bracteosum* all possess this adaptation. It is not easy to explain the existence of amphicarpy in these four *Centrosema* species (at least in terms of their present distribution) simply as an adaptation to drought or temperature stress. *Centrosema grazielae*, for example, is distributed in a range of environments that includes those that are humid and relatively benign. The nature and adaptive significance of amphicarpy and geocarpy deserve closer study, not only in *Centrosema* but in other genera also. Is amphicarpy an adaptation to low soil-calcium levels? Is it an adaptation to fire?

The question of adaptation to fire deserves special consideration. According to Sarmiento (1984) and other ecologists, fire has been a normal factor in the evolution of neotropical savannas. The burying of biomass in the form of enlarged underground organs such as rhizomes and xylopods, is a common adaptation to fire. *Centrosema rotundifolium*, *C. bracteosum*, and *C. venosum* possess xylopods or greatly thickened roots. R. Schultze-Kraft (personal communication) has collected an accession of *C. brasilianum* possessing an underground storage organ, but this is not a characteristic feature of this species. One accession of *C. angustifolium* has also been observed to have such an organ. *Centrosema arenarium* appears not to possess xylopods.

Adaptations to Subtropical Environments

The main environmental stresses to be overcome by "tropical" plants growing in subtropical climates are low temperatures (especially at night) and frosts, and large cyclical changes in daylength. Night temperatures below 10-15 °C cause chilling damage to the chloroplasts of many tropical grasses and legumes (Lyons, 1973) and severely limit
their growth, while freezing temperatures kill their living tissues. In the case of *Centrosera*, tissues exposed to frosts of -2 to -5 °C are killed.

The mechanism of adaptation to chilling temperatures has not been studied in *Centrosera*, but some general comments can be made. Tropical accessions of *C. pubescens* are notoriously susceptible to chilling. Their leaves become yellow and stunted, and growth ceases when night temperatures fall below 13 °C (Bowen, 1959). Accessions from elevated tropical regions and southern parts of the distribution range are much more resistant (Clements and Williams, 1980; R. J. Clements, unpublished data). They begin growth much earlier in the growing season in the Australian subtropics, continue to grow slowly in the late autumn, and often remain green until frosted.

A similar pattern of within-species adaptation occurs in several other species, including *C. virginianum*, although the potential for autumn growth may be modified by the onset of dormancy or by prolific seed production (Figure 2). Accessions of *C. schiedeanum* from elevated

![Bar chart showing percentage of total yield occurring in growth period.](image)

**Figure 2.** Distribution of herbage yield of subtropical and tropical accessions of *Centrosera virginianum* during the growing season (October to April) in subtropical Queensland. Data are means from two sites, cut at 6-weekly intervals. ☛ Mean of 5 subtropical accessions (latitudes 23°-31°); ☐ Mean of 11 tropical accessions (latitudes 10°-14°). (Taken from unpublished data from the experiment described by Clements, 1977.)
parts of Mexico and Central America, *C. macrocarpum* from the Colombian Andes (Schultze-Kraft, 1986), and *C. brachypodium* and *C. acutifolium* from the southern part of the Brazilian shield appear to possess good chilling resistance (R. J. Clements, unpublished data). Studies with *C. virginianum* (Clements and Ludlow, 1977) have shown that chilling to induce "leaf hardening" has little or no effect on the resistance of leaves to frost or on the survival of plants after frost. Experience in Australia with this and other species indicates that accessions with good tolerance of chilling are scarcely superior in frost tolerance to those without chilling tolerance.

Winter survival of *C. virginianum* in the subtropics depends on an efficient frost-avoidance mechanism (Clements and Ludlow, 1977; R. J. Clements, unpublished data). Buds and leaves that are exposed to freezing temperatures (-2 to -3 °C) are killed. Whether a particular plant dies depends on whether its lowest buds are exposed to these lethal temperatures. The lowest buds on most plants are borne at the cotyledonary node. Tropical accessions bear their cotyledons 1 to 3 cm above the ground. As latitude of origin increases, the height to which the cotyledons are raised decreases (Figure 3), and plants can survive

![Figure 3. Relationship between the height of the cotyledonary node and the latitude of origin of Centroomea virginianum accessions. Seeds were planted at a depth of 1 cm in sand. Growing conditions were temperature at 28 °C; photoperiod of 14 hours; light intensity of 450 micronewtons; and relative humidity of 44%. (R. J. Clements, unpublished data.)](image-url)
progressively colder radiation frosts because their lowest buds are located in the warmer air near the ground. At about latitude 22°-25° N in Cuba and the USA, the species switches from epigeal to hypogeal germination and produces an underground crown. At even more northerly latitudes where convection frosts occur and the soil freezes, an extensive tuberous root system develops, with underground buds protected at depths of 1 to 10 cm. At or before the onset of winter, the leaves of these plants die. The plants become dormant, and regrowth in spring is supported by carbohydrate reserves in the roots. These mechanisms are under precise genetic control.

*Centrosema arenicola* also possesses a frost-avoidance mechanism. Although it produces runners which twine and climb, it also produces stolons which develop thickened taproots with underground crowns, and which eventually become new plants. Leaves and twining stems commonly die at or before the onset of winter. *Centrosema arenicola* is a poor seed producer, and this asexual reproductive strategy may partly compensate for its reduced ability to reproduce sexually. It is not clear whether this mechanism evolved as a means of combating frost or low temperatures, fire, drought, infertile soils, seed or foliage predators, some other stress, or any combination of stresses.

Mechanisms of adaptation to daylength have not been studied carefully in *C. arenicola* or *C. virginianum*. Near Brisbane (27°30' S, 153°00' E), which has a similar latitude to that of the area of natural distribution of *C. arenicola*, this species begins flowering during the longest days of the year and flowers for only 2 to 3 months. This behavior suggests a long-day photoperiodic response. Accessions of *C. virginianum* from the USA, north of about latitude 32° N, behave similarly (Clements, 1977 and unpublished data). This flowering pattern is maintained between about latitudes 28° and 32° N, with some apparent increase in flowering duration. In southern Florida (24°-28° N), flowering specimens have been collected in all months of the year, suggesting that the species may be day neutral in those latitudes. Day neutrality may be characteristic of tropical and southern subtropical races of *C. virginianum*, judging from the flowering patterns described by Clements (1977), but there are seasonal peaks and troughs which require further study.
The Agronomic Potential of *Centrosema* in the Semiarid Tropics

Interest in the development of *Centrosema* species for the Australian semiarid tropics was stimulated by observations at Katherine, Northern Territory (14°28' S, 131°19' E, V3 climate according to Troll, 1966), during the midseventies. One accession of *C. pascuorum*, one of *C. schottii*, and three of *C. brasilianum* had shown vigorous growth and persisted for 3 years in plot trials (Winter, 1978). Earlier screening of these species at other sites in northern Australia had given mixed results. Intensive efforts were made to multiply seeds of other accessions and to obtain new accessions by plant introduction and seed exchange. During the late 1970s, small collections of each species were screened at Katherine in small plots (Clements et al., 1984). The results (Table 2) confirmed the potential value of *C. pascuorum* in this environment. Two accessions had herbage yields exceeding 6 t/ha and seed reserves exceeding 1 t/ha in the third year. All three *Centrosema* species were leafier than *Stylosanthes hamata* cv. Verano. Although it was relatively low yielding, *C. brasilianum* was considered to be a potential source of high-quality forage during the dry season. However, its ability to maintain plant populations by seedling recruitment is uncertain.

From 1976 to 1981, a plant-breeding program was conducted with *C. pascuorum* in an attempt to improve its herbage and seed yields.

**Table 2. Herbage yields, soil-seed reserves, and leaf-to-stem ratios of *Centrosema* species and other legumes in small plots at Katherine Research Station, Northern Territory, Australia.**

<table>
<thead>
<tr>
<th>Species</th>
<th>Herbage yield of legume (t/ha)a</th>
<th>Soil seed reserves (kg/ha)a</th>
<th>Leaf-to-stem ratiob</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. pascuorum</em>b</td>
<td>4.3</td>
<td>344</td>
<td>0.92</td>
</tr>
<tr>
<td><em>C. brasilianum</em>b</td>
<td>1.8</td>
<td>97</td>
<td>1.04</td>
</tr>
<tr>
<td><em>C. schottii</em>c</td>
<td>2.7</td>
<td>296</td>
<td>0.94</td>
</tr>
<tr>
<td><em>Macroptilium atropurpureum</em>d</td>
<td>2.8</td>
<td>65</td>
<td>0.99</td>
</tr>
<tr>
<td><em>S. hamata</em>e</td>
<td>3.7</td>
<td>104</td>
<td>0.51</td>
</tr>
</tbody>
</table>

b. Means of eight accessions.
c. Means of two accessions.
e. *Stylosanthes hamata* cv. Verano.

(Clements et al., 1986; Miles et al., this volume). The best bred line was released as the variety Cavalcade in 1984 (New releases . . . , 1985) after it had been shown to produce more herbage and seed than its best parent (Stockwell et al., 1986).

During 1979-84, in Australia, research conducted by the staff of Mt. Bundey Station (13°05' S, 131°00' E), in collaboration with the Northern Territory Department of Primary Production, showed that C. pascuorum was able to survive prolonged flooding and to grow vigorously as the soil dried (Cameron and McCosker, 1986; McCosker, 1987). Seasonal flooding occurs over significant areas in the Top End of Northern Territory. Late-flowering lines of C. pascuorum are most appropriate for this role because they are better able to take advantage of suitable conditions for herbage growth as floodwaters recede at the end of the wet season. They can also produce a large bulk of herbage before flowering and seeding. The three latest flowering accessions available in 1979 were evaluated (McCosker, 1987), and one of them was released in 1984 as the cultivar Bundey. Recent screening of the complete set of 66 introductions available in 1984 (Figure 1) has revealed that Bundey is among the latest flowering accessions so far obtained by plant collection (Thomson et al., n.d.). (At the other extreme, some accessions flower as much as 1 month earlier than Cavalcade (Figure 1), suggesting that varieties could be developed for regions having shorter wet seasons than Katherine).

Some information on animal production from C. pascuorum pastures has been obtained. This species is expected to be most useful in Australia as a high-quality dry-season feed. At Katherine, a pasture containing a mixture of C. pascuorum accessions and volunteer grasses was grazed during the dry season (June-November, inclusively) at a stocking rate of 3.3 steers/ha for 6 years (W. H. Winter, unpublished data). The legume content of the pasture remained high, and liveweight gains of 20-50 kg/beast during the dry season were consistently obtained. Steers grazing native pastures at much lower stocking rates during the dry season lost weight. Good liveweight gains also have been obtained from cattle grazing C. pascuorum pastures plus crop residues in the dry season (Winter et al., 1984). Another pasture sown to a mixture of breeding lines was grazed for 9 months (late December to late September, inclusively) at 3.3 steers/ha. The animals gained over 150 kg per beast during this time (W. H. Winter, unpublished data). Liveweight gains from flood-plain pastures, sown to C. pascuorum and Setaria sphacelata and grazed during the dry season at stocking rates of
Centrosera species for semiarid and subtropical regions

1 and 3 weaner heifers/ha, averaged 18 kg per beast from 5 months of grazing (McCosker, 1987).

Less information is available on animal production from C. brasilianum pastures in the semiarid tropics. A pasture at Katherine sown to a mixture of accessions was grazed at 3.3 steers/ha during the dry season (June-November) for 7 years, with rest periods in some years to allow the legume to recover from heavy selective grazing. Liveweight gains were similar to those obtained on C. pascuorum pastures. Unfortunately, the number of C. brasilianum plants in the pasture has steadily decreased despite reasonable seed production in most years (W. H. Winter, personal communication).

Centrosera pascuorum has a potential role in the semiarid tropics as a self-regenerating leguminous ley in cropping systems. Research on this subject has been conducted and reviewed by McCown et al. (1985). Several legumes are being evaluated for this proposed farming system. Some important results concerning C. pascuorum are as follows:

It fixes relatively large amounts of atmospheric nitrogen (Jones et al., 1982).

As intercrop, it competes with the crop for light and nitrogen, reducing grain yield unacceptably (Chamberlin et al., 1986; McCown et al., 1983).

It sometimes reestablishes poorly, particularly on bare soil, leading to invasion by grasses (McCown et al., 1985 and 1986).

Cattle grazing native pastures during the wet season and C. pascuorum leys and crop residues during the dry season gain much more liveweight than those grazing only native pastures. However, they may not gain more liveweight than those grazing Stylosanthes hamata cv. Verano leys and crop residues during the dry season (McCown et al., 1986; Winter et al., 1984).

The phosphorus requirement of C. pascuorum in these systems is similar to that of S. hamata cv. Verano and Alysicarpus vaginalis (Probert and McCown, 1985). Other results from pot trials (R. M. Schunke, unpublished data; W. H. Winter, unpublished data) and pasture plots (McCosker, 1987) consistently show that C. pascuorum does not have a high P requirement.

Centrosera pascuorum has shown promise in Thailand (Topark-Ngarm and Moolsiri, 1983; Topark-Ngarm et al., 1980), Nusa Tenggara
in Indonesia (Nulik et al., 1986), Laos, and Timor in Indonesia (Humphreys et al., this volume). The particular requirements for its success are still not well understood. For example, in Australia, it has not yet found an agricultural niche outside the Top End of Northern Territory (Anning, 1982; Clements et al., 1984; Jones, 1979; Teitzel et al., this volume). Even in favorable locations, it has sometimes failed to establish or to regenerate for unknown reasons (Clements et al., 1986; McCown et al., 1985 and 1986; Wilaipon, 1981). Poor survival of seed after fire during the dry season was reported by Stockwell et al. (1986). Damage caused by root-knot nematodes (Meloidogyne sp.) has been reported by Kretschmer et al. (1980) and Clements et al. (1986). Anning (1982) commented on the inability of C. pascuorum to withstand competition from native grasses in north Queensland. In contrast, McCosker (1987) found that late-flowering lines suppressed native grasses on seasonally flooded sites.

Little is known of the requirements of C. pascuorum for mineral nutrients other than phosphorus. McCosker (1987) obtained responses to sulfur on one soil but not on another, and obtained no responses to potassium, copper, or molybdenum. The Rhizobium specificity of C. pascuorum has not been studied. Centrosema brasilianum is known to have a specific Rhizobium requirement (Clements et al., 1983b).

The Agronomic Potential of Centrosema in the Subtropics

The idea of developing Centrosema for subtropical pastures is not new. In Australia, C. pubescens was first grown in nurseries at Lawes (27°34′S, 152°20′ E), near Brisbane, in 1930 (CSIRO, unpublished data). During the next 10 years, several accessions of C. pubescens, C. plumieri, and C. virginianum were grown at Lawes, Fitzroyvale (28°28′S, 150°39′ E), and Brisbane (CSIRO, unpublished data; Miles, 1949; Schofield, 1945). This occurred several years before Centrosema species were first evaluated in the Australian tropics (Schofield, 1941). These early attempts in Australia and other countries to commercialize these species in the subtropics were conducted with a narrow range of tropical material and were unsuccessful. In view of the variation in C. pubescens and closely related species, a modern breeding program might succeed in producing a subtropical cultivar. Other “tropical” Centrosema species have been tested in the subtropics in recent years, without success.
The subtropical species *C. arenicola* has not been tested widely. Very few collections have been made. Two accessions were unproductive and failed to persist in plant introduction nurseries near Brisbane.

Accessions of *C. virginianum* have been screened in the American subtropics (Vorano et al., this volume) and in subtropical Africa. In Australia, a sustained effort to develop *C. virginianum* for subtropical pastures has been made. The species was first introduced in 1931. By 1986, more than 100 introductions had been screened in subtropical Australia (Clements, 1977 and 1983a; Teitzel et al., this volume). The conclusions from this work were that, firstly, except in mild environments near the coast, all these accessions lacked vigor after the first years and were unable to persist through the winter or through dry periods; and, secondly, useful adaptive genetic variation exists, on which a plant breeding program could be based (Clements, 1977 and 1983b). From 1973 to 1981, breeding was conducted at a range of subtropical sites, but principally at Narayen Research Station (25°41' S, 150°52' E, average annual rainfall 720 mm, 19-45 frosts per year) (Clements, 1983a; Clements and Thomson, 1983). The best bred lines from this program were as high yielding as siratro (*Macroptilium atropurpureum*) in small plots at Narayen for two successive growing seasons. Winter survival of these lines was excellent in the first year but inferior to siratro in the second. A mixture of these lines, designated “cross 31,” is now being evaluated under grazing in southeastern Queensland.

Long-term persistence data are available for some of the earliest products of the breeding program and their parent lines (Jones and Clements, 1987). Because this early material is not well adapted to the Narayen environment, it was evaluated at Beerwah Research Station (26°50' S, 153°03' E, average annual rainfall 1630 mm, 2-10 frosts per year). After establishing slowly, the best line has now persisted for 8 years when rotationally grazed at a stocking rate of 1.5 steers/ha, contributing 17%-32% of the herbage on offer at the end of the growing season. Other lines persisted well at this stocking rate until the exceptionally dry 1985-86 summer, when their performance slumped (Figure 4). Siratro persisted for only 3 or 4 years, while Belalto (*C. schiedeanum*) also failed during a dry summer. At a higher stocking rate of 2.3 steers/ha, none of the *C. virginianum* lines was able to persist.

The meager information on management requirements of *C. virginianum* pastures indicates that the species must be allowed to seed (Jones and Clements, 1987). Fertilizer requirements have not been
Figure 4. Legume content of herbage during the late autumn, for pastures grazed rotationally (1.5 steers/ha/year) in subtropical coastal Queensland for 8 years. Plots were sown with *Macroptilum atropurpureum* cv. Siratro or with a *Centrosema virginianum* line, and with *Setaria sphacelata* cv. Nandi as a common grass. (Taken from Jones and Clements, 1987.)

studied. *Centrosema virginianum* is sensitive to competition from grasses during establishment, and is slow to establish (Figure 4); this factor seems to be important in explaining the variable results obtained in small-plot studies. Root-knot nematodes have attacked this species in southeast Queensland.

**Research Priorities**

Development of *Centrosema* species for both the subtropics and semiarid tropics has reached the stage where animal production, pasture establishment, and management studies must have the highest priority.
Ways of capitalizing on the high nitrogen-fixing capability of *C. pascuorum* in cropping systems should also be sought.

Further collecting and breeding of the most promising species can be postponed until the weaknesses of the existing material (including the bred lines) have been defined. Some simple screening of *C. brasilianum*, *C. arenarium*, and *C. rotundifolium* in the Australian semiarid tropics is needed. In other countries, species of *Centrosema* and other legumes adapted to the semiarid tropics should be compared, using small representative collections. Studies on competition between *C. pascuorum* and associated grass species are needed.

Further work by specialists is needed on *Centrosema* rhizobiology, mineral nutrition, diseases, and pests. The importance of these topics extends beyond the regions considered here, and readers should consult the reviews elsewhere in this volume.

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Chapter 4

CENTROSEMA SPECIES FOR ACID SOILS

R. Schultze-Kraft*

Abstract

Vast areas of tropical lands are covered by very acid, highly aluminum-saturated soils which limit agricultural potential. Development of pastures based on adapted, acid-soil tolerant species is a promising means of efficiently using these marginal areas.

Seventeen Centrosema species are listed as acid-soil tolerant, most of them occurring, in their native habitat, predominantly on acid soils. Among them, C. acutifolium, C. brasilianum, and C. macrocarpum have been identified as species with high potential as pasture legumes. Other acid-soil tolerant species with a lesser known agronomic potential are C. arenarium, C. brachypodum, and a new, as yet undescribed, species (C. "tetragonolobum"). The well-known C. pubescens also appears to have germplasm with potential for acid soils and warrants systematic screening and evaluation of the full range of its available germplasm.

Research priorities are to increase the germplasm base of poorly collected promising species such as C. arenarium and C. brachypodum; assess the agronomic and forage potential of little-known species such as C. bifidum and C. capitatum; perform urgently needed analyses of the individual effects of soil chemical factors which affect plant growth and are associated with low pH; and investigate the mechanism of acid-soil tolerance in Centrosema.

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The Acid-Soil Problem

Acid soils of low native fertility cover considerable areas in the tropics. Cochrane et al. (1985) estimate that the central lowlands of tropical South America contain an area of 570 million ha of soils with a pH lower than 5.3 (0-20 cm); almost all are Oxisols or Ultisols. Unpublished estimates for the Caribbean, Central America, and tropical Mexico are 26 million ha, almost exclusively Ultisols (J. G. Salinas, personal communication). For tropical Africa, Sánchez and Salinas (1981) list 316 and 136 million ha of Oxisols and Ultisols, respectively. For Southeast Asia and the South Pacific islands, Blair et al. (1986) report that Ultisols cover 51% and 19% of the area, respectively, and Oxisols 4% and 3%, respectively.

The agricultural potential of Oxisols and Ultisols is limited because of their acidity: pH values lower than 5.3-5.5 are normally associated with high levels of exchangeable aluminum. When these levels reach 70% Al saturation of the effective cation-exchange capacity in the topsoil, the soil is usually considered as Al toxic and, unless amended with high lime doses, is not suitable for most crops. According to Cochrane et al. (1985), the soils of 358 million ha in the central lowlands of tropical South America, that is, 44% of the entire region, have such low pH values and are considered as potentially Al toxic.

Besides the high Al levels which are the main consequence of low soil pH, other factors contribute frequently to a general infertility complex of acid soils in the tropics. Such factors are low cation-exchange capacity; low contents of exchangeable bases and of available phosphorus (often associated with high P-fixing capacity); toxic manganese contents; low contents of organic matter; and deficiencies of sulfur and micronutrients such as boron, copper, molybdenum, and zinc (Cochrane et al., 1980). In most cases, the effect of these factors is masked by that of low pH combined with high Al saturation, and vice versa. Therefore, authors such as Hutton (1983), when discussing plant growth on Oxisols and Ultisols, frequently avoid the difficult separation of individual effects and use the term "acid, infertile soils."

On these marginal soils, pasture development, using acid-soil tolerant species with low nutrient requirements, appears to be an economically and ecologically sound possibility for the more efficient use of the vast land resources of the tropics. The relevant technology is being generated by research institutions in tropical America, among them the Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia. An
essential research strategy component is the development of adapted germplasm. It requires the assembly of large collections of potential forage species, particularly legumes, with a broad genetic base. This assembling is principally done by plant collecting throughout the tropics.

**The Search for Acid-Soil Tolerant Centrosema**

Compared with *Stylosanthes*, which is the most researched of tropical pasture legumes (Stace and Edye, 1984), research on *Centrosema* as a possible source of acid-soil tolerant germplasm is only of recent history. This is probably and simply because of a lack of germplasm: early *Centrosema* collections comprised a very limited range of species (Clements et al., 1983) that were not particularly well adapted to acid soils.

As a result of the systematic germplasm-collecting missions which CIAT and collaborating institutions have been carrying out since 1974 (Schultze-Kraft, 1985), a broad base of *Centrosema* germplasm has become available. Because these collection trips heavily emphasized the Oxisol and Ultisol regions in tropical America, much of the collected germplasm was expected to be acid-soil tolerant. This expectation was justified when preliminary evaluation work during 1978 in Colombia showed that some of the new *Centrosema* accessions grew vigorously on an Ultisol of pH 4.1 and 89% Al saturation at the CIAT-Quilichao experiment station in Colombia (CIAT, 1979). These accessions were later identified as *C. macrocarpum* and *C. acutifolium* (R. J. Clements, personal communication).

This finding stimulated three types of *Centrosema* research activities: initiation of a breeding program aimed at transferring the acid-soil adaptation of *C. macrocarpum* into *C. pubescens* (Hutton, 1983); continuation of systematic germplasm collection with emphasis on acid-soil regions of tropical America; and continuation of systematic evaluation and screening for acid-soil tolerance of new material. Continuing positive results from evaluation work led to a gradual shift of germplasm collection emphasis from *Stylosanthes* toward *Centrosema*.

As a consequence, the South American collections of *Centrosema* have increased considerably during the past years. Table 1 presents the development of the collection assembled by CIAT, principally during joint plant-exploration trips with national institutions. The species
Table 1. Development of the CIAT *Centrosera* collection, 1973-1986, excluding bred lines and naturalized material from Southeast Asia.

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<tbody>
<tr>
<td><em>C. acutifolium</em></td>
<td>—</td>
<td>2</td>
<td>10</td>
<td>21</td>
<td>36</td>
</tr>
<tr>
<td><em>C. angustifolium</em></td>
<td>—</td>
<td>3</td>
<td>9</td>
<td>22</td>
<td>24</td>
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<tr>
<td><em>C. arenarium</em></td>
<td>—</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><em>C. arenicola</em></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><em>C. bifidum</em></td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td><em>C. brachypodium</em></td>
<td>—</td>
<td>—</td>
<td>9</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td><em>C. bracteosum</em></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><em>C. brasilianum</em></td>
<td>3</td>
<td>16</td>
<td>119</td>
<td>135</td>
<td>203</td>
</tr>
<tr>
<td><em>C. capitatum</em></td>
<td>—</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><em>C. carajasense</em></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td><em>C. coriaceum</em></td>
<td>—</td>
<td>—</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td><em>C. fasciculatum</em></td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><em>C. grandisflorum</em></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td><em>C. graziella</em></td>
<td>—</td>
<td>3</td>
<td>20</td>
<td>42</td>
<td>45</td>
</tr>
<tr>
<td><em>C. latidens</em></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>—</td>
<td>2</td>
<td>63</td>
<td>179</td>
<td>312</td>
</tr>
<tr>
<td><em>C. pascuorum</em></td>
<td>1</td>
<td>10</td>
<td>52</td>
<td>63</td>
<td>67</td>
</tr>
<tr>
<td><em>C. platycarpum</em></td>
<td>—</td>
<td>—</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><em>C. plumieri</em></td>
<td>2</td>
<td>15</td>
<td>50</td>
<td>77</td>
<td>138</td>
</tr>
<tr>
<td><em>C. pubescens</em></td>
<td>54</td>
<td>118</td>
<td>277</td>
<td>430</td>
<td>611</td>
</tr>
<tr>
<td><em>C. rotundifolium</em></td>
<td>—</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td><em>C. sagittatum</em></td>
<td>—</td>
<td>4</td>
<td>18</td>
<td>22</td>
<td>34</td>
</tr>
<tr>
<td><em>C. schiedeanum</em></td>
<td>—</td>
<td>6</td>
<td>7</td>
<td>19</td>
<td>35</td>
</tr>
<tr>
<td><em>C. schottii</em></td>
<td>3</td>
<td>25</td>
<td>33</td>
<td>35</td>
<td>50</td>
</tr>
<tr>
<td><em>C. tapirapoanense</em></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><em>C. &quot;tetragonolobum&quot;</em></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td><em>C. triquetrum</em></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td><em>C. venosum</em></td>
<td>—</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td><em>C. vexillatum</em></td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>5</td>
<td>41</td>
<td>98</td>
<td>119</td>
<td>152</td>
</tr>
<tr>
<td><em>Centrosera</em> new sp. No. 4</td>
<td>—</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td><em>Centrosera</em> spp. (unident.)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Total accessions: 68 256 794 1232 1794
Total species: 6 17 23 30 32


Names used are those considered as valid by Williams and Clements (this volume). Table 1 shows that, from 1975 onward, an increasing range of *Centrosera* species has been gathered and that, within some species, large numbers of accessions have become available for
systematic screening and evaluation. Based on information of their native habitats (Schultze-Kraft et al., this volume) and on results of evaluations carried out between 1978 and 1986 on the very acid, low-fertility Ultisol at the CIAT-Quilichao experiment station, the following species are considered to contain germplasm adapted to acid soils with high Al saturation: *Centroserma acutifolium*, *C. angustifolium*, *C. arenarium*, *C. bifidum*, *C. brachypodum*, *C. bracteosum*, *C. brasiliyanum*, *C. capitatum*, *C. carajasense*, *C. coriaceum*, *C. grazielae*, *C. macrocarpum*, *C. pubescens*, *C. schiedeanum*, *C. "tetragonolobum"*, and *C. venosum*, and *Centroserma* new sp. No. 4.

The Acid-Soil Tolerant *Centroserma* Species and Their Agronomic Potential

**Reflections on the term “acid-soil tolerant species”**

In this paper, acid-soil tolerance means the ability of a plant to grow satisfactorily in soils with pH values lower than 5.5 and without pH-raising additions of lime. The range of *Centroserma* species adapted to moderately acid soils with pH values higher than 5.5 and, thus, without any significant stress of exchangeable Al, is considerably broader than that under discussion in this section.

The use of the term “acid-soil tolerant species” causes problems because the statement is frequently based on observations of only a few plant populations or small numbers of germplasm accessions rather than on evaluations of samples representing the full range of intraspecific diversity. Such representative samples do not exist for most *Centroserma* species; instead, neither the extent of available collections nor the knowledge about the variability included is adequate. Therefore, whenever in this paper the term “species” is used in connection with the attribute “acid-soil tolerance,” it stands for the entirety of only those accessions which have been used to generate present knowledge. It is stressed that such a generalization to the species level should always be considered in relation to the number of available and actually tested accessions.

1. *C. "tetragonolobum"* is a working term for a new, as yet undescribed, species which appears closely related to *C. brasiliyanum* and *C. bifidum*. A distinguishing characteristic is its winged pods.
Acid soils and native *Centrosema* habitats

The information on soil chemical properties at collection sites of *Centrosema* herbarium or germplasm material is, on the whole, scarce and often very general. In spite of this and other limitations, there is sufficient justification to state that the above-mentioned acid-soil tolerant species occur in their native habitats on acid soils, although variably. A rough classification into three groups is proposed:

Group A. Species which occur exclusively on acid soils, that is, *C. bifidum*, *C. bracteosum*, *C. coriaceum*, and *C. venosum*.

Group B. Species which occur predominantly on low pH soils but which extend into habitats with less acid soils, that is, *C. acutifolium*, *C. angustifolium*, *C. brasiliannum*, *C. grazielae*, *C. macrocarpum*, and *C. "tetragonolobum".*

Group C. Species which occur predominantly on higher pH soils but which extend into acid-soil habitats, that is, *C. pubescens* and *C. schiedeanum*.

Information available on *C. arenarium*, *C. brachypodum*, *C. carajasense*, and *Centrosema* new sp. No. 4 is not enough to classify these species unambiguously into any of the three groups.

To illustrate the pattern of adaptation of species in Group B, Figure 1A shows the frequency distribution of soil pH values at the original collection sites for a major portion (119 accessions) of the *C. macrocarpum* collection. Most of the accessions belong to a particularly promising group that has a well-defined geographic distribution: they are low-altitude ecotypes from northern South America (Schultze-Kraft, 1986). The pH range is very wide, with 69% of the accessions originating in acid to very acid soils. The remainder extend to habitats with soil pH higher than 5.5 (Figure 1A). The same wide pH range and a similar frequency distribution can be observed for 102 acid-soil tolerant *C. macrocarpum* accessions (Figure 1B) which had shown vigorous growth on the very acid, highly Al-saturated Ultisol of the CIAT-Quilichao experiment station in Colombia. Twenty-seven percent of these accessions come from soils with a pH higher than 5.5 and, therefore, without Al stress. Thus, for *C. macrocarpum*, higher soil pH at the original collection site does not necessarily mean lack of adaptation to acid soils.
Assessment of the agronomic potential: an overview

Besides soil adaptation, other important plant characteristics must be taken into account when assessing the agronomic potential of a forage legume. These include dry-matter and seed production potential, tolerance of biotic stresses such as insect pests and diseases, dry-season performance, nitrogen-fixing capacity, nutritive value, competitiveness with grasses, and other characters related to plant persistence.

Acid-soil tolerant *Centrosema* species can be classified according to their known or suspected agronomic potential, as follows:

**Known agronomic potential**

<table>
<thead>
<tr>
<th>High</th>
<th>Intermediate</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. acutifolium</em></td>
<td><em>C. arenarium</em></td>
<td><em>C. bracteosum</em></td>
</tr>
<tr>
<td><em>C. brasilianum</em></td>
<td><em>C. brachypodum</em></td>
<td><em>C. venosum</em></td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td><em>C. pubescens</em></td>
<td></td>
</tr>
</tbody>
</table>
Unknown agronomic potential, but believed to be:

<table>
<thead>
<tr>
<th>Intermediate to high</th>
<th>Intermediate to low</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. capitatum</em></td>
<td><em>C. angustifolium</em></td>
</tr>
<tr>
<td><em>C. graziellae</em></td>
<td><em>C. bifidum</em></td>
</tr>
<tr>
<td><em>C. schiedeanum</em></td>
<td><em>C. carajasense</em></td>
</tr>
<tr>
<td><em>C. &quot;tetragonolobum&quot;</em></td>
<td><em>C. coriaceum</em></td>
</tr>
<tr>
<td><em>Centrosema</em> new sp. No. 4</td>
<td></td>
</tr>
</tbody>
</table>

This assessment is largely based on 9 years' of plant introduction and preliminary evaluation work that was carried out on an Ultisol with a pH of 4.1 and 89% Al saturation at the CIAT-Quilichao experiment station in Santander de Quilichao, Cauca, Colombia (CIAT, 1978 to 1987; Schultze-Kraft and Keller-Grein, 1985). The classification of some species is based on observations of only a few accessions, and so may be an inadequate generalization. The scheme should, therefore, be considered as preliminary.

The acid-soil tolerant *Centrosema* germplasm discussed on p. 104 is subdivided into those species whose agronomic potential can be determined confidently from systematic evaluation experiments (*C. acutifolium*, *C. brasilianum*, *C. macrocarpum*, *C. arenarium*, *C. brachypodum*, *C. pubescens*, *C. bracteosum*, and *C. venosum*); and those whose potential is still unknown but for which a preliminary guess can be made on the basis of some observations at the plant nursery level: *C. capitatum*, *C. graziellae*, *C. schiedeanum*, *C. "tetragonolobum, C. angustifolium*, *C. bifidum*, *C. carajasense*, *C. coriaceum*, and *Centrosema* new sp. No. 4.

The first group is subdivided into three, according to the known level of agronomic potential. **High potential** species are *C. acutifolium*, *C. brasilianum*, and *C. macrocarpum* and are briefly discussed in the next section. A particularly positive feature common to these species is their broad adaptability; in many regional trials sites in tropical America they have shown outstanding performance (Pizarro, 1986). Encouraging results are also reported from Southeast Asia and tropical Africa (Humphreys et al., this volume; Lazer and Clatworthy, this volume), even though the testing of these species is only in its initial phase. Species with **intermediate potential** are *C. arenarium*, *C. brachypodum*, and *C. pubescens*, and those with **low potential** are *C. bracteosum* and *C. venosum.*
Species with high potential: *Centrosema acutifolium*

In pre-1987 publications such as that of Schultze-Kraft and Keller-Grein (1985), this species was referred to as a new species: “Centrosema sp. n.” It was recently identified by R. J. Williams and R. J. Clements of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, and is considered as a very promising pasture legume for a wide range of ecological conditions (Dias Filho and Serrão, n.d.; Pizarro, 1986; Thomas and Grof, 1986). Results from animal production trials in the Colombian Eastern Plains (Llanos Orientales) show high animal gains combined with good legume persistence in *C. acutifolium-Andropogon gayanus* pastures (CIAT, 1987). Accession CIAT 5277 is now being considered for cultivar release in Colombia by the Instituto Colombiano Agropecuario (ICA) (P. Mendoza, personal communication).¹

Low nutrient requirements, stoloniferous growth habit, high nutritive value, good dry-season performance, and good seed-production potential are the outstanding characteristics of those *C. acutifolium* accessions that have reached advanced stages of testing (CIAT, 1982, 1985, and 1987; Grof, 1986). Diseases such as pseudomonas bacterial blight and rhizoctonia foliar blight (RFB), are major limitations to the use of *C. acutifolium* (Lenné et al., 1985).

A preliminary evaluation, carried out recently at the CIAT-Quilichao station in Colombia with a, so far, small germplasm collection, showed clear differences between the group of nine accessions from the Orinoco region (var. “orinicense”), and the 19 accessions originating in central Brazil (var. “matogrossense”). Under experimental conditions, the accessions of the latter group consistently flowered earlier and had a lower nutritive value in terms of protein content and in vitro dry-matter digestibility (Schultze-Kraft et al., 1987).

Species with a high potential: *Centrosema brasillianum*

Based on agronomic evaluations under cutting, as well as on results from animal production trials, this species is considered as promising in a wide range of ecological conditions (CIAT, 1987; Pizarro, 1986; Thomas and Grof, 1986). Particularly valuable characters are especially

¹ Editor’s note: CIAT 5277 was released as cultivar Vichada on 9 October 1987 by ICA.
low mineral-nutrient requirements (CIAT, 1981); high seed-production potential (CIAT, 1985); and a high nutritive value which, combined with outstanding dry-season performance, contributes significantly to animal production (CIAT, 1987). Diseases, particularly RFB, are the major limitation (Lenné et al., 1985) and restrict the potential use of the species to less humid environments. A germplasm collection of about 200 accessions has been assembled; it contains considerable variation within a series of plant characters, including tolerance to RFB (Belalcázar and Schultze-Kraft, 1986; Schultze-Kraft and Belalcázar, 1988).

**Species with high potential: Centrosema macrocarpum**

In general, *C. macrocarpum* is also reported as promising for a wide range of ecological conditions throughout the tropics (Pizarro, 1986). Vigorous growth and excellent dry-season performance (CIAT, 1987; Dias Filho and Serrão, n.d.; Duque and Vargas, 1986; Thomas and Grof, 1986), high nutritive value (CIAT, 1987), and disease tolerance (Lenné et al., 1985) are considered to be particularly valuable characteristics. Major limitations are a restricted flowering and seed-setting potential in some locations (Argel et al., this volume; Thomas and Grof, 1986) and a lack of persistence under grazing in some of the earlier flowering, nonstoloniferous accessions, particularly when associated with very competitive grasses such as *Andropogon gayanus* (da Veiga and Serrão, 1986; Thomas and Grof, 1986). Flowering is influenced by photoperiod (Schultze-Kraft, 1986) and seed-setting depends on flowers being visited by bumblebees (Escobar et al., 1985).

The germplasm collection comprises more than 300 accessions, representing five distinct groups, each with a well-defined geographic distribution. Of these, lowland ecotypes from northern South America have particularly high potential for acid soils. They vary considerably in earliness, dry-matter (DM) and seed production potential, and stoloniferous growth habit (Keller-Grein, 1984; R. Schultze-Kraft, unpublished data). When grown on the Quilichao Ultisol, the DM production of high-yielding accessions of this group is not influenced by the degree of soil acidity at the original collection site (Schultze-Kraft et al., 1985; Figure 1).
Species with intermediate potential

*Centrosera pubescens*. This species is the most common, is well researched, and has the largest number of collected germplasm accessions. It has usually been considered as acid-soil intolerant, particularly the commercial varieties (Clements et al., 1983; Hutton, 1983). Documented experimental results showing the poor performance of commercial *C. pubescens* on acid soils, however, are scarce and are limited to data presented by Schultze-Kraft and Keller-Grein (1985). Nevertheless, commercial *C. pubescens* lines, although widely tested on Oxisols and Ultisols in tropical America, have had no major impact, encouraging the speculation that lack of acid-soil tolerance has been a reason for their failure.

Some systematic screening has been carried out on noncommercial lines of *C. pubescens*. Several dozen germplasm accessions were tested for their acid-soil adaptation under greenhouse and field conditions during 1978-1981 (CIAT, 1984b; Hutton, 1983; Schultze-Kraft and Keller-Grein, 1985). This work resulted in the identification of a series of accessions that were acid-soil tolerant such as CIAT 5126, 5172, and 5189. In subsequent years, they were tested regionally throughout the American tropics, together with the hybrid accession CIAT 438 (Grof, 1982) which showed promise on an acid Ultisol in Colombia at the level of grazing trials (Ramirez, 1983). Regional reports (Pizarro, 1986) show, in a varying degree, that these accessions have potential for acid-soil sites in humid tropical environments, but not in savanna ecosystems. Disease susceptibility, particularly to cercospora leaf spot and anthracnose, is the major limitation.

Considerable variation in acid-soil tolerance was found among fewer than 75 accessions tested in the 1978-81 trials. Such variation justifies a major screening effort with the available *C. pubescens* collection that, at CIAT alone, comprises about 600 accessions.

*Centrosera arenarium* and *C. brachypodum*. These species are taxonomically so closely related that they are sometimes considered as, for example, by Barbosa-Fereiro (1977), only one species, that is, *C. arenarium*. However, without discussing the minor morphological details significant to the taxonomist, there are such striking macromorphological and physiological differences that the agronomist cannot but consider them as belonging to two plant groups which, for the sake of better understanding among scientists, require different names. Whereas *C. arenarium* exhibits, at latitudes 30°-40° N, a high seed-
production potential and an erect, bushlike growth habit with a conspicuous leaflet polymorphism within the same plant, most *C. brachypodum* ecotypes have an extremely low seed-production potential in spite of profuse flowering in some accessions. The growth habit is trailing-climbing and, in some ecotypes, remarkably stoloniferous.

Only two *C. arenarium* germplasm accessions are available, and these have good acid-soil tolerance (CIAT, 1986). One was reported to exhibit extraordinary vigor in the Quilichao Ultisol (Schultzze-Kraft and Keller-Grein, 1985) but to be of low palatability (Keller-Grein, 1984). Consisting of only 10 accessions, the *C. brachypodum* collection also has an inadequate genetic base. It contains, however, very wide variation in leaf size and shape, flowering time, and growth on acid soil (R. Schultzze-Kraft, unpublished data). The major limitation close to the equator is the extremely low seed-production potential. Neither the untested, acid-soil tolerant germplasm of *C. arenarium* nor that of *C. brachypodum* appears severely affected by diseases.

**Species with low potential**

These are *C. bracteosum* and *C. venosum*, two typical representatives of herbaceous, fire-climax, savanna vegetation. They have a very low DM production potential, and it appears impossible to grow them outside their native habitat. Excellent adaptation to extremely poor, acid, sandy soils and resistance to fire by regeneration from amphicarpic seed and tuberous roots are positive characters that may eventually be valuable for interspecific hybridization programs.

**Species with unknown potential**

*Centrosera capitatum*. This species is closely related to *C. pubescens* and *C. macrocarpum*, but its agronomic potential is virtually unknown. Only three accessions are available but they do not grow well at the Quilichao experiment station, being susceptible to pseudomonas bacterial blight.

*Centrosera grazieleae*. Until clarified by recent taxonomic studies (Williams and Clements, this volume), on the few occasions where this species was used experimentally, it was referred to as *C. acutifolium*, for example, by Hutton (1983). Very little is known of its potential, but its occurrence in Oxisol savanna habitats suggests that it is adaptable to
Centrosema species for acid soils

Acid soils. However, none of the accessions so far tested was considered as particularly acid-soil tolerant (CIAT, 1984b; Hutton, 1983). An especially valuable feature of *C. grazielae* is true amphicarpy or the ability to produce short, eventually pod-bearing, peduncles at soil surface. Low DM production potential is its principal limitation. The present collection comprises about 50 accessions from Brazil, Colombia, and Venezuela. A systematic evaluation of the agronomic potential of this species is warranted.

*Centrosema schiedeanaum.* Knowledge about the agronomic potential of this species has not changed since a brief summary was given by Schultze-Kraft and Keller-Grein (1985). The respective germplasm collection, however, has increased and now comprises 36 accessions. They include acid-soil intolerant ecotypes (all Mexican materials), as well as acid-soil tolerant germplasm. The collection of acid-soil tolerant material is composed of two morphologically distinct ecotype groups: from Costa Rica and Panama, and from the Colombian Llanos. This collection also warrants agronomic evaluation in order to clarify the potential of *C. schiedeanaum* for acid soils.

*Centrosema tetragonolobum.*” This new, still undescribed, species is closely related to *C. brasiliianum*. Its outstanding features are leafiness, vigorous growth on the Quilichao Ultisol, and tolerance to *Rhizoctonia*.

*Centrosema angustifolium.* Very low DM production is the principal limiting characteristic of this species. Its potential may be higher on poorly drained soils than on well-drained soils.

*Centrosema bifidum* and *C. coriaceum*. The forage potential of both these species appears to be seriously limited by their lack of leafiness, their very coriaceous leaves, and their unfavorable nontrailing growth habit.

*Centrosema carajasense*. This species is very tolerant to shade, a characteristic shared with *C. fasciculatum* and *C. sagittatum*, the other two unifoliolate *Centrosema* species (which, however, are intolerant of acid soils). The potential of *C. carajasense* appears limited by inadequate DM production and, in particular, poor seed production.

*Centrosema new sp. No. 4.* This species has a trailing, rather than climbing, growth habit and is an intermediate DM producer. Its main limitations are poor seed-production potential and a lack of drought tolerance.
Although they have not been included in the list of acid-soil tolerant *Centrosema* species, *C. pascuorum*, *C. plumieri*, *C. rotundifolium*, *C. sagittatum*, and *C. triquetrum* may have a potential for certain ecological niches with acid, although not too marginal, soils.

The Nature of Acid-Soil Adaptation in *Centrosema*

Virtually nothing is known about the nature of acid-soil adaptation in *Centrosema*—a serious knowledge gap. A first step must be to identify and understand which factors associated with acid soils such as low pH per se, high concentrations of Al and Mn, or deficiencies of Ca, Mg, and micronutrients, are responsible for depressed plant growth. Research on mineral nutrition and rhizobiology so far carried out is discussed by Salinas et al. (this volume) and Sylvester-Bradley et al. (this volume).

The identification and understanding of such factors, however, are very complex because of the interactions between factors and because there is frequently poor correlation between results of pot experiments and field trials. For example, Schultze-Kraft and Keller-Grein (1985) reported, from their field trials in very acid, highly Al-saturated Quilichao Ultisol, that Australian commercial centro (accession CIAT 413) grew poorly, but *C. pubescens* hybrid CIAT 438 grew well. In pot trials with very acid, highly Al-saturated Carimagua Oxisol, CIAT 438 grew only after heavy lime applications (Grof et al., 1979). CIAT 413, however, showed good growth, without any liming, comparable with that of other acid-soil tolerant *C. pubescens* accessions such as CIAT 5126 and 5189 (Useche and Schultze-Kraft, 1984). Neither accession grows acceptably under Carimagua field conditions (Grof et al., this volume).

Recent studies stressed the importance of efficient Ca absorption in *C. macrocarpum* and its hybrids with *C. pubescens* (Hutton, 1985). In fact, high plant Ca concentrations combined with high DM yields have been frequently found in *C. macrocarpum* when grown under the field conditions of the very acid, Ca-deficient, Quilichao Ultisol (Schultze-Kraft et al., 1985). This supports the hypothesis that efficient Ca absorption contributes heavily to the acid-soil tolerance of this species.
Research Priorities

Germplasm collection

It may not be possible to further increase the number of acid-soil tolerant *Centrosoea* species. Regarding intraspecific variation, however, and possibly excepting *C. brasilianum*, *C. macrocarpum*, and *C. pubescens*, most species are only poorly represented in available germplasm. More collection and systematic evaluation within these species is needed.

Nature of acid-soil tolerance

It is necessary to better understand which of those soil chemical properties associated with low pH values limit *Centrosoea* growth. Once the individual effects, which may differ according to species, are separated, the mechanism of acid-soil tolerance must be studied in order to eventually develop more efficient screening methods and to provide better characterization of the evaluated germplasm.

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Centrosema species for acid soils


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Centrosema species for acid soils

Chapter 5

MINERAL NUTRITION OF

CENTROSEMA

J. G. Salinas, P. C. Kerridge, and R. M. Schunke*

Abstract

The nutrition of Centrosema pubescens (centro) has been well studied, and it is only recently that studies have been made on other species. Common centro is less tolerant to soil acidity than some other lines of C. pubescens, while C. macrocarpum, C. acutifolium, and C. brasilianum lines show the most tolerance, and C. pascuorum and C. schottii show the least. In some species, efficient root absorption of Ca is associated with vigor and persistence on acid soils.

Yield responses to applications of 20–100 kg of P/ha have been obtained. Phosphorus uptake is greatly enhanced by vesicular-arbuscular mycorrhizae. The internal P requirement is 0.14%-0.18% of P. Applications of 30-50 kg of K/ha and of 20-30 kg of S/ha are suggested for soils containing less than 0.2 meq of exchangeable K/100 g of soil and less than 8 ppm of phosphate-extractable S, respectively. Responses to Mo, Zn, and Cu have been reported.

Centrosema species adapted to acid, low-fertility soils have been established with band applications of 20 kg of P/ha, 100 kg of Ca/ha, 30 kg of K/ha, and 20 kg of S/ha. Fertilizer banding and use of rock phosphate, elemental S, or other cheap fertilizers are of practical significance.

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Research is required on the mechanism of tolerance to soil acidity, on the efficiency in extraction of P and Mo from soil, and on maintenance fertilizer requirements of *Centrostepa* in mixtures with grasses.

**Introduction**

Mineral nutrient requirements can be considered both in terms of nutrient demand by the plant and the ability of the soil to meet this demand. Thus, ideally, nutrient requirements can be expressed in terms of internal and external indexes. However, because these indexes are affected by many factors and, in many instances, are difficult to measure accurately, nutrient requirements are often expressed in terms of more empirical measures of soil fertility or in terms of comparative response.

Most information on the nutrition of *Centrostepa* relates to commercial lines of *C. pubescens* or common centro. More recently, selections have been made from other *Centrostepa* species to extend the use of *Centrostepa* to highly weathered Oxisols and Ultisols (Schultze-Kraft and Keller-Grein, 1985; Schultze-Kraft et al., 1985) and semiarid areas (Clements et al., 1984). Some nutritional studies have been made on these species (CIAT, 1981, 1982, 1984, 1985, and 1987; Clements et al., 1983; Useche and Schultze-Kraft, 1984; R. M. Schunke, D. G. Edwards, and C. J. Asher, unpublished data; W. H. Winter, unpublished data).

This paper reviews the main nutrient limitations of soils for *Centrostepa*, the comparative requirements within and between *Centrostepa* species, the most appropriate methods to diagnose nutrient requirements, fertilizer strategies as they affect production and persistence, and future research priorities.

**Mineral Nutrient Requirements and Limitations**

Differences between plants in their internal requirements for essential nutrients are not usually large for similar rates of growth. There are larger differences in plants' ability to extract nutrients from the soil and to regulate the intake of necessary and toxic elements. At the same time, the rhizosphere ecosystem affects these soil and root interactions.
Mineral nutrition of Centrosema

Nutrients are concentrated in the surface soil, and most studies concentrate on relationships between nutrient availability in this surface layer and plant growth. However, the roots of some plants penetrate deeper soil layers and therefore can compete better for water and nutrients.

In areas to which Centrosema species are adapted, the most common responses to soil and fertilizer amendments are those associated with soil acidity (low pH; Ca, Mg, and Mo deficiencies; and Al and Mn toxicities) and with P, S, K, and the micronutrients Cu and Zn.

Soil acidity: pH, Ca, Mg, Al, and Mn

Acid soils have low pH (≤5.3); deficiencies of Ca, Mg, and Mo; toxicities of Al and Mn; and, usually, low P status. These factors affect the survival and growth of rhizobia, nodulation, N₂ fixation, and growth of the host legume. Here, pH, Ca, Mg, Al, and Mn are treated together because they are closely associated and because surface amelioration does not remove their detrimental effect on root growth in the subsoil.

pH. The effect of pH per se has not been studied on Centrosema. Studies with other genera (Andrew, 1976) and studies on soils on which Centrosema species have been grown (CIAT, 1986; Schultzze-Kraft et al., 1985) suggest that legume growth is good in the pH range of 4.2-7.5. However, nodulation and N₂ fixation may be influenced by pH in the pH range of 4-6 (Andrew, 1976). Soils with a pH of 8.0 or more induce Fe deficiency in C. pubescens (Gutteridge, 1978), but not in C. pascuorum nor in C. schottii (P. C. Kerridge, unpublished data).

Calcium, magnesium, and aluminum. Low Ca (Hutton, 1985; Spain et al., 1975) and high Al (CIAT, 1979; Hutton, 1983) affect the growth of several Centrosema species. Common C. pubescens is less tolerant of soil acidity than other lines of C. pubescens. Centrosema macrocarpum lines show the most tolerance and C. pascuorum and C. schottii lines show the least tolerance (Schultze-Kraft and Keller-Grein, 1985).

The individual effects of Ca deficiency and Al toxicity on N₂ fixation and growth are difficult to assess in soil culture, even though soils with low Ca and low Al can be used to examine effects of Ca deficiency separately from those of Al toxicity. In one study with such a soil, which had a pH of 5.5 and 0.1 meq of exchangeable Ca/100 g of soil, C. pubescens was well nodulated and gave 52% of its potential maximum
yield, compared with *Stylosanthes guianensis* which gave 64%, and *Desmodium uncinatum* which gave 26% (Table 1).

Aluminum toxicity has been studied in solution culture (Murphy et al., 1984). *Centrosema pubescens* showed the same tolerance as *S. guianensis* cv. Schofield. Plant growth was not affected at 125 μM of Al. Work with *Stylosanthes* suggests that Al affects noduleation, but not fixation once nodules are formed (de Carvalho et al., 1981). High Al concentrations inhibit acetylene reduction in *C. pubescens* and *S. humilis*, but not in *Macroptilium atropurpureum* (Ogata et al., 1985). However, it is not known whether this is because noduleation was affected. Hutton (1983) observed that, in a soil low in Ca and high in Al, there was less Al in the tops of the more acid-soil tolerant *C. macrocarpum* (53 ppm) than in those of the less tolerant *C. pubescens* (198 ppm) and intolerant *C. virginianum* (764 ppm). High Al levels may also reduce P availability and uptake (Ayarza and Salinas, 1982).

In most acid soils, both low Ca and high Al may limit growth, and liming with CaCO₃ may correct either limitation. In an Oxisol at Carimagua (pH 4.3; 0.5 meq of exchangeable Ca/100 g of soil; 80% Al saturation), *C. pubescens* responded to CaCO₃ more strongly than *C. acutifolium* or *C. macrocarpum* (Table 2). The pH (and hence available Al) was little changed by any CaCO₃ addition.

In another field study on Oxisols and Ultisols in Malaysia (pH 4.5-5.0; <1 meq of exchangeable Ca/100 g of soil; 60%-80% Al saturation), there were large yield increases by *C. pubescens* in response to additions of 400-500 kg of CaCO₃/ha (Tham and Kerridge, 1982). In the soil where 2000 kg of CaCO₃/ha were applied, response also

Table 1. The effect of calcium saturation and pH on yield, noduleation, and Ca and N concentrations of *Desmodium uncinatum* (D), *Centrosema pubescens* (C), and *Stylosanthes guianensis* (S).

<table>
<thead>
<tr>
<th>Ca sat. (%)</th>
<th>pH</th>
<th>Yield (g/pot)</th>
<th>Nodule weight (g/pot)</th>
<th>Ca (%)</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>D  C  S</td>
<td>D  C  S</td>
<td>D  C  S</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5.5</td>
<td>4.2  5.9  6.1</td>
<td>0.01 0.34 0.13</td>
<td>0.34   0.37 0.77</td>
<td>2.1  1.9  2.4</td>
</tr>
<tr>
<td>14</td>
<td>5.5</td>
<td>6.1  6.7  7.8</td>
<td>0.22 0.56 0.14</td>
<td>0.77  0.93 1.29</td>
<td>1.6  2.5  2.5</td>
</tr>
<tr>
<td>26</td>
<td>5.8</td>
<td>9.7  8.1  8.5</td>
<td>0.76 0.81 0.16</td>
<td>1.08  1.11 1.58</td>
<td>2.6  3.3  2.5</td>
</tr>
<tr>
<td>37</td>
<td>6.4</td>
<td>10.8 9.9  9.1</td>
<td>0.94 1.04 0.18</td>
<td>1.20  1.35 1.75</td>
<td>2.2  3.2  2.4</td>
</tr>
</tbody>
</table>

### Table 2. Rates of CaCO$_3$ application and plant Ca concentration associated with 80% maximum yield for some forage legumes grown in an Oxisol at Carimagua, Colombia.

<table>
<thead>
<tr>
<th>Species</th>
<th>CIAT accession no.</th>
<th>CaCO$_3$ application (kg/ha)</th>
<th>Dry-matter yield (t/ha)</th>
<th>Ca concentration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wet season</td>
<td>Dry season</td>
</tr>
<tr>
<td>Centroselecta acutifolium</td>
<td>5277</td>
<td>125</td>
<td>3.2</td>
<td>1.2</td>
</tr>
<tr>
<td>C. macrocarpum</td>
<td>5065</td>
<td>250</td>
<td>2.5</td>
<td>0.7</td>
</tr>
<tr>
<td>C. pubescens</td>
<td>5053</td>
<td>1000</td>
<td>2.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Stylosanthes capitata</td>
<td>1315</td>
<td>150</td>
<td>6.0</td>
<td>1.1</td>
</tr>
<tr>
<td>Pueraria phaseoloides</td>
<td>9900</td>
<td>250</td>
<td>4.4</td>
<td>0.9</td>
</tr>
<tr>
<td>Desmodium ovalifolium</td>
<td>350</td>
<td>250</td>
<td>4.9</td>
<td>1.3</td>
</tr>
</tbody>
</table>

SOURCE: CIAT, 1982.

occurred, once the Mo deficiency had been corrected (Table 3). This may have resulted from the lime overcoming Al toxicity or from enhanced N$_2$ fixation. However, even with the addition of 2000 kg of CaCO$_3$/ha, soil pH and plant Ca concentrations were still low. These studies suggest a high Ca requirement by C. pubescens.

In contrast, Spain et al. (1975) obtained, in C. pubescens, a maximum response to only 150 kg of Ca + Mg/ha in a soil similar to that used in the 1982 CIAT study. However, the plant N concentration remained low, suggesting a continuing limitation of N$_2$ fixation. Nutrient requirements must be evaluated in the presence of an effective Rhizobium inoculant (Figure 1). Rhizobium requirements for Centroselecta are more specific than for many other tropical species (Sylvester-Bradley et al., this volume).

Liming has frequently been shown to be beneficial to the growth of C. pubescens (Colozza and Werner, 1984; de França and de Carvalho, 1970; Döbereiner and Aronovich, 1966; Jones and de Freitas, 1970). Centroselecta pubescens is less tolerant of acid soils than several Stylosanthes species, but more tolerant than Neonotonia wightii, and there is considerable variation within C. pubescens (EMBRAPA, 1981).
Table 3. Comparative effect of CaCO$_3$ and Mo on yield and chemical composition of _Centrosera pubescens_ and _Stylosanthes guianensis_ and of CaCO$_3$ on soil pH, on a Rengam series soil, 1977 harvest, Malaysia.

<table>
<thead>
<tr>
<th>Variable evaluated</th>
<th>Mo treatment</th>
<th><em>C. pubescens</em> (kg of CaCO$_3$/ha)</th>
<th><em>S. guianensis</em> (kg of CaCO$_3$/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>500</td>
</tr>
<tr>
<td>Yield (kg/ha)</td>
<td>-Mo</td>
<td>70</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>+Mo</td>
<td>120</td>
<td>360</td>
</tr>
<tr>
<td>N(%)</td>
<td>-Mo</td>
<td>2.4</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>+Mo</td>
<td>3.2</td>
<td>3.5</td>
</tr>
<tr>
<td>Ca(%)$^a$</td>
<td></td>
<td>0.43</td>
<td>0.52</td>
</tr>
<tr>
<td>Soil pH$^a$ (0.01 CaCl$_2$)</td>
<td></td>
<td>4.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

a. Mean over Mo treatments.
b. Means for both _C. pubescens_ and _S. guianensis_ at 0, 500, and 2000 kg of CaCO$_3$/ha.


Figure 1. Effect of fertilization rate and fertilizer solubility, with and without *Rhizobium* inoculation, on yield and number of nodules in _Centrosera macrocarpum_ CIAT 5065. Low and high fertilization rates (kg/ha) are, respectively, P = 20, 50; K = 30, 60; Ca = 100, 500; and Mg = 38, 75. Basal dressing is with S, Zn, B, and Mo in both treatments. Slow release fertilizers are rock phosphate, K feldspar, and Mg serpentine. (●● = inoculated; □ = uninoculated.) (Adapted from CIAT, 1985.)
Yield responses have been obtained when *C. pubescens* was limed at rates well above those required to neutralize excess Al and supply sufficient Ca (Snyder et al., 1978). Similar responses have been obtained with a range of tropical legumes (Munns and Fox, 1977), probably because pH was increased above the pH range of 4-6 rather than because Ca was increased (Andrew, 1976). Both Ca and pH affect nodulation and N₂ fixation (Table 1). Field responses to higher lime application could also result partly from greater movement of Ca to the subsoil and the alleviation of Ca deficiency there.

Efficient root absorption of Ca is associated with vigor in *Centrosoema* on acid soils (Hutton, 1985), probably reflecting ability to overcome the Al inhibition of Ca uptake. Schultze-Kraft and Keller-Grein (1985) found no relationship between yield and Ca leaf concentration, but there was a relation between yield and P concentration. However, in this field study, plants were not dependent on symbiotic N₂ fixation because of N application and high organic-matter content in soil.

Magnesium may limit growth on highly weathered soils (Tham, 1976), although only a few field responses have been observed. The absence of response may be because Mg is present in many limestone materials. A positive interaction has been observed between Mg and S with *C. macrocarpum* and *C. acutifolium* (CIAT, 1987). Magnesium deficiency reduces the N concentration in *C. pubescens*, but does not affect nodulation (Andrew, 1977b).

**Manganese.** *Centrosoema pubescens* is more tolerant to high levels of Mn than are *Stylosanthes humilis, Desmodium uncinatum, Neonotonia wightii, Macroptilium atropurpureum,* and *Leucaena leucocephala* (Andrew and Hegarty, 1969; Souto and Döbereiner, 1969). In a continuously flowing solution culture, Mn concentrations greater than 1.7 μM were toxic for *Glycine max, Phaseolus vulgaris,* and *Vigna unguiculata,* whereas *C. pubescens* tolerated 42 μM (Asher and Edwards, 1978). However, while toxic effects of Mn have been demonstrated in pot studies (Döbereiner and Aronovich, 1966), there are few reported instances of Mn toxicity occurring under field conditions. At Quilichao, Colombia, in a soil with high exchangeable Mn (> 50 ppm), lower yields were obtained with *C. macrocarpum, C. brasilianum, C. acutifolium,* and *C. pubescens* than on a soil with low exchangeable Mn (0-20 ppm) (CIAT, 1982).
Phosphorus

One of the most widespread soil constraints in tropical soils for *Centrosema* is P deficiency. Yield increases have been obtained, in pot and field studies on a range of soils, from applications of 20 to 100 kg of P/ha (CIAT, 1985 and 1986; Javier and Marasigan, 1976; Kretschmer and Snyder, n.d.; Snyder et al., 1978; Teitzel and Bruce, 1972; Werner and de Mattos, 1972). The amount of P needed to correct a deficiency varies with the P-sorption characteristics of the soil.

Although plants take up P from a common pool of soil P (Smith, 1983), there are differences between species in their ability to extract this phosphorus and use it. In flowing solution culture, the external requirement for growth of *C. pubescens* was 3.0 μM of P compared with 0.7 μM for *S. humidis* and 0.24 μM for *S. guianensis* (Chantkam et al., 1983). The requirement decreased with age; the maximum relative growth rate of *C. pubescens* at 6-8 weeks occurred at the minimum concentration used: 0.6 μM. The root's absorbing power, that is, the ratio of the rate of nutrient absorption to external concentration, of *C. pubescens* was half that of *S. humidis*. This, in turn, was half that of *S. guianensis*, at an external concentration of 0.6 μM of P (Chantkam et al., 1984). However, the DM produced per unit of P taken up was higher for *C. pubescens* than for the two *Stylosanthes* spp. A similar effect has also been observed in N₂ fixation, where *C. pubescens* and *Desmodium heterophyllum* gave a higher N yield per unit of P taken up than *Pueraria phaseoloides* or *S. guianensis* for P concentrations below the critical level (Kerridge and Ratcliff, 1982).

The external P requirement in soil has been estimated by observing yield response to different soil-solution-P concentrations set up on the basis of P-sorption measurements. Estimates obtained in different experiments were 1.5 μM for *C. pubescens*, 1.2 μM for *S. guianensis* (Moody and Standley, 1980), and 2.6 μM for *D. intortum* (Moody, 1979). However, the external requirement estimated in this way may vary with the sorption capacity of the soil and the age of the plant.

Several comparative studies in soils confirm that *C. pubescens* has a higher P requirement than *S. guianensis*, *P. phaseoloides*, or *Desmodium ovalifolium* (Falade, 1973; Fenster and León, 1979; Kerridge and Ratcliff, 1982), but a similar requirement to *S. humidis* (Andrew and Robins, 1969a; Wilaipon, 1981).

The P requirement for *C. pascuorum* CPI 55697 was similar to that for *S. hamata* and *Alysicarpus vaginalis* (Probert and McCown, 1985),
and there is evidence that other accessions may have a lower P requirement (W. H. Winter, unpublished data). In Colombia, *C. macrocarpum* CIAT 5065 had a lower P requirement than *C. pubescens* CIAT 5126 (CIAT, 1982), while intraspecific variation was observed in *C. acutifolium*, *C. brasilianum*, and *C. macrocarpum* (Table 4).

Table 4. Dry-matter (DM) yields of several accessions of three *Centrocoma* species obtained in the greenhouse under three P rates on a clay Oxisol from Carimagua, Colombia. Basal dressing (kg/ha) was Ca at 100, K at 30, Mg at 20, and S at 20. 

<table>
<thead>
<tr>
<th>Species</th>
<th>CIAT accession no.</th>
<th>DM (g/pot) with applied P at rates (kg/ha equiv. per pot):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5452</td>
<td>2.16</td>
</tr>
<tr>
<td></td>
<td>5713</td>
<td>2.03</td>
</tr>
<tr>
<td><em>C. acutifolium</em></td>
<td>5277</td>
<td>2.20</td>
</tr>
<tr>
<td></td>
<td>5568</td>
<td>2.36</td>
</tr>
<tr>
<td><em>C. brasilianum</em></td>
<td>5810</td>
<td>1.73</td>
</tr>
<tr>
<td></td>
<td>5671</td>
<td>1.53</td>
</tr>
<tr>
<td></td>
<td>5234</td>
<td>2.26</td>
</tr>
</tbody>
</table>


Phosphorus response data have been obtained for a number of *Centrocoma* species and lines (Table 5, Figure 2). Differences within species in P requirement were related to the maximum yield (Table 5). Responsiveness (the increase in yield to applied P) and “efficiency” (the yield at nil P) provided a further separation of accessions (Figure 2). Efficiency as used here must be interpreted with caution as it is influenced by seed size and, presumably, by P content of the seed; thus, *C. schottii* accessions, which have large seeds, had high yields at nil P. Also, they are not well adapted to very acid soils (Schultze-Kraft and Keller-Grein, 1985). The arbitrary division of Figure 2 into four quadrants highlights differences among and within species. While there was a large range of responsiveness within *C. pubescens*, efficiency was low. The most efficient accessions in *C. pubescens* and *C. schottii* had low responsiveness.

Phosphorus uptake in *Centrocoma* is greatly enhanced by vesicular-arbuscular mycorrhizae in P-deficient soils (Crush, 1974; Mosse et al., 1973; Saif, 1986). Mycorrhizal activity can extend the absorbing surface and may decrease the threshold level required for P uptake by *C.*
Table 5. Coefficients\(^a\) for P response data for 24 *Centrosema* accessions fitted to the model 
\(y = a - be^{-cx}\), P requirement for 80% maximum yield, and P uptake at 40 kg of P/ha equivalent per pot.

<table>
<thead>
<tr>
<th>Species</th>
<th>CPI accession</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>P requirement</th>
<th>P uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>no. b</td>
<td></td>
<td></td>
<td></td>
<td>(kg/ha)</td>
<td>(mg/pot)</td>
</tr>
<tr>
<td><em>C. brasiliannum</em></td>
<td>(1) 40065</td>
<td>13.6</td>
<td>11.0</td>
<td>0.026</td>
<td>53</td>
<td>11.7</td>
</tr>
<tr>
<td></td>
<td>(2) 95520</td>
<td>14.5</td>
<td>10.9</td>
<td>0.036</td>
<td>37</td>
<td>14.4</td>
</tr>
<tr>
<td></td>
<td>(3) 95544</td>
<td>13.5</td>
<td>9.2</td>
<td>0.031</td>
<td>40</td>
<td>12.8</td>
</tr>
<tr>
<td></td>
<td>(4) 55698</td>
<td>16.4</td>
<td>11.6</td>
<td>0.023</td>
<td>55</td>
<td>14.6</td>
</tr>
<tr>
<td><em>C. pascuorum</em></td>
<td>(5) 55697</td>
<td>18.4</td>
<td>12.1</td>
<td>0.031</td>
<td>38</td>
<td>13.6</td>
</tr>
<tr>
<td></td>
<td>(6) 65950</td>
<td>15.6</td>
<td>9.1</td>
<td>0.037</td>
<td>29</td>
<td>12.9</td>
</tr>
<tr>
<td><em>C. pubescens</em></td>
<td>(7) 95497</td>
<td>11.3</td>
<td>7.7</td>
<td>0.031</td>
<td>40</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>(8) 95493</td>
<td>13.7</td>
<td>9.6</td>
<td>0.027</td>
<td>46</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>(9) 95512</td>
<td>14.8</td>
<td>11.8</td>
<td>0.020</td>
<td>69</td>
<td>12.9</td>
</tr>
<tr>
<td></td>
<td>(10) 95541</td>
<td>13.5</td>
<td>9.6</td>
<td>0.016</td>
<td>80</td>
<td>12.7</td>
</tr>
<tr>
<td></td>
<td>(11) 58575</td>
<td>12.9</td>
<td>9.1</td>
<td>0.034</td>
<td>38</td>
<td>15.5</td>
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<td></td>
<td>(12) 43197</td>
<td>9.0</td>
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<td>9.4</td>
<td>0.036</td>
<td>32</td>
<td>11.8</td>
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<td><em>C. schottii</em></td>
<td>(17) 87954</td>
<td>14.4</td>
<td>8.9</td>
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<td>23</td>
<td>17.6</td>
</tr>
<tr>
<td></td>
<td>(18) 55705</td>
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<td>6.8</td>
<td>0.042</td>
<td>21</td>
<td>14.3</td>
</tr>
<tr>
<td></td>
<td>(19) 91975</td>
<td>17.1</td>
<td>11.4</td>
<td>0.024</td>
<td>50</td>
<td>16.8</td>
</tr>
<tr>
<td></td>
<td>(20) 65967</td>
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<td>10.1</td>
<td>0.032</td>
<td>34</td>
<td>15.8</td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>(21) 93065</td>
<td>12.9</td>
<td>8.9</td>
<td>0.031</td>
<td>40</td>
<td>12.3</td>
</tr>
<tr>
<td></td>
<td>(22) 40057</td>
<td>11.6</td>
<td>6.7</td>
<td>0.037</td>
<td>29</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>(23) 57979</td>
<td>14.7</td>
<td>11.5</td>
<td>0.032</td>
<td>43</td>
<td>14.6</td>
</tr>
<tr>
<td></td>
<td>(24) 40556</td>
<td>15.3</td>
<td>9.9</td>
<td>0.027</td>
<td>43</td>
<td>15.9</td>
</tr>
</tbody>
</table>

\(^a\) \(y = a - be^{-cx}\) described as \(y = \text{yield}; x = \text{fertilizer applied}; a = \text{maximum yield}; b = \text{yield response to fertilizer (thus, } a - b = \text{response at nil P}); c = \text{curvature.}

\(^b\) Numbers in parentheses identify accessions so marked in Figure 2.


*pubescens* (Kretschmer and Snyder, n.d.; Mosse et al., 1973). This results in increased nodulation and N\(_2\) fixation (CIAT, 1986; Mosse et al., 1976). Kretschmer and Snyder (n.d.) suggest that higher P rates are needed at establishment because time is required for the mycorrhizal association to develop. Although natural infection with VA mycorrhizae appears to be universal, there are certain field situations where a response may occur to mycorrhizal inoculation (CIAT, 1985 and 1986).
Mineral nutrition of Centrosema

Figure 2. Phosphorus response diagram for fitted data, from \(\bullet\) Centrosema brasilianum; \(\Delta\) C. pascuorum; \(\square\) C. virginianum; \(\bigcirc\) C. pubescens; \(\triangle\) C. schottii, as listed in Table 5. (R. M. Schunke, D. G. Edwards, and C. J. Asher, unpublished data.)

The internal P requirement of C. pubescens for DM yield is 0.16%–0.18% P in young shoots (Andrew and Robins, 1969a and 1969b; CIAT, 1982; Jones et al., 1970), although the N concentration continues to increase to 0.19%–0.22% P. The critical values for yield are similar to those for S. humilis, S. hamata, and S. guianensis. Internal P requirements reported for other Centrosema species for 80% maximum DM yield are 0.16% P for C. macrocarpum, 0.18% P for C. acutifolium, and 0.14% P for C. brasilianum (CIAT, 1982).

Micronutrients

Molybdenum. Centrosema pubescens is more susceptible to Mo deficiency than S. guianensis or P. phaseoloides. Responses are
widespread (Table 3) (De-Polli et al., 1979; Tham and Kerridge, 1982), and often occur in the presence of liming (de Oliveira et al., 1985; Tham and Kerridge, 1982; Werner and de Mattos, 1975). Deficiency may not be apparent when available soil N levels are high (Teitzel and Bruce, 1972). Responses to fritted trace element mixtures may result from Mo deficiency (De-Polli et al., 1979; Monteiro et al., 1983b).

**Zinc.** There is conflicting evidence of the relative requirement for Zn by *C. pubescens*. In one study, there was a greater response than with *S. humilis* (Andrew et al., 1981), while in another, growth was less depressed in the absence of Zn than it was for *S. guianensis* (Jones et al., 1970). A critical level of 20 ppm of Zn has been suggested where the P concentration is less than 0.35% (Andrew et al., 1981).

**Copper.** *Centroessa pubescens* displays intermediate response to Cu deficiency (Bruce, 1978), being less responsive than *S. guianensis* but more responsive than *D. uncinatum* (Andrew and Thorne, 1962). Values of 4-5 ppm of Cu are considered marginal.

Monteiro et al. (1980) recommended initial applications of 2 kg of Cu/ha, 100-200 g of Mo/ha, and 2 kg of Zn/ha to overcome deficiencies of these elements. Initial applications of Cu and Zn have been shown to be effective for more than 15 years (Bryan, 1973), although, in some situations, reapplication is recommended every 4 years (Teitzel et al., 1978). However, the residual value of Mo may be reduced to 2-3 years on soils with a high capacity to adsorb Mo (Little and Kerridge, 1978). Further research is required to compare the micronutrient requirements over a range of *Centroessa* species and accessions.

**Salt tolerance**

*Centroessa pubescens* is moderately tolerant of high NaCl concentration, more so than *S. humilis*, *N. wightii*, and *D. intortum*, but less so than *M. atropurpureum* (Hutton, 1971).

**Regulation of nutrient uptake**

*Centroessa pubescens* appears to control the uptake of nutrients more closely than some other legumes. Thus, while plant P concentration increased rapidly with increasing external P concentration in *S. guianensis*, there was little increase in the percentage of P in *C. pubescens* after maximum yield had been reached (Chantkam
et al., 1983). *Centrosema pubescens* did not accumulate excessive concentrations of Mg in tops as did *M. atropurpureum* (Andrew, 1977b). Increasing plant K concentration did not decrease the Mg concentration as with some other species (Andrew and Robins, 1969d).

**Diagnostic Methods for Mineral Nutrient Deficiency**

Diagnostic techniques with *Centrosema* do not differ in principle from those used for other plants. The techniques of visual symptoms, plant tissue analysis, soil analysis, and greenhouse and field trials have all been applied to *Centrosema*. All techniques have limitations, and must be chosen to suit the problem, the level of available knowledge, the available facilities, and the skills of the operator. Better and more rapid procedures are needed. In future, modeling techniques may be helpful.

**Potassium**

When a legume is grown in grass-legume mixtures, higher external K is required to maintain an adequate internal K concentration than when the legume is grown alone. This is because, for soil K, the legume is a poorer competitor than grass (Hall, 1974), with some grasses being more competitive than others (Braga and de Ramos, 1978; Hall, 1970) (Table 6). This poorer competitive advantage of legumes has been

Table 6. Plant K concentration (%) of three forage legumes grown in association with three grasses.

<table>
<thead>
<tr>
<th>Legume</th>
<th>Grass</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>Panicum maximum</em></td>
<td><em>Cenchrus ciliaris</em></td>
<td><em>Melinis minutiflora</em></td>
</tr>
<tr>
<td><em>Centrosema pubescens</em></td>
<td>0.93</td>
<td>1.19</td>
<td>1.50</td>
</tr>
<tr>
<td><em>Neonotonia wightii</em></td>
<td>1.96</td>
<td>2.29</td>
<td>3.18</td>
</tr>
<tr>
<td><em>Calopogonium mucunoides</em></td>
<td>1.18</td>
<td>1.59</td>
<td>2.06</td>
</tr>
</tbody>
</table>

attributed to a higher cation-exchange capacity of legume than grass roots (Braga and de Ramos, 1978; CIAT, 1984). *Centrosea pubescens* and *S. guianensis* responded to K to the same extent when grown in association with *Panicum maximum* (Tham and Kerridge, 1982). Where little apparent effect of competition from the grass has been observed (Gutteridge and Whiteman, 1978), the legume may be extracting K from greater depths than the grass.

Results of cutting trials with legume-grass mixtures suggest K response may occur below 0.20 meq of exchangeable K/100 g of soil where other nutrient deficiencies have been corrected (Kerridge, 1978). This is higher than for monospecific crops. In pot trials, application of K on soils with 0.07-0.16 meq of exchangeable K/100 g of soil did not increase the yield of *C. pubescens* (Jones and de Freitas, 1970; Werner and de Mattos, 1972; de Oliveira et al., 1985), but there were increases in K concentration (Jones et al., 1970), nodulation, and N production (Monteiro et al., 1983a; Werner et al., 1983). The K requirement for establishment of *Centrosea* species in soils with exchangeable K of 0.05-0.1 meq/100 g of soil ranges from 30 to 50 kg of K/ha (CIAT, 1982).

**Sulfur**

Few field responses to S have been reported. Sulfur is a component of many P fertilizers, is acquired from rainfall, and is strongly adsorbed by soil. These and other factors may limit the response. Response is more likely where high-analysis P fertilizers are used which contain little S (Blair et al., 1978). The requirement of *C. pubescens* for S may be higher for N₂ fixation than for DM production (Watson and Whiteman, 1981); the critical level for DM production was 0.15%-0.17% S, while N concentration increased to 0.19% S (Watson and Whiteman, 1978). These values are similar to those reported for other tropical legumes (Andrew, 1977a).

Probert and Jones (1977) took account of available S at depth in predicting S requirement and suggested a weighted critical level of 4 ppm phosphate-extractable S for establishment of *Stylosanthes* species. Gualdrón and Salinas (1982) have suggested a S requirement of 20 kg of S/ha for acid tropical soils where phosphate-extractable S was less than 8 ppm. This is similar to the recommendation of 30 kg of S/ha every 2 years for *C. pubescens* pastures on S-deficient soil by Watson and Whiteman (1981) and to that by Vitti and Novães (1986).
Visual symptoms

Shorrocks (1964) described deficiencies of most essential nutrients for *C. pubescens*. There are also other descriptions for N, P, K, Ca, and Mg deficiencies (Souto and Franco, 1972), Cu deficiency (Andrew, 1963), K deficiency (Andrew and Pieters, 1970a), and Mn toxicity (Andrew and Pieters, 1970b; Souto and Döbereiner, 1969). Descriptions of deficiencies for other *Centrosema* species have been presented by Salinas et al. (1982). Symptoms observed in the field may not be the same as those developed in greenhouse studies because of the presence of multiple deficiencies or effects from insect or disease attack.

Diagnosis of deficiency from visual symptoms is criticized because by the time symptoms are evident, growth has been severely depressed. However, appearance of symptoms in small areas of a paddock may indicate an incipient deficiency in the area as a whole. Foliar symptoms are useful in the diagnosis of N, S, Mo, and K deficiencies and Mn toxicity.

Plant tissue analysis

The “critical value” concept. Internal nutrient requirements can be used to contrast the requirements of different species or lines, provided that comparisons are made with plants of similar maturity, grown under similar environmental conditions, and usually within the one experiment. However, the use of “critical” internal nutrient concentrations to diagnose nutrient deficiencies is more difficult, because comparison is often attempted among analyses made from plants grown at different times and under different conditions.

Nutrient concentrations vary with the tissue sampled, the physiological stage of growth, the treatment of the sample, and the environmental factors affecting plant growth (Smith, 1978). The critical concentration, defined as the concentration of the nutrient just deficient for maximum growth, must account for all these factors. Interpretation is difficult where samples have not been collected under prescribed conditions. In particular, plant growth should not have been limited by moisture or temperature in the few weeks prior to sampling. It is more useful to consider a critical range of concentrations, below which response is likely and above which it is unlikely, rather than a specific critical value (Shaw and Andrew, 1979).
Table 7 includes critical ranges and critical values of nutrient elements for *Centrosema* that have been reported or can be inferred from published results. Validation and appraisal of the usefulness of these values is needed, as has been done for *Stylosanthes* (Probert, 1984). Some assessment can be made for P. In pot culture, the maximum yield of *C. pubescens* was not reached when the P concentration was 0.15% (Kerridge and Ratcliff, 1982). Under grazing, in Malaysia, 80% of the maximum yield of *C. pubescens* was obtained with P concentrations of

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Species</th>
<th>Experimental details</th>
<th>Range or critical value (%)</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>C. pubescens</td>
<td>G, T</td>
<td>0.16</td>
<td>Andrew and Robins, 1969a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F, L</td>
<td>0.17-0.20</td>
<td>Andrew and Robins, 1969a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G, T</td>
<td>0.17-0.19b</td>
<td>Jones et al., 1970</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F, T</td>
<td>0.18</td>
<td>CIAT, 1981</td>
</tr>
<tr>
<td></td>
<td><em>C. brasilianum</em></td>
<td>F, T</td>
<td>0.14</td>
<td>CIAT, 1981</td>
</tr>
<tr>
<td></td>
<td><em>C. macrocarpum</em></td>
<td>F, T</td>
<td>0.16</td>
<td>CIAT, 1981</td>
</tr>
<tr>
<td>K</td>
<td>C. pubescens</td>
<td>G, T</td>
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<td>Andrew and Robins, 1969c</td>
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<tr>
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<td>F, T</td>
<td>1.24</td>
<td>CIAT, 1981</td>
</tr>
<tr>
<td>Ca</td>
<td>C. pubescens</td>
<td>F, T</td>
<td>1.1-1.3</td>
<td>Andrew and Norris, 1961</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G, T</td>
<td>0.6-1.0</td>
<td>Shorrocks, 1964</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F, T</td>
<td>1.0</td>
<td>CIAT, 1981</td>
</tr>
<tr>
<td></td>
<td><em>C. macrocarpum</em></td>
<td>F, T</td>
<td>0.7</td>
<td>CIAT, 1981</td>
</tr>
<tr>
<td>Mg</td>
<td>C. pubescens</td>
<td>G, T</td>
<td>0.24-0.32</td>
<td>Andrew et al., 1974</td>
</tr>
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<td></td>
<td></td>
<td>G, T</td>
<td>0.30-0.46</td>
<td>Shorrocks, 1964</td>
</tr>
<tr>
<td>S</td>
<td>C. pubescens</td>
<td>G, T</td>
<td>0.15</td>
<td>Andrew et al., 1974</td>
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<td></td>
<td></td>
<td>F, A</td>
<td>0.15-0.17</td>
<td>Watson and Whiteman, 1981</td>
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<td></td>
<td></td>
<td>F, A</td>
<td>0.19d</td>
<td>Watson and Whiteman, 1978</td>
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<td>C. pubescens</td>
<td>G, T</td>
<td>20 ppm</td>
<td>Andrew et al., 1981</td>
</tr>
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<td></td>
<td></td>
<td>G, L</td>
<td>20-25 ppm</td>
<td>Shorrocks, 1964</td>
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<td>Cu</td>
<td>C. pubescens</td>
<td>G, T</td>
<td>4 ppm</td>
<td>Andrew and Thorne, 1962</td>
</tr>
<tr>
<td>Mn</td>
<td>C. pubescens</td>
<td>G, T</td>
<td>1600 ppm (threshold)</td>
<td>Andrew and Hegarty, 1969</td>
</tr>
</tbody>
</table>

a. G = greenhouse; F = field; T = whole tops; A = apical tissue; L = leaves from terminal half of stems.

b. Underlined value is concentration at maximum N concentration.

c. Concentrations for Ca are those associated with maximum yield.
d. Concentration in healthy tissue.
0.17% for shoot (to 3 expanded leaves) and 0.20% for tip (to last expanded leaf) samples (P. C. Kerridge, unpublished data). In north Queensland, the highest yields of *C. pubescens* (>80% maximum) were associated with P concentrations of 0.17%-0.19% during the main growing season when moisture and temperature were not limiting growth (Standley, 1980). Thus, it appears a critical range of 0.17%-0.20% P is useful in the diagnosis of the P status of *C. pubescens*.

**Other uses of plant analysis for diagnostic purposes.** A possible nutrient deficiency may be identified by comparing analyses of healthy and unhealthy plants, providing that normal nutrient concentrations are known.

Monitoring nutrient concentrations over time permits observation of trends in fertilizer needs (Eng et al., 1978). A decreasing concentration may indicate that a nutrient requirement has not been met, while an increasing one suggests it may be oversupplied.

It is imperative to take N concentration into account when assessing the adequacy of other nutrients in a legume, because nodulation and N₂ fixation are often more sensitive to a deficiency or toxicity than the host plant. Apical tips of well-nodulated *C. pubescens* usually contain as much as 3% N, provided other nutrients and environmental conditions do not limit growth. Where critical values are calculated or requirement of a nutrient or amendment assessed when N concentrations remain low, the interpretation of results is open to question (Falade, 1973; Spain et al., 1975).

The change in N concentration with Mo application was found to be a more sensitive method of detecting Mo deficiency in *C. pubescens* than changes in yield (Kerridge, 1981).

**Soil tests**

In general, there is less variation as a result of environmental factors in soil tests than in plant analyses, but errors resulting from soil spatial variation are large. When available soil nutrients are low, soil tests may be less sensitive to slight increases in available nutrients than is the plant (Salinas, 1984; Standley, 1980). It is necessary to calibrate soil tests against actual plant responses and on different soil types before they are used to predict deficiency or requirement, and to state the method used when reporting the results. Soil tests are commonly used for fertilizer recommendations for P, K, and Ca or lime additions.
Critical levels of soil parameters to be used as a guide in interpreting soil test data for the *Centrosema* species adapted to Oxisols have been tabulated (Table 8). They should be used only when the qualifications mentioned above are taken into account.

**Greenhouse and field trials**

Andrew and Fergus (1976) have discussed the use of these trials. Greenhouse trials are useful for soil surveys but require good facilities. Field trials are necessary to develop relationships between plant responses and soil and plant analytical parameters. Field test strips are useful in monitoring the need for fertilization and permit a good sampling of paddock variation (Johansen, 1980).

**Fertilizer Management**

Diagnosis of nutrient deficiency is only one aspect of determining the fertilizer requirement for a particular situation. The amount of fertilizer to be used is influenced by the extent of the soil deficiency, the requirement of a particular species on that soil, the degree to which the manager decides to overcome the deficiency, the form of the fertilizer, and how it is applied.

Selection of well-adapted species may reduce the effect of a particular nutrient constraint. This has been the aim behind selecting and breeding *Centrosema* species for acid infertile soils (Hutton, 1985; Schultze-Kraft and Keller-Grein, 1985). Well-adapted species such as *C. acutifolium* and *C. brasilianum*, have been established successfully in association with the competitive grass *Andropogon gayanus*, using band application of 100 kg of Ca/ha, 30 kg of K/ha, and 20 kg of P/ha (CIAT, 1987).

For economic reasons, pastures are usually fertilized at a level below that necessary for maximum growth. This is a reasonable strategy; where a gross nutrient deficiency or toxicity exists, large responses can be achieved by partial correction. For example, the requirement (and hence cost) to achieve 70% maximum yield may be only one-third of that required for 90% maximum yield (Kerridge et al., 1986; Sánchez and Salinas, 1981). Also, less fertilizer is required to subsequently maintain soil with a lower rather than higher level of available nutrient (Standley et al., 1982).
Table 8. Chemical soil parameters for *Centrosema* species<sup>a</sup> adapted to tropical acid soils.

<table>
<thead>
<tr>
<th>Soil parameter</th>
<th>Level</th>
<th>Method of analysis&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Critical (range)</td>
<td>High</td>
</tr>
<tr>
<td>pH</td>
<td>4.5</td>
<td>4.5-5.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Al saturation (Al toxicity) (%)</td>
<td>60</td>
<td>60-80</td>
<td>80</td>
</tr>
<tr>
<td>Ca saturation (%)</td>
<td>20</td>
<td>20-30</td>
<td>30</td>
</tr>
<tr>
<td>Mg saturation (%)</td>
<td>5</td>
<td>5-15</td>
<td>15</td>
</tr>
<tr>
<td>P (ppm)</td>
<td>3</td>
<td>3-5</td>
<td>5</td>
</tr>
<tr>
<td>K (meq/100 g soil)</td>
<td>0.05</td>
<td>0.05-0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>S (ppm)</td>
<td>4</td>
<td>4-8</td>
<td>8</td>
</tr>
<tr>
<td>Zn (ppm)</td>
<td>0.5</td>
<td>0.5-0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Cu (ppm)</td>
<td>0.2</td>
<td>0.2-0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>B (ppm)</td>
<td>0.3</td>
<td>0.3-0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Mn toxicity (ppm)</td>
<td>50</td>
<td>50-80</td>
<td>80</td>
</tr>
</tbody>
</table>

<sup>a</sup> C. *macrocarpum*, *C. acutifolium*, and *C. brasilianum*. A few data are for *C. pubescens*.

<sup>b</sup> 1 N KCl extractant for Al, Ca, and Mg

Bray-II = 0.1 N HCl + 0.03 N NH₄F
Mehlich-2 = 0.05 N HCl + 0.025 N H₂SO₄
DTPA = 0.005 M DTPA + 0.01 M CaCl₂ + 0.1 M triethanolamine.
Banding of soluble P fertilizer gives an advantage over broadcast application where the rate applied, calculated on an area basis, is less than that for near maximum growth (Salinas, 1984). This is of practical significance because the P requirement during establishment is higher than that needed in the maintenance phase (Fox et al., 1974).

On acid infertile soils, rock phosphate is an obvious P source, provided it is of medium to highly reactive grade (León et al., 1986), because it supplies a higher amount of Ca than superphosphate per unit of P applied. *Centrosera pubescens* has been shown to use rock phosphate effectively (Bryan and Andrew, 1971; Kerridge and Ratcliff, 1982).

Generalized fertilizer recommendations (Kerridge, 1978) lack precision because of wide variation in soil fertility (Sánchez, 1976). Specific recommendations can be made when there has been wide-scale experimentation across soil and vegetation types (Teitzel, 1979). More use should be made of models to determine maintenance requirement (Rayment and Helyar, 1980).

The approach to determining Mo requirement should be similar to that for P because of variable Mo adsorption by different soils (Little and Kerridge, 1978) and large differences in the external requirement among species (Johansen et al., 1977).

There are no known effects of mineral imbalance resulting from fertilizer application other than the case of high rates of lime in experimental situations (Snyder et al., 1978).

The importance of nutrition on the yield and persistence of *C. pubescens* in pastures is well documented (Table 2) (De-Polli et al., 1978; Kretschmer and Snyder, n.d.; Standley, 1980; Tham and Kerridge, 1982). Slow establishment of *C. pubescens* may be partly because of nutrition: the proportion of the legume in a pasture increases in time with moderate levels of fertilization (Eng et al., 1978). To what extent the decline of *C. pubescens* in a pasture is a result of withholding fertilizer; and how much recovery can be achieved by reapplying fertilizer are questions that, so far, are only partially answered. In north Queensland, the percentage of *C. pubescens* in a commercial *Panicum maximum* pasture increased from less than 5% to 15% when Mo was applied (Teitzel and Bruce, 1972; Teitzel et al., this volume). In this instance, there had not been a requirement for Mo at establishment because of high available soil N.
Future Research Priorities

Although acid-soil tolerant *Centrosema* species and accessions have been identified, it is not known how they obtain their Ca in the presence of high Al. What is the relative importance of Ca and Al in plants dependent on symbiotic N\textsubscript{2} fixation? Why is there a marked effect of liming on yield, presumably through N\textsubscript{2} fixation, once Ca deficiency and Al toxicity have been corrected? These are important topics for future research.

Common *C. pubescens* seems to have a relatively high requirement for P and Mo, but there are likely to be accessions within *C. pubescens* or other species (especially those well adapted to acid infertile soils) which would extract P and Mo more effectively than common centro. This possibility deserves further study.

More long-term trials, in which suitable data are collected for the development of models of nutrient requirements, are needed on different soil types. These trials should be with *Centrosema*-grass mixtures. Emphasis should be placed on maintenance requirements, and competition for nutrients should be taken into account.

References


Mineral nutrition of Centrosema


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Chapter 6
RHIZOSPHERE BIOLOGY AND NITROGEN FIXATION OF CENTROSEMA

R. Sylvester-Bradley, S. M. Souto, and R. A. Date

Abstract

Centrosema spp. form nitrogen-fixing symbioses with root-nodule bacteria of the genus Bradyrhizobium. About 500 strains of Bradyrhizobium for Centrosema are maintained in four collections at CIAT, CSIRO, EMBRAPA-UAPNPBS, and NifTAL. Recommendations for inoculating Centrosema species with appropriate strains exist in various countries. In field and greenhouse experiments, C. pubescens, C. schiedeanum, C. macrocarpum, C. brasilianum, C. acutifolium, C. virginianum, and C. pascuorum respond to inoculation in unsterilized soil by increasing yields. The strains used differ in their host range, and the legume genotypes, in their turn, differ in their strain specificity. The number of nodules formed by the different strains, however, do not correlate with nitrogen yield. The quantities of N₂ fixed in associated grass-Centrosema pastures were estimated at an annual 72-280 kg of N/ha. Other factors such as inoculation methods, seed-coat toxins, soil humidity, and mycorrhizal associations, were also observed to affect N₂ fixation by Centrosema.

Introduction

Centrosema can be used as a forage, sown either with grass as a mixed species pasture or into existing grass swards, or it can be used as a

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ground cover in plantation crops. Its success depends largely on its ability to provide its own nitrogen for growth. This nitrogen is made available by fixing, that is, reducing, atmospheric nitrogen when the legume is in symbiosis with its appropriate root-nodule bacteria. The formation of legume-root nodules and their subsequent activities in N₂ fixation are known to be affected by a number of soil environmental factors, including P supply from mycorrhizal associations and genotype specificity between the symbionts.

_Centroomega_ has many desirable features such as improving cattle-weight gains (Aronovich et al., 1970 and 1971; Garza et al., 1978; Gutteridge and Boonklinkajorn, 1979; Lascano et al., 1981; Reynolds, 1977; Reynolds and Lovang, 1977; Rika et al., 1981; Sartini et al., 1970-71; Smith and Whiteman, 1985) and winter milk-production (Serpa et al., 1973), when it is introduced into a grass sward. It persist under grazing (Primo, 1979). When used as a cover crop in plantations, rubber and coconut production increases (Broughton, 1977; Clements et al., 1983; Waidyanatha et al., 1984; Watson, 1963). It is relatively tolerant to drought, soil acidity, and Al and Mn toxicities (Andrew and Hegarty, 1969; Ara et al., 1981; Kitamura and Abe, 1984; Kitamura et al., 1983; Murphy et al., 1984; Souto and Döbereiner, 1969; Souto and de Lucas, 1973; Useche and Schultze-Kraft, 1984). And it has a higher protein content when compared with other tropical legumes (de Mattos and Werner, 1975). All these features have stimulated interest in understanding more of the requirements for N₂ fixation and the management of factors that affect it.

**Characteristics and Collections of Root-Nodule Bacteria for Centroomega, and Recommended Strains for Inoculation**

There are several collections of root-nodule bacteria which contain strains suitable for Centroomega. Some of the strains held at the different institutions are identical, but there are probably at least 500 confirmed isolates of rhizobia from Centroomega. Reports indicate that most isolates from nodules of Centroomega are of the slow-growing genus Bradyrhizobium. Nevertheless, in one study, nodulation—though ineffective—did occur after inoculation with a fast-growing isolate of Rhizobium from Lablab purpureus (Trinick, 1980).
The CIAT collection of root-nodule bacteria for tropical forage legumes contains a total of 3300 strains of which 351 isolates came from 13 identified, and 87 from unidentified, species of *Centrosema*. The majority, however, are from *C. macrocarpum* and *C. pubescens*. The most effective strains fall into at least five serogroups, one of which (CIAT 590) contains many more strains than the others (CIAT, unpublished data). Evaluations of strain effectivity, based on yield of uninoculated and inoculated treatments in undisturbed soil cores, or in the field, have been summarized in a strain catalog by Franco D. et al. (1986). The site and species of origin of the strains showed no relationship to their effectivity. On the basis of yield data, strains CIAT 1780, CIAT 1670 (serologically identical to CIAT 590), and CIAT 3101 are recommended for inoculating various *Centrosema* spp.

A similar, but smaller, collection of strains is held by the Division of Tropical Crops and Pastures at the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Brisbane, Australia. It has 110 strains from six identified *Centrosema* species and 56 from unidentified species (most likely to be *C. pubescens* and *C. brasilianum*). A number of strains such as CB 1923, form black nodules on *C. schiedeanum* and *C. pubescens*, a characteristic which can be exploited as an identification technique in need-to-inoculate and strain-competition studies. Most strains are slow-growing (5-7 days) or very slow-growing (over 10 days), forming moderately gummy, opaque colonies on standard yeast-mannitol-agar medium. The strain recommended in Australia for inoculation of *C. schiedeanum* cv. Belalto and imported *C. pubescens* is CB 1923. This strain originates from Brazil (C 101a, BR 1805). However, it is not effective for *C. brasilianum* (see p. 155-157).

Thirty-four rhizobial strains, isolated from nodules of *Centrosema* spp., are held at Km 47, near Rio de Janeiro, Brazil, by the Unidade de Apoio ao Programa Nacional de Pesquisa de Biologia do Solo (UAPNPBSS) of the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). They are designated as BR 1801 to BR 1834. BR 1808 is also held at the Microbiological Resources Center, Porto Alegre, Brazil, as strain SEMIA 6146, and is recommended for inoculating *C. pubescens* in Brazil.

The NifTAL (Nitrogen Fixation for Tropical Agricultural Legumes) Project at the University of Hawaii holds 24 strains from *Centrosema* spp., two of which are recommended for inoculating *C. pubescens*. These two strains, known as UMKL 44 and UMKL 09 or as TAL 651
and TAL 655, respectively, were isolated in Malaysia from *Calopogonium mucunoides* and *Centrosema pubescens*, respectively. NifTAL also recommends TAL 1146, that is, CIAT 590.

Other laboratories such as those at the United States Department of Agriculture, Beltsville; Nitragin, Wisconsin; Escuela Nacional de Ciencias Biológicas, Mexico; and Balai Penelitian Ternak, Bogor, Indonesia, also maintain strains of root-nodule bacteria for *Centrosema* spp.

**Rhizobium-Plant Compatibility, Strain Selection, and Inoculation Responses**

It is important that the compatibility (specificity) of legumes and root-nodule bacteria for nodulation and nitrogen fixation is evaluated in plant selection and breeding programs (Serpa, 1972a). Many cultivars of tropical legumes were previously considered not to need inoculation because they lacked specificity for nodule formation and nodulated freely with the existing soil strains. For example, *C. pubescens* nodulates effectively with native strains in the field (Broughton et al., 1975; López et al., 1983; Pahwa and Patil, 1983; Tang et al., 1982). However, this does not necessarily mean that it will not respond to inoculation with more effective or competitive strains. Indeed, several tropical legumes respond to inoculation, for example, species of *Desmodium, Stylosanthes, Centrosema, Macroptilium*, and *Pueraria* (Date, 1977b; Döbereiner, 1978; Halliday, 1979; Sylvester-Bradley et al., 1983).

The nodulation and N$_2$ fixation cross-compatibility of strains isolated from some cultivars of *Centrosema* was found to be limited (Bowen, 1959b; Bowen and Kennedy, 1961; Döbereiner, 1971). Guzmán and Döbereiner (1969) noted that homologous strains from *C. pubescens* were superior to strains from other species. Halliday (1979) reported responses of *Centrosema* hybrid CIAT 438 to inoculation with rhizobial strains CIAT 590 and CIAT 594, the latter giving a more marked response in the field than CIAT 590. Vargas and Suhet (1981) observed a response to inoculation of *C. pubescens* in cerrado soil (Brazil), whereas other legumes tested did not respond.

*Centrosema macrocarpum* accessions CIAT 5062 and CIAT 5065 and *C. acutifolium* CIAT 5112 and CIAT 5568 showed marked increases
Rhizosphere biology and nitrogen fixation of *Centrosoema*

(200%–300%) in nitrogen yield after inoculation when grown in cores of undisturbed soil from Carimagua, Colombia, with strains isolated from a range of *Centrosoema* spp. Responses of *C. brasilianum* CIAT 5234 and *C. acutifolium* CIAT 5277 were significant but less marked: the increase in nitrogen yield from the most effective strain was 40%–60% (Franco D. et al., 1986; Sylvester-Bradley et al., 1983).

In greenhouse sand culture experiments, strain CB 1923 (syn. C 101a) was ineffective in N2 fixation with *C. brasilianum* accessions CPI 40061, CPI 40065, CPI 55698, and CQ 1320 (mean for accessions was only 8% of the +N control), but in soil it was highly effective on *C. schiedeanum* cv. Belalto, *C. pubescens* CPI 46543, *C. virginianum* CPI 40057, and *C. pascuorum* CPI 65950 (Table 1). Strains CB 2947 and CB 2949, which were isolated from *C. brasilianum* CPI 55698 and CPI 55696, respectively, growing at Katherine, Northern Territory, Australia, were effective on both CPI 55698 and *C. schiedeanum* cv. Belalto (Table 2).

<table>
<thead>
<tr>
<th>Legume</th>
<th>Total N (mg/pot)</th>
<th>CB 1923</th>
<th>CB 2947</th>
<th>Uninoculated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>With N</td>
</tr>
<tr>
<td><em>C. schiedeanum</em> cv. Belalto</td>
<td>278</td>
<td>299</td>
<td>182</td>
<td>74</td>
</tr>
<tr>
<td><em>C. pubescens</em> CPI 46543</td>
<td>263</td>
<td>276</td>
<td>157</td>
<td>67</td>
</tr>
<tr>
<td><em>C. virginianum</em> CPI 40057</td>
<td>232</td>
<td>155</td>
<td>148</td>
<td>53</td>
</tr>
<tr>
<td><em>C. pascuorum</em> CPI 65950</td>
<td>204</td>
<td>147</td>
<td>168</td>
<td>75</td>
</tr>
</tbody>
</table>

SOURCE: R. A. Date, unpublished data.

An experiment, comparing six *C. macrocarpum* accessions uninoculated or inoculated with 15 strains of *Bradyrhizobium* in cores of undisturbed Carimagua soil, showed relatively low numbers of nodules formed by native strains, except for accession CIAT 5713 (Table 3). Large increases in nodulation as a result of inoculation were observed. Analysis of variance showed a highly significant interaction between *C. macrocarpum* accessions and *Bradyrhizobium* strains. Strain CIAT 3111 formed more nodules across all accessions than the other strains (Table 3). Nitrogen-yield data showed that the most effective strain across ecotypes was CIAT 3101 (Franco D. et al., 1986).
Table 2. Effectivity in sand culture of *Bradyrhizobium* strain CB 1923 (syn. C 101a) and six other isolates on *Centrosema schiedeana* cv. Belalto and *C. brasiliannum* CPI 55698.

<table>
<thead>
<tr>
<th>Strain no.</th>
<th>Original host</th>
<th>Dry weight of whole plants (g/jar)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><em>C. schiedeana</em> cv. Belalto</td>
</tr>
<tr>
<td>CB 1923</td>
<td><em>C. pubescentis</em></td>
<td>0.99</td>
</tr>
<tr>
<td>CB 1945</td>
<td><em>C. brasiliannum</em> CPI 55698</td>
<td>0.89</td>
</tr>
<tr>
<td>CB 1948</td>
<td>CPI 55698</td>
<td>1.05</td>
</tr>
<tr>
<td>CB 2947</td>
<td>CPI 55698</td>
<td>1.21</td>
</tr>
<tr>
<td>CB 2949</td>
<td><em>C. brasiliannum</em> CPI 55696</td>
<td>0.71</td>
</tr>
<tr>
<td>CB 2950</td>
<td>CPI 55696</td>
<td>0.49</td>
</tr>
<tr>
<td>CB 2951</td>
<td><em>C. brasiliannum</em> CPI 40062</td>
<td>0.38</td>
</tr>
<tr>
<td>Uninoculated with N</td>
<td></td>
<td>2.10</td>
</tr>
<tr>
<td>Uninoculated without N</td>
<td></td>
<td>0.20</td>
</tr>
</tbody>
</table>

SOURCE: R. A. Date, unpublished data.

Table 3. Nodulation of six accessions of *Centrosema macrocarpum* by 15 strains of *Bradyrhizobium* in cores of undisturbed Carimagua soil (Oxisol, pH 4.5), Colombia.

<table>
<thead>
<tr>
<th><em>Bradyrhizobium</em> strain</th>
<th>CIAT no.</th>
<th>Synonym</th>
<th>No. of nodules/core according to CIAT accession no.:</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3111</td>
<td></td>
<td>5065  5713  5737  5740  5744  5887</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3334</td>
<td></td>
<td>65    62    55    68    69    82    67</td>
<td></td>
</tr>
<tr>
<td></td>
<td>590</td>
<td></td>
<td>64    67    47    48    51    68    58</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1780</td>
<td></td>
<td>56    55    47    57    57    68    57</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2348</td>
<td></td>
<td>53    54    42    62    48    56    53</td>
<td></td>
</tr>
<tr>
<td></td>
<td>49</td>
<td>CB 1923 (C 101a)</td>
<td>55    55    42    41    57    61    52</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3694</td>
<td></td>
<td>53    45    47    51    46    61    50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2290</td>
<td></td>
<td>51    55    37    41    51    52    48</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3101</td>
<td></td>
<td>51    47    33    70    41    45    48</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1670</td>
<td></td>
<td>45    51    30    45    51    58    46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3196</td>
<td></td>
<td>48    47    41    47    49    45    46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3773</td>
<td>C 101a</td>
<td>50    25    23    33    30    71    39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3714</td>
<td></td>
<td>23    43    25    15    28    18    25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3174</td>
<td></td>
<td>7     16    18    35    33    37    25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3774</td>
<td>C 102</td>
<td>27    18    19    17    30    15    21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Uninoculated</td>
<td></td>
<td>13    19    26    15    21    13    18</td>
<td></td>
</tr>
</tbody>
</table>

SOURCE: CIAT, unpublished data.

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Rhizosphere biology and nitrogen fixation of Centrosema

Strains CIAT 3773 and 3774 were obtained from Brazil as C 101a and C 102, respectively, but in this experiment they were not effective. The most effective strains (CIAT 3101, 2348, 1780) were not the same as the strains forming most nodules (CIAT 3111, 3334, 590). A lack of correlation between nodule number and strain effectivity has been observed previously by Souto and Döbereiner (1968), Serpa (1972b), and Franco D. et al. (1973). Some strains can be characterized according to their ability to form more abundant smaller nodules or fewer larger nodules.

A subsequent field experiment (CIAT, 1986b; R. Sylvester-Bradley, unpublished data) showed large increases (four- to eight-fold), resulting from inoculation, in dry-matter yields during establishment in C. macrocarpum CIAT 5713, CIAT 5744, and CIAT 5452, and C. acutifolium CIAT 5568. Smaller yield increases (about 30%) were observed in C. acutifolium CIAT 5277 and C. brasiliananum CIAT 5234, because these two accessions nodulated more effectively with native strains. The strain giving the highest nitrogen yields across ecotypes was CIAT 3101. It was isolated from native C. plumieri (CIAT 5750) which was collected in the Sierra Nevada of Santa Marta, Colombia (R. Schultze-Kraft, personal communication). This strain is also effective on Arachis pintoi and partly effective on Pueraria phaseoloides and Desmodium ovalifolium (R. Sylvester-Bradley, unpublished data). Strain CIAT 49 (CB 1923) showed a somewhat inferior performance in this field experiment to that indicated by the previous greenhouse experiment on soil cores.

Several other field experiments at various sites in Colombia such as those by CIAT (1984), Sylvester-Bradley (1984), and Sylvester-Bradley and Mosquera P. (1985), have shown yield responses to inoculation during the establishment of C. macrocarpum. They also showed the persistence of the inoculation effect on the yields of C. macrocarpum CIAT 5065 and Pueraria phaseoloides CIAT 9900 in the second year after establishment.

Various plant improvement programs have emphasized effects of Centrosema genotypes on nodulation. Genetic differences in nodulation of C. pubescens lines have been observed (Bowen and Kennedy, 1961; Franco et al., 1973; Serpa and De-Polli, 1976; Souto and Döbereiner, 1968). Heritability of nodule number, and early and later nodulating lines was found to be low (Serpa and Cunha, 1970). Franco et al. (1973) compared four C. pubescens lines with the original cultivar Deodoro, but only one line showed increased nitrogen yield. Strains differed in
their effectiveness at the two sampling dates, and it was suggested that strain mixtures may be needed to overcome this problem. Miranda et al. (1985) evaluated *Centrosera acutifolium* CNP GC 372/79, *Centrosera* interspecific hybrid Itagal, and *C. macrocarpum* CIAT 5065 with 11 strains of rhizobia. Strain C 106 was found to be superior to the other strains, but not competitive when inoculated in mixture, whereas strain C 551 was ineffective but highly competitive.

Hybrids of *C. pubescens x C. macrocarpum* and the parent *C. pubescens* CIAT 5052 nodulated more with native rhizobia in Carimagua soil than did the parent *C. macrocarpum* CIAT 5062 (Table 4). However, once inoculated, *C. macrocarpum* showed similar nodulation and nitrogen yield to those of the other accessions (Tables 4 and 5). The interaction between legume accession and *Bradyrhizobium* strain was significant (P<0.05) and highly significant (P<0.01) for nodulation and nitrogen yield, respectively. Strain CIAT 3101 stimulated the greatest yield response across hybrids and their parents, although strains CIAT 1780 and 1670 were also effective. Even though the hybrids and *C. pubescens* formed abundant nodules with native strains, marked increases in nitrogen yield were observed on inoculation. The strains used in this experiment may overcome the suspected nodulation problems reported for these hybrids in the cerrado soils of Brazil by J. R. Peres (personal communication).

Inoculating *Centrosera* seed with selected strains of *Bradyrhizobium* may make the difference between success and failure at establishment. It may also increase plant vigor even in situations where plant growth is

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**Table 4. Nodulation of hybrids of *Centrosera pubescens x C. macrocarpum* and their parents in cores of undisturbed Carimagua soil without inoculation or inoculated with one of three strains of *Bradyrhizobium*, Colombia.**

<table>
<thead>
<tr>
<th>Legume</th>
<th>Accession no.</th>
<th>No. of nodules/core when inoculated with:</th>
<th>Strain CIAT 3101</th>
<th>Strain CIAT 1780</th>
<th>Strain CIAT 1670</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No strain</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>CIAT 5062</td>
<td>19</td>
<td>53</td>
<td>35</td>
<td>48</td>
</tr>
<tr>
<td><em>C. pubescens</em></td>
<td>CIAT 5052</td>
<td>66</td>
<td>56</td>
<td>37</td>
<td>43</td>
</tr>
<tr>
<td>Hybrid</td>
<td>CPAC 2510</td>
<td>51</td>
<td>68</td>
<td>75</td>
<td>56</td>
</tr>
<tr>
<td>Hybrid</td>
<td>CPAC 2511</td>
<td>43</td>
<td>60</td>
<td>73</td>
<td>68</td>
</tr>
<tr>
<td>Hybrid</td>
<td>CPAC 2512</td>
<td>40</td>
<td>57</td>
<td>44</td>
<td>54</td>
</tr>
<tr>
<td>Hybrid</td>
<td>CPAC 2513</td>
<td>54</td>
<td>46</td>
<td>60</td>
<td>62</td>
</tr>
</tbody>
</table>

**SOURCE:** CIAT, unpublished data.

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Table 5. Nitrogen yield of hybrids of *Centroema pubescens* x *C. macrocarpum* and their parents in cores of undisturbed Carimagua soil without inoculation or inoculated with one of three strains of *Bradyrhizobium*, Colombia.

<table>
<thead>
<tr>
<th>Legume</th>
<th>Accession no.</th>
<th>N yield in tops (mg/core) when inoculated with:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No strain</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>CIAT 5062</td>
<td>42</td>
</tr>
<tr>
<td><em>C. pubescens</em></td>
<td>CIAT 5052</td>
<td>75</td>
</tr>
<tr>
<td>Hybrid</td>
<td>CPAC 2510</td>
<td>70</td>
</tr>
<tr>
<td>Hybrid</td>
<td>CPAC 2511</td>
<td>77</td>
</tr>
<tr>
<td>Hybrid</td>
<td>CPAC 2512</td>
<td>87</td>
</tr>
<tr>
<td>Hybrid</td>
<td>CPAC 2513</td>
<td>85</td>
</tr>
</tbody>
</table>

SOURCE: CIAT, unpublished data.

adequate without inoculation. When new cultivars are being studied, or when *Centroema* is introduced into new areas, they should be tested for inoculation response with strains already known to be effective. Further strain collection and screening will be necessary should these strains prove inadequate because of, for example, the presence of specific limiting factors.

Quantities of Fixed Nitrogen

The amount of nitrogen contributed by the legume in a *Centroema pubescens*-grass sward compared with grass alone usually varies from 72 to 108 kg of N/ha annually (de Mattos and Werner, 1979; Miller and van der List, 1977; Paulino et al., 1983). There are reports of amounts as high as 280 kg of N/ha annually in variously grazed pastures (Bruce, 1965; de Carvalho, 1986; Gomide et al., 1984; Horrell and Newhouse, 1965; Moore, 1962; Stobbs, 1969; Vallis, 1972) and in cover crops (Broughton, 1977). Estimates from pot experiments are between 90 and 140 kg of N/ha annually (Bowen, 1959a; Odu et al., 1971; Watson, 1957; Whitney et al., 1967). Increases in organic nitrogen in surface soils have also been observed in *Centroema* pastures (Bruce, 1967; Gumaste et al., 1982; Vallis, 1972).

Cadisch and Sylvester-Bradley (1986) used the $^{15}$N dilution technique to measure N$_2$ fixation by *C. acutifolium* and *C. macrocarpum* under a cutting regime in association with native savanna at Carimagua,
Colombia. During the most vigorous growth period, 55%-75% (equivalent to 7-25 kg of N/ha in 38 days) of the nitrogen in the two *Centrosema* spp. was derived from fixation. The percentage of nitrogen fixed by the two *Centrosema* species increased with P and K fertilization, but was lower than that observed in *Pueraria phaseoloides*, *Stylosanthes macrocephala*, and *S. capitata*; higher than that in *S. guianensis* and *Desmodium ovalifolium*; and the same as that for *Zornia glabra*.

Although the amount of nitrogen measured in the plant tops is a good index of the amount of $N_2$ fixed by a nodulated legume in associated grass-legume pastures, it is important to realize that only a part of this nitrogen is consumed by animals. Henzell (1968) has calculated that the legume of a tropical grass-legume pasture with average legume growth will yield an annual total of 40-200 kg of N/ha. However, not all of this nitrogen comes from $N_2$ fixation, and only about half of the legume nitrogen becomes available as mineral nitrogen. In such pastures, an annual total of about 60-180 kg of N/ha is estimated as available for grasses and weeds—which may not be sufficient to support the maximum yield of tropical grasses.

**Factors Affecting Nodulation and Nitrogen Fixation by *Centrosema***

The general response of nodulation and $N_2$ fixation by legumes to environmental and biological factors apply also to *Centrosema* (Bushby, 1982; Gibson, 1971; Munns, 1978; Robson, 1978; Roughley, 1985). Most available information for *Centrosema* refers to *C. pubescens*. It is important that methods of inoculation take into account any special problem associated with *Centrosema*, as well as the traditional aspects of availability of materials and farmer expertise if pelleting is required or seed inoculation is a new technology.

**Inoculation and survival of rhizobia on inoculated seed**

Inoculated seeds are sometimes stored or planted under conditions which are unfavorable for the inoculum’s survival. In certain cases, survival may be improved through seed-pelleting.

Poor survival of rhizobia on *Centrosema* seeds may be because of toxic substances in the seed coat. Bowen (1961) showed that a double "
pellet, using absorbent materials in the inner layer, protected inoculated strains from water-soluble seed-coat toxins of *C. pubescens*. Souto and Döbereiner (1968) observed an increase of nodule weight in *C. pubescens* lines when using a double pellet in which charcoal replaced peat in the inner coating. Each coating comprised dolomitic lime, Olinda rock phosphate, and gum arabic. However, nodule number was not affected, indicating that the effect may have resulted from improved nutrition rather than toxin absorption.

Positive effects of lime pelleting on *C. pubescens* nodulation have been observed (Döbereiner and Aronovich, 1966). Ahmed and Quilt (1981) observed no positive effect of lime pelleting on *C. virginianum*. Sylvester-Bradley et al. (1983) showed no statistical difference in yield of *C. macrocarpum* inoculated with lime or rock-phosphate pellets in acid soil. Paterno and Espíritu (1978) report a negative effect of lime pelleting of *C. pubescens*, whereas calcium phosphate or superphosphate together with lime was beneficial. Coloza and Werner (1982) showed a positive interaction between Mo combined in the pellet and inoculation of *C. pubescens*. Deficiencies of micronutrients B, Mo, Fe, Mn, and Zn for *C. pubescens* growing in Red-Yellow Podzolic soils (De-Polli et al., 1976) could be corrected by pelleting with fritted trace elements or mixtures of fritted trace elements and lime (De-Polli and Döbereiner, 1974; Nery et al., 1976). Halliday (1979) indicated a strain-pellet interaction for *Centroserma* hybrid CIAT 438 in acid soil.

Recent studies by R. Sylvester-Bradley et al. (unpublished data) and Eaglesham and Goldman (1987 and unpublished data) have shown that *C. macrocarpum* and *C. acutifolium* can be inoculated with freeze-dried *Bradyrhizobium* strain CIAT 1780 or CIAT 3101 that has been suspended in oil or water. However, survival on seeds was not as good as with peat-based inoculant, unless the inoculated seeds were desiccated. These data imply that the death of freeze-dried rhizobia on seeds, also reported by Vincent (1965) and Date (1977a), could be caused by water-soluble seed-coat toxins or by toxicity from oxygen at relative humidities above 15% (Bushby, 1982). Desiccation of inoculated seed is not a practical recommendation, but survival of freeze-dried cells on seeds may be improved by coating with appropriate substances. Development of freeze-dried inoculant technology is important, because the inoculants have a longer shelf life, thereby widening the range of inoculants available to farmers (McLeod and Roughley, 1961).

The most frequently recommended method for inoculating seeds of *Centroserma* and other tropical forage legumes (CIAT, 1987; Roughley
et al., 1966) is to mix 50 g of peat-based inoculant with about 30 ml of an adhesive such as 4% methyl cellulose or 40% gum-arabic solution. If the inoculant is of good quality (about $10^9$ cells/g), this quantity is sufficient for inoculating 1 kg seeds, which are mixed well with the inoculant in a bucket. Then 200-400 g of ground rock phosphate, which may be supplemented with 5-100 g of molybdenum oxide or ammonium molybdate (not sodium molybdate which is toxic), is coated onto the inoculated seeds by gently rotating the container. Larger quantities of seed may be mixed in drums or a cement mixer. Because of the rapid mortality of the bacteria on the seeds, it is usually recommended that they be sown soon after inoculation. There are some products which claim long life of the cells on preinoculated seeds, but they are not usually available in the tropics.

**Soil humidity**

Flooded soils are important for cattle production in areas with marked dry seasons. De-Polli et al. (1971) showed that *Bradyrhizobium* strains introduced on inoculated seeds were more sensitive to flooding than native strains, but that nodule numbers of both decreased rapidly on flooding.

Furthermore, flooding effects on rhizobia differ according to soil type. In a greenhouse experiment, *Stylosanthes guianensis* tolerated as many as 45 days of flooding, whereas *C. pubescens* was the most sensitive legume tested, showing complete decomposition of roots and nodules in soil flooded for over 30 days (De-Polli et al., 1973). Whiteman et al. (1983) reported similar results: *Macroptilium atropurpureum* occupied a position between *S. guianensis* and *C. pubescens*. Although roots and nodules rotted in the soil, new roots and nodules were formed in the water layer, and none of the three species died during 45 days of flooding.

In another experiment, De-Polli et al. (1973) showed *C. pubescens* was affected less by water deficiency and more by excess water than *Glycine max* cv. Santa María. On a vermiculite, a highly water-absorbing substrate, soybean was able to nodulate even when the substrate was soaked at 135% of its water-retention capacity, whereas *C. pubescens* reached a maximum nodulation at 65%. Some *Centrosema* spp. such as *C. vexillatum*, occur naturally in seasonally flooded habitats (Schultze-Kraft et al., this volume), but nothing is known about nodule formation by these species in waterlogged soil, or whether they
fix more nitrogen than other species which are less adapted to these conditions.

The effect of drought on N₂ fixation of *Centrosema* has not yet been evaluated. It is possible that lines differ in persistence of active nodules after the rainy season. Differences between strains in their ability to form new nodules after the dry season may also occur.

**Other factors**

As discussed by Salinas et al. (this volume), soil acidity and related factors (Ca, Mg, and Mo deficiencies, and Mn and Al toxicities) affect N₂ fixation by *Centrosema* spp. Both inter- and intraspecific differences have been observed in tolerance to low soil pH. Some of the negative effects of soil acidity on N₂ fixation may be overcome by lime pelleting, although this is not always the case (see p. 161). To increase N₂ fixation by *Centrosema* spp. in acid soils, further studies are needed on the effects of soil acidity-related factors and phosphorus levels on N₂ fixation by different species and lines.

Mineral nitrogen levels in the soil may also be important. For example, when established in furrows in native savanna, *C. macrocarpum* showed a greater response to inoculation than when the land was prepared by ploughing (Sylvester-Bradley and Mosquera P., 1985), presumably because there was more soil nitrogen available in the more disturbed ploughed treatment. Increased yield and reduced levels of nodulation were observed for *C. pubescens* growing in a sandy loam (pot) soil as levels of nitrogen increased (Fayemi et al., 1970).

**Mycorrhizae and Other Microorganisms**

Phosphorus uptake is enhanced by mycorrhizal infection of tropical forage legumes (Cabala-Rosand and Wild, 1982; Huang et al., 1985; Mosse, 1977). Crush (1974) showed that *C. pubescens* and *Stylosanthes guianensis* had a higher degree of mycorrhizal dependence than *Trifolium repens* and *Lotus pedunculatus*. Dependence was related to the degree of root-hair development. This relationship has also been observed by Baylis (1975). Higher levels of available P inhibit mycorrhizal development, whereas lower levels stimulate it (Barea and Azcón-Aguilar, 1983; Barea et al., 1983; Crush, 1976). However, these responses are interrelated with soil characteristics and legume and
fungal species (Crush, 1974; Munns and Mosse, 1980; Powell, 1977). Mosse et al. (1976) showed that mycorrhizal inoculation of *C. pubescens* increased yield of soil-grown plants when tissues of uninoculated plants contained less than 0.15% of P. In soils with very low P contents, nodulation occurred only in the presence of mycorrhizae; rock phosphate also increased nodulation and N₂ fixation. Saif (1986) reports a range of native mycorrhizal infection among accessions of *C. brasiliananum, C. acutifolium*, and *C. macrocarpum*. Also, a high degree of mycorrhizal dependency in *Centrosema* spp. has been shown (CIAT, 1986).

Paulino et al. (n.d.) showed an increase in growth and P uptake of *C. pubescens* in response to inoculation with the mycorrhiza *Glomus fasciculatus*, although nitrogen uptake was not increased. In another study (Paulino and Azcón, n.d.), improved nutrient uptake by *C. pubescens* was shown when inoculated with the appropriate rhizobial strain, *G. fasciculatus*, and fungal or bacterial phosphate-solubilizers. The results indicated that growth, nutrition, nodulation, and nitrogenase activity of *C. pubescens* were improved through colonization of the roots by *G. fasciculatus*, and that the phosphate-solubilizing bacterium improved the efficiency of the mycorrhizal association.

**Future Work**

There are three priority areas: research for inoculant development; regional trials to evaluate the effectiveness of native rhizobial populations; and nitrogen management research.

*Centrosema* spp. show more marked inoculation responses than many other tropical forage legume species. The maximization of N₂ fixation by this genus therefore depends on the availability of appropriate inoculants to farmers. In many tropical countries, the production and distribution of inoculants, even for crop legumes such as soybeans, is inadequate. Research to improve the availability and use of high-quality inoculants for a wider range of legumes would help to overcome one of the major limitations to maximizing N₂ fixation by *Centrosema* spp.

It is not known to what extent the native rhizobial populations nodulating *Centrosema* spp. vary within and among soil types and ecosystems. Such information would permit an evaluation of the extent to which inoculation recommendations can be generalized. A network of scientists carrying out agronomic trials designed to evaluate the need
for inoculation at different sites is being coordinated by CIAT, and will, to some extent, achieve this objective. Trials to evaluate the need for inoculation and inoculation responses should be carried out at as wide a range of sites as possible.

Nutritional and climatic factors are known to affect N₂ fixation by *Centrosema* spp. Further studies are needed so that recommended management practices may take these effects into account and ensure that, in *Centrosema*-based pastures, maximum nitrogen inputs can be obtained. Such studies would require an evaluation of nitrogen cycling under different management conditions.

Other studies such as persistence and competitiveness of inoculated strains; and management of mycorrhizae, other soil microorganisms, and the soil fauna could be carried out in parallel to these three priority research areas.

References


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Livestock and Pasture Agronomy report series no. 10. Department of Agriculture, Apia, Western Samoa. 27 p.


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Chapter 7

DISEASES AND PESTS OF CENTROSEMA

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Abstract

Centrosema spp. are attacked by a variety of fungi, viruses, and nematodes, one bacterium, and one mycoplasma. Potential arthropod pests include leaf-eating insects, principally Chrysomelidae, other Coleoptera, and the ladybird beetle, Epilachna indica. Other pests are thrips, aphids, leafhoppers, leaf beetles, caterpillars, pod borers, leafrollers, flies, and mites. The relative importance of each disease and pest varies among Centrosema species and locations.

Rhizoctonia foliar blight is the most important disease of Centrosema in tropical America, C. brasilianum being the most susceptible species. At least three species of Rhizoctonia are implicated, and isolates vary in virulence, making studies of host resistance complicated and time consuming.

Other diseases are of secondary importance or site specific: pseudocercospora leaf spot, bacteriosis, and centrosema mosaic virus (CeMV).

Research priorities include investigating rhizoctonia foliar blight, CeMV, Epilachna indica, and the specificity of insect pest species to individual sites.

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Introduction

Diseases and insect pests have been recorded on *Centrosera* spp., especially *C. pubescens*, since the early 1900s, but research to evaluate their importance has been lacking. Increased agronomic research and more widespread cultivation have fostered an increased awareness of the potential role of diseases and pests as major constraints to the productivity of *Centrosera*.

This chapter collates information on diseases and pests of *Centrosera*, describes their distribution and relative importance, and discusses the management of some of them.

Diseases of *Centrosera*

Diseases caused by 38 genera of fungi, one genus of bacterium, one mycoplasma, 13 viruses, and six genera of nematodes have been recorded on *Centrosera*. The wealth of information from tropical America (Appendix 1 of the chapter) and other tropical and subtropical regions (Appendix 2 of the chapter) reflects intensive activity by plant pathologists. The apparent lack of diseases in some regions and countries is partly a reflection of lack of interest or plant pathology skills. Detailed comparisons of pathogen identities and disease severity among regions are therefore of little value except within tropical America. Also, many reports of diseases occur in host lists, Commonwealth Mycological Institute unpublished records, and in personal surveys made by the authors and colleagues. Hence, it is difficult to discuss the relative importance of many of the diseases. Nevertheless, the most widely occurring and/or damaging diseases are discussed below, and their symptomatology is illustrated on color plates X and XI in Appendix I of the book.

Diseases caused by fungi

Leaf spots caused by *Cercospora* and related genera. Three species of *Cercospora* have been recorded across major ecosystems of tropical America. *Cercospora canescens* is the most common and widespread—it is recorded on nine *Centrosera* species in all ecosystems in more than eight countries. It causes dark brown to black angular leaf lesions with chlorotic halos which expand, causing chlorosis, necrosis, and
Diseases and pests of Centrosea

defoliation (Lenné et al., 1983). High relative humidity and moderately high temperatures favor infection and disease development. *Centrosea pubescens* may be defoliated, but other species are usually less affected. Thus, *C. canescens* is not an especially serious disease (CIAT, 1982 to 1986; Lenné et al., 1983). *Cercospora centrosemæ* and *C. cylindrospora* have been recorded on *C. virginianum* in Venezuela and Mexico (Chupp, 1953), and six other *Cercospora* species have been recorded on *Centrosea* in other regions.

*Pseudocercospora bradburyae* (syn. *Cercospora bradburyae*) is the most widespread leaf spot. It is recorded on nine *Centrosea* species across major ecosystems of tropical America in more than seven countries. It is present in other regions (17 countries) on *C. plumieri*, *C. pubescens*, and *C. virginianum*. *Pseudocercospora bradburyae* forms small, rounded, cream to pale grey leaf spots with dark borders. Coalescence of lesions causes defoliation, but rarely plant death. In north Queensland, leaf lesions of *P. bradburyae*, together with *Colletotrichum gloeosporioides*, can cause severe defoliation in the winter when *C. pubescens* is not growing actively (R. Davis, personal communication). However, plants recover when growth resumes. In tropical America, pseudocercospora leaf spot sometimes severely damages *C. brasilianum* under humid conditions (CIAT, 1986).

**Leaf spots and pod anthracnose caused by Colletotrichum spp.** *Colletotrichum gloeosporioides* and *C. truncatum* are common on *Centrosea* spp. in tropical America. Rounded to irregular, cream-colored lesions are formed on leaves, while on pods, similar lesions tend to be ulcer-like, affecting developing seeds (Lenné et al., 1983). Often, dark fruiting bodies can be seen in these lesions. They occur together in latent infection of pods (J. M. Lenné, unpublished data). *Colletotrichum gloeosporioides* is frequently associated with rhizoctonia foliar blight. Both *Colletotrichum* spp. are seed-borne (Lenné, 1981a).

Anthracnose has also occurred on *C. pubescens* and *Centrosea* spp. in the Pacific and subtropical USA. In Florida, slight to moderate leaf spotting caused by *C. gloeosporioides* and *C. truncatum* was common on mature leaves of *C. pubescens* and *C. virginianum* (Lenné and Sonoda, 1978).

**Widely distributed leaf-spotting fungi.** *Curvularia pallescens* and *Curvularia* spp. have been recorded from leaf spots on *C. plumieri*, *C. pubescens*, and other species in French Guiana, Colombia, Malaysia, and Florida. In Colombia, *Curvularia* spp. were commonly associated with small, rounded, medium-brown lesions which rarely caused serious
damage. In Florida, leaf lesions incited by *Curvularia* spp. were found on 42 of 86 *Centroselecta* accessions but incidence was low (Sonoda and Lenné, 1979). These leaf spots are minor diseases.

*Phoma* spp. and the *Phomopsis* state of *Diaporthe phaseolorum* cause moderate to severe leaf spotting in *Centroselecta* in several regions. Both *Phoma sorghina* and the *Phomopsis* state of *D. phaseolorum* have been isolated from large, rounded to irregular, medium-brown lesions on leaves of *C. macrocarpum*, *C. pubescens*, and *C. acutifolium* in Colombia and Brazil (CIAT, 1986; L. Nasser, personal communication). Leaf spot and dieback caused by *D. phaseolorum* has also been recorded on *C. pubescens* in other regions. In Colombia, isolates of *Phomopsis* spp. from Colombia and Brazil caused similar lesions on seedlings of the above-mentioned species, while only the Colombian isolate of *P. sorghina* was pathogenic.

The only leaf-spotting fungus found, to date, in both tropical America and other regions is the sooty mold, *Meliola*. *Meliola denticulata* was recorded on *C. virginianum* in Brazil, while *M. bicorin*s has been recorded on *C. pubescens* and *C. virginianum* in Trinidad and USA, respectively. The importance of these diseases was not documented.

**Localized leaf-spotting fungi.** Zonate leaf spot caused by *Cylindrocladium colhounii* causes moderate to severe defoliation of *C. pubescens* and *C. acutifolium* in the Eastern Plains (Llanos Orientales) of Colombia (CIAT, 1985). Lesions first appear as small, irregular, medium-brown spots which enlarge into zones of varying shades of brown. Affected leaves become chlorotic. Although this disease is, at present, localized, it is potentially serious under humid conditions.

Many other leaf-spotting fungi have been recorded on *Centroselecta* spp., but their distribution and importance is unknown.

**Fungi causing root, crown, and collar diseases.** In tropical America, only two fungi have been found colonizing *Centroselecta* roots. A *Fusarium* sp. was found in root lesions of *C. pubescens* in Carimagua, Colombia, but was not subsequently a problem. Wilt and dieback caused by *Sclerotium rolfsii* were recorded on *C. brasiliannum* in Santander de Quilichao, Colombia. An isolate of *S. rolfsii* from *Stylosanthes capitata* was pathogenic to *C. pubescens* (Lenné, 1979). These fungi are, at present, minor problems. In other regions of the world, soil-borne diseases caused by several fungi have been recorded.

1. Not including *Rhizoctonia* spp.
Diseases and pests of Centrosema

Diseases caused by rusts. Three rusts have been recorded on Centrosema in tropical America. These are Puccinia sp. on C. virginianum in Venezuela (Standen, 1952), Uromyces neurocarpi on C. pubescens in El Salvador (Stevenson and Wellman, 1944), and soybean rust Phakopsora pachyrhizi on C. pubescens in Puerto Rico (Vakili and Bromfield, 1976).

Diseases caused by Rhizoctonia spp. Rhizoctonia solani and binucleate Rhizoctonia-like fungi (BNR) are regarded as the most damaging pathogens of Centrosema, particularly of C. brasilianum, in tropical America. Foliar blight caused by Rhizoctonia spp. has been recorded on C. acutifolium, C. arenarium, C. brasilianum, C. macrocarpum, C. pascuorum, C. plumieri, C. pubescens, C. schiedeanum, and C. virginianum throughout tropical America (de Alvarez and Lenné, 1983 and 1986; Lenné et al., 1983). Symptoms appear as small water-soaked lesions which enlarge, and become cream to light brown, necrotic, irregularly shaped spots which may cover whole leaflets. Profuse growth of fungal mycelium results in mats of leaves being stuck together, thereby explaining the common use of the term “web blight.” Sclerotia are common on blighted leaves. Foliar blight often begins as foci which enlarge under humid conditions, causing considerable forage losses (de Alvarez and Lenné, 1986). Although the sexual stage Thanatephorus cucumeris has not yet been found in Centrosema, the common initiation of the disease in foci at the beginning of the wet season suggests that the sexual stage may be involved.

Foliar blight caused by R. solani has been recorded on C. plumieri in Malaysia, Sierra Leone, and New Guinea; on C. pubescens in Malaysia, New Guinea, New Hebrides, Solomon Islands, and Australia; and on several species of Centrosema in Florida (A. Johnson, 1960; Sonoda and Lenné, 1979; Williams and Liu, 1976). Whether BNR were also present was not documented. In Florida, many accessions of C. brasilianum, C. plumieri (especially P.I. 330567), and C. pubescens were blighted (Sonoda et al., 1971).

Rhizoctonia spp. may also cause crown-and-root rot. BNR caused severe crown rot of isolated plants of C. macrocarpum in Palmira, Colombia, in 1985. It is commonly associated with foliar blight of Centrosema (Olaya H. and Lenné, 1986). About 50% of isolates collected from Centrosema leaves were BNR. In greenhouse seedling inoculations, many isolates of BNR were as virulent as R. solani (Olaya H. and Lenné, 1986). In addition, R. zeae was also found associated with soil near blighted C. brasilianum plants (de Alvarez and Lenné,
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1986). A complex of three species of *Rhizoctonia* is contributing to foliar blight of *Centrosema* spp. in Colombia and possibly elsewhere (de Alvarez and Lenné, 1986).

Initiation and development of foliar blight at the beginning of the wet season is favored by high relative humidity, frequent rains, and moderately high temperatures. The initial primary inoculum is probably sclerotia and/or sexual spores. Foliar blight is usually most severe during the first months of the wet season and commonly decreases in intensity toward the middle and end of the wet season. Sclerotia readily survive in soil for several years and are disseminated by wind, rain, and animals. Fungal mycelium also survives with plant residues (Lenné et al., 1983).

**Fungi with potential as biocontrol agents against *Rhizoctonia* spp. isolated from *Centrosema* leaves.** Various fungi have been isolated from leaves of *Centrosema* spp. which may have a role in biological control of various pathogens. These include species of *Gliocladium*, *Penicillium*, and *Trichoderma*.

High populations of *Gliocladium roseum*, *Penicillium* spp. (including *P. funiculorum*), *Trichoderma hamatum*, *T. harzianum*, and *T. koningii* were associated with leaves of moderately diseased plants of *C. brasilianum* (CIAT, 1984a; de Alvarez and Lenné, 1983). In vitro studies confirmed antagonism of these fungi to mycelia growth of *R. solani*, indicating that they may naturally manage *R. solani* on *Centrosema* spp. Association of fungi such as *Epicoccum nigrum*, *G. roseum*, *P. funiculorum*, *P. janthinellum*, *P. oxalicum*, and *T. koningii*, may also have potential for the natural control of *Rhizoctonia*.

**Other fungi.** *Pithomyces* species, *P. chartarum*, and *P. maydicus* have been found on *C. pubescens* in Malaysia. The former produces a toxin responsible for photosensitization in animals. If profuse spore production occurs on *Centrosema*, *P. chartarum* could be a problem in *Centrosema*-based pastures. Several other fungi have been described on *Centrosema* spp. in various countries, but are of minor importance.

**Diseases caused by bacteria**

*Pseudomonas fluorescens* Biotype II was found to cause dieback and wilting of young plant parts of *C. acutifolium*, *C. pubescens*, and, to a lesser extent, *C. brasilianum*, *C. macrocarpum*, *C. schiedeanum*, and *C. virginianum* in Colombia (Guevara Gómez et al., 1983; Lenné et al.,
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1981. *Centrosema acutifolium* was the most susceptible species and Santander de Quilichao was the most favorable location. The disease is characterized by water-soaked lesions on young growth, progressing into wilting, rotting, necrosis, dieback, and defoliation of the plant. Necrotic spots develop on older leaves (Guevara Gómez, 1982; Lenné et al., 1983). Dry-matter yields during the establishment of *C. acutifolium* were severely decreased (Guevara Gómez et al., 1983). Disease is favored by high relative humidity and moderately high temperatures (Lenné et al., 1983). The bacterium can survive unfavorable periods on affected plants and in soil for as long as 6 weeks (CIAT, 1982). The bacterium is seed borne; levels of infection as high as 32% have been found in some seed lots (Guevara Gómez, 1982; Lenné et al., 1983).

A pseudomonas leaf spot has been recorded as a minor disease of *C. pubescens* in north Queensland (R. Davis, personal communication). In addition to disease-causing *Pseudomonas* spp., other bacteria antagonistic to *R. solani* in vitro are resident on leaves of *C. brasilianum* with foliar blight. These include species of *Acinetobacter, Chromobacterium, Pseudomonas, Serratia, Bacillus*, and *Enterobacter* (de Alvarez and Lenné, 1983).

**Diseases caused by mycoplasmas**

Little leaf (witches’ broom or phyllody) caused by mycoplasma-like organisms (MLOs) has been observed on various *Centrosema* species, including *C. brasilianum*, *C. macrocarpum*, *C. pubescens*, *C. acutifolium*, *C. virginianum*, and *C. pascuorum* in tropical America and Australia. Symptoms appear initially as marginal and/or interveinal chlorosis, accompanied by leaf deformation. Proliferation of shoots and leaves occurs from axillary buds with shortening of internodes and stunting. Proliferation of buds, leaves, and branches increases progressively and plants become chlorotic and stunted. Fruiting ceases on affected portions. Work done on clover phyllody in Ireland (Joshi et al., 1967) showed that MLOs interfere with the plants’ ability to form symbiotic relationships with rhizobia—which explains their chlorotic appearance.

MLOs are disseminated by leafhoppers of the Cicadellidae family, particularly *Orosius argentinatus*, which has been recorded in Australia (Hutton and Grylls, 1956) and Indonesia (Iwaki, 1979); *Scaphytopius fuliginosus* in Colombia (Granada, 1980), and various species of *Agallia, Empoasca, Hortensia*, and *Acinopterus* in Florida (McCoy et al., 1983).
In recent years, buildups of little leaf have occurred in small plots of *C. brasilianum* in the humid tropics of Colombia, and in the well-drained savanna ecosystem (Cerrados) of Brazil in *C. macrocarpum*, *C. brasilianum*, and hybrids. Its incidence in pastures under grazing is being investigated at both sites.

**Plant-parasitic nematodes**

At various sites in Colombia, M. R. Siddiqi (personal communication) found four genera and eight species of parasitic nematodes associated with *C. acutifolium*, *C. brasilianum*, *C. macrocarpum*, and *C. pubescens* in the well-drained savanna ecosystem (Llanos) of Colombia.

In a greenhouse study, Lenné (1981b) found *Centrosema* hybrid CIAT 438 to be only slightly susceptible to *Meloidogyne javanica*. Charchar and Huang (1981) found commercial *C. pubescens* to be a good host to *Pratylenchus brachyurus*. *Meloidogyne javanica* was observed on *C. pubescens* in Australia (J. M. Lenné, unpublished data), and *Meloidogyne* sp. on *C. pubescens* in Cameroun (Atu and Ogbuji, 1983) and the Philippines, although yields were not reduced (Valdez, 1973). *Meloidogyne* spp. have been recorded on *C. plumieri* and *C. pubescens* in Africa (Tapia, 1971). In Florida, *C. pubescens* was resistant but *C. pascuorum* was severely galled by *Meloidogyne* spp. (Kretschmer et al., 1980).

**Diseases caused by viruses**

Worldwide, 13 viruses have been described on *Centrosema* spp., mostly on *C. pubescens* (Appendix 3 of the chapter). These include the groups of comoviruses, potyviruses, cucumoviruses, potexviruses, carlaviruses, and geminiviruses.

The first reported was centrosema mosaic virus (CaMV or CenMV), a potexvirus with a particle length of 580 nm, found in New Guinea (Crowley and Francki, 1963; Magee, 1954; Purcifull and Edwardsen, 1981; van Velsen and Crowley, 1961 and 1962). CenMV can be transmitted by both aphids and plant bugs (van Velsen and Crowley, 1961), but is not seed transmitted (Shaw, 1968). A second centrosema mosaic virus (CeMV), a potyvirus with a particle length of 700 nm, was isolated and characterized in Colombia in 1984 (CIAT, 1985 and 1986; F. J. Morales, personal communication). Hosts included *C. acutifolium*,
Diseases and pests of *Centrosea*

*C. brasilianum*, *C. macrocarpum*, *C. pascuorum*, *C. pubescens*, *C. schotii*, and *Glycine max*. It is transmitted by aphids and is seed borne at low levels (CIAT, 1984a, 1984b, and 1985; A. Niessen, personal communication).

In Colombia, CeMV causes chlorosis, mosaic, leaf deformation, stunting, and plant death (CIAT, 1985 and 1986). *Centrosea macrocarpum* and *C. brasilianum* are most affected. The virus has been severe in sites with high aphid activity. Symptoms of CeMV are rarely detected in large pastures (5-20 ha) of *C. macrocarpum*, *C. brasilianum*, or *C. acutifolium* in the Colombian Llanos, although the same hosts in nearby areas of high aphid activity are severely affected. Because the virus is seed borne at low levels, there is a risk of introducing it to other regions.

A number of cowpea viruses has been shown to have *Centrosea* spp. among their hosts. All have been recorded in tropical America. Passionfruit woodiness virus (PWV), a potyvirus with a particle length of 730-745 nm and described from Australia (Greber, 1971; Teakle and Wildermuth, 1967), attacks *C. pubescens*. The virus occurs as many different strains in Australia, and the *Centrosea* isolates are regarded as host-selected variants of the virus (Greber, 1971). Whether PWV is seed borne needs to be determined. PWV and CeMV are distinct viruses (J. Thomas, personal communication). Several viruses affecting peanut have also been found on *Centrosea* spp.

Apart from descriptions of symptoms caused by these viruses and observations on the role of *Centrosea* spp. as a natural host, no indication has been given of their effect on *Centrosea*. Research is needed to fully characterize them, and to determine their distribution and modes of transmission.

**Arthropod Pests of *Centrosea***

Many works list species that have been collected or observed on *Centrosea* but little information is available concerning pest biology, distribution, severity of damage, population dynamics, or appropriate control measures. Some useful information, however, can be gleaned from observations on other crops. Brief comments from the extensive literature are given.

The complex of pests which damage *Centrosea* varies by locality, especially in small plots where neighboring or previous crops, weeds, or
other sources of infestation, influence pest populations. For example, some soil-dwelling insects, particularly polyphagous rootfeeders, may present a temporary problem during establishment but decline over time if they are unable to complete their life cycle in Centrosema. Since its introduction in the 1940s to the wet tropical areas of northern Australia, C. pubescens has been reported to be relatively free of major insect pests (Cameron, 1986; Teitzel and Burt, 1976). However, significant insect damage has been reported from Asia and tropical America. The following catalog lists potential pests.

**Thysanoptera**

The thrips *Taeniothrips sjöstedti* is present year-round on *C. pubescens* with peak populations during the main flowering period. *Centrosema* is a reservoir for thrips because it flowers intermittently over several months. *Taeniothrips sjöstedti* populations on *C. pubescens* do not reach the levels observed on cowpea because the flowers are less succulent and produce less pollen (Taylor, 1974). Thrips cause discoloration and distortion of flowers, loss of pollen, and reduced seed set (Taylor, 1965). Thrips have caused moderate damage to *Centrosema* spp. in Peru (S. L. Lapointe, unpublished data).

**Hemiptera and Homoptera**

**Plant-sucking bugs.** During the dry season of 1986-1987, introduction plots of *Centrosema* in the Colombian Llanos experienced a heavy infestation of a small black bug, *Cyrtocapsus* sp. (Miridae). It has been collected from *Centrosema* spp. in Brazil (Felixlândia in Minas Gerais, and Belém in Pará), and from *Stylosanthes* spp. in southern Colombia and the Colombian Llanos. There is a considerable range of susceptibility within *Centrosema*. *Centrosema acutifolium* CIAT 5568 was least damaged (S. L. Lapointe, unpublished data).

*Euschistus crenator* (Pentatomidae) (Chinche). Stink bugs feed by sucking from pods and may damage seed and cause pod abscission and seed abortion. *Euschistus crenator* has been reported feeding on *Centrosema* in Brazil, Peru, and Colombia (Calderón C. and Arango S., 1985).

**Aphids.** Although high infestations of aphids during early growth can cause significant damage to many tropical legumes, aphids are more
important as vectors of viral pathogens. Five of the 13 viruses reported on *Centrosea* spp. are transmitted by aphids.

**Leafhoppers.** Various genera and species of Cicadellidae have been reported on *Centrosea* in tropical America (Calderón C. and Arango S., 1985). *Empoasca* spp. are especially common and cause damage by removing sap from the foliage. Severely attacked foliage turns yellow or brown with curling of the leaves, resulting in characteristic “hopperburn.”

**Coleoptera**

Adult *Cerotoma* and *Colaspis* spp. (Chrysomelidae) (bean leaf beetles) are leaf feeders, the larvae feeding on bean roots (King and Saunders, 1984). *Cerotoma salvini* and *C. facialis* have been reported from Costa Rica, Panama, Colombia, Peru, and Brazil (Calderón C. and Arango S., 1985; King and Saunders, 1984; Nichols et al., 1974). In Brazil, these have been observed attacking *Centrosea*.

*Diabrotica balteata* (Chrysomelidae) (banded cucumber beetle) feeds on a wide range of crop plants (King and Saunders, 1984). It occurs in United States, Central America, Cuba, Colombia, Venezuela, and Peru (Heyer and Cruz, 1983; King and Saunders, 1984; Pulido and López, 1973). Together with *Cerotoma facialis*, *D. balteata* is considered to be the most important pest of common beans through direct damage to all parts of the plant and transmission of plant viruses (González et al., 1982). Considerable information is available, concerning biology and development (González et al., 1982; Heyer and Cruz, 1983) and influence of tillage systems on oviposition and colonization (Shenk and Saunders, 1984; Troxclair and Boetherl, 1984). Compared with traditional field preparation, no-tillage systems maintain greater arthropod diversity, including species of predators and parasites. Susceptibility of *Centrosea* to *D. balteata* may be greatest during sward establishment. Natural enemies of *D. balteata* include a tachinid fly, the fire ant (*Solenopsis geminata*), various Reduviidae, a cantharid beetle, and two species of nematode (Creighton and Fassuliotis, 1982 and 1985; King and Saunders, 1984).

**Lagria villosa** (Lagriidae) is a common Old World beetle (Spilman, 1978). It was first reported in Brazil (Pacheco et al., 1976). It attacks a great variety of crops (Fröhlich and Rodewald, 1970; Lamborn, 1914; Peacock, 1913) and has been reported attacking inflorescences of *Centrosea* in Brazil (Ribeiro, 1980). The adult beetle apparently enters
diapause during the dry season in Brazil from June until December and is univoltine. Natural enemies include the fungus *Paecilomyces* sp. and a parasitoid *Apanteles* (Braconidae) (García and Pierozzi Júnior, 1982). A tachinid fly has also been reported as a parasitoid of adults (Guimarães, 1978).

In Malaysia, *C. pubescens* suffers severe leaf damage from *Epilachna indica* (Coccinellidae) (Chee and Wong, 1986). *Naupactus* spp. (Curculionidae) are especially damaging to *Centrosema* during the first months of the rainy season in the Colombian Llanos. Burning adjoining areas at planting may reduce infestations (Spain, 1983). This group of weevils may be only an initial pest after *Centrosema* has been planted in an area previously occupied by native savanna. Similarly, *Pantomorus* sp. (Curculionidae) has caused damage to *Centrosema* in newly established plots in the Colombian Llanos. It is not known if these weevils are capable of completing their life cycle in *Centrosema*.

**Lepidoptera**

*Centrosema* is attacked by the larvae of numerous lepidopterous species. *Anticarsia gemmatalis* (Noctuidae) (the velvetbean caterpillar) was reported on *Centrosema* in Brazil (Ribeiro, 1980) and Colombia (Calderón C. and Arango S., 1985). It has been studied on other crops in Florida (Pohronezny et al., 1981) and in Brazil where it is considered a major pest (Kogan et al., 1977; Leite and Lara, 1985). Eggs are laid on the underside of leaves. Larvae consume leaves and vines and can completely defoliate plants when populations are high. Parasites are listed by King and Saunders (1984). The fungus *Nomuraea rileyi* is a major biological control agent in larval populations of *A. gemmatalis* (Allen et al., 1971; Carner et al., 1975; Correa et al., 1977; Hinds and Osterberger, 1931; Leite and Lara, 1985). An inexpensive pheromone trapping system for *A. gemmatalis* has been developed (Mitchell and Heath, 1986).

*Phurys basilians* (Noctuidae) and *Etiella zinckenella* (Pyralidae) (legume pod borer, lima bean pod borer) have been reported on *Centrosema* in Brazil (Ribeiro, 1980). Feeding by *E. zinckenella* can result in seed loss, and early feeding damage to inflorescences may cause the flowers to abort (Kling and Saunders, 1984). *Etiella zinckenella* is parasitized by *Bracon* sp., *Tetrastichus* sp., and Pteromalidae species (Sandhu and Verma, 1969).

*Urbanus proteus* (Hesperiidae) (bean leafroller) is reported to attack *Centrosema* in Brazil (Ribeiro, 1980). *Urbanus proteus* is an endemic
Diseases and pests of Centrosema

pest of *Phaseolus vulgaris* in northern Chile and is apparently well
tested by natural enemies, including chalcidid wasps (Dias P.,
1976). It is also a minor pest of beans and other legumes in Central
America (King and Saunders, 1984). In Colombia, *U. proteus* feeding
on *P. vulgaris* are parasitized at the egg stage by *Trichogramma* sp. and
as larvae by *Ardalus* sp. (Hymenoptera) and *Calpodomyia* sp. (Diptera)
(Van Dam and Wilde, 1977).

*Elasmopalpus lignosellus* (Pyralidae) was found on *Centrosema* in
Colombia in August 1986 (S. L. Lapointe, unpublished data). In
Central America, *E. lignosellus* is of sporadic or local importance in
sandy or well-drained soils during the dry season and after burning.
Denser planting may be helpful and a fallow period reduces infestation.
Eggs are placed singly or in small groups on the stems and leaves that
are close to the soil and on the surface of the soil at the base of host
plants (King and Saunders, 1984).

*Omiodes* (syn. *Hedylepta* indicata) (Pyralidae) (leaf rollers) attacks
*Centrosema* in Cuba during the rainy season. Larvae are leaf rollers and
feed on leaf parenchyma. Kapoor et al. (1972) reported eulophids,
braconids, and ichneumonids as larval parasites. Life-history data and
laboratory-rearing techniques have been published (de Bortoli et al.,
1982; Kapoor et al., 1972). In recent years, population densities of *O.
indicata* have grown notably in various regions of Brazil with high
infestations of soybean fields during 1982-83 (Lourençã£o et al., 1985).

**Diptera**

Bean fly, *Melanagromyza centroseumatis* (Agromyzidae), is a minor
pest of *Centrosema* in Malaysia (Clements et al., 1983). In north
Queensland, *M. phaseoli* lays its eggs on the leaves of *Centrosema* and
other legumes, usually on the upper surface. Heavy infestations will thin
out legume stands (G. W. Saunders and R. J. Elder, personal
communication). Seed treatment with endrin or dieldrin has been
recommended before planting. However, such treatment will damage
*Rhizobium* inoculum on the seed surface.

**Mites**

Red spider mites (*Tetranychus* spp.) commonly attack *Centrosema*
foliage, mostly in introduction gardens, but also in seed-production
plots and pastures (Clements et al., 1983).
Distribution and Relative Importance of Diseases and Pests Across Major Ecosystems of Tropical America

Diseases and pests of *Centrocomma* vary in distribution and importance among the major ecosystems of tropical America (Lenné et al., 1985; Pizarro, 1983 and 1986). Rhizoctonia foliar blight is by far the most important disease in three major ecosystems (Table 1). Its secondary importance in the Cerrados is probably because of the short wet season. Cercospora leaf spot and pseudocercospora leaf spot are usually considered as secondary except in the savanna ecosystems where pseudocercospora leaf spot is of primary importance (Table 1).

Table 1. Distribution and relative importance\(^a\) of various diseases\(^b\) of *Centrocomma* spp. across major ecosystems of tropical America.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Savannas</th>
<th>Humid tropics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Llanos</td>
<td>Cerrados</td>
</tr>
<tr>
<td>Cercospora leaf spot ((C. canecescens))</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Pseudocercospora leaf spot ((P. bradburyae))</td>
<td>S to I</td>
<td>S to I</td>
</tr>
<tr>
<td>Cylindrocladium leaf spot ((C. colhounii))</td>
<td>S</td>
<td>ND</td>
</tr>
<tr>
<td>Anthracnose ((Colletotrichum) spp.)</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Phoma-and-phomopsis leaf-spot complex ((Phoma) spp.; *Diaporthe\ phaseolorum)</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Rhizoctonia foliar blight ((Rhizoctonia) spp.)</td>
<td>I</td>
<td>S</td>
</tr>
<tr>
<td>Bacteriosis ((Pseudomonas fluorescens) Biotype II)</td>
<td>NI</td>
<td>ND</td>
</tr>
<tr>
<td>Little leaf or phyllody</td>
<td>NI</td>
<td>S to I</td>
</tr>
<tr>
<td>Centrocomma mosaic virus ((CeMV))</td>
<td>NI</td>
<td>ND</td>
</tr>
</tbody>
</table>

\(a\) I = important; S = secondary; NI = not important; ND = not detected.
\(b\) Only better known and/or widely distributed diseases are listed.
\(c\) At one site it was rated as important (Quilichao, Colombia).

SOURCE: Modified from Lenné et al., 1983.
Recently, severe damage has been recorded on *C. brasiliannum* CIAT 5234 in Planaltina (Cerrados, Brazil) and Carimagua (Llanos, Colombia), suggesting that *Pseudocercospora bradburyae* has potential to be a serious pathogen (CIAT, 1985).

Cylindrocladium leaf spot has been recorded as a secondary disease in the Llanos. Spot-and-pod anthracnose is widespread, but is regarded as a secondary disease. Pod anthracnose causes concern because seeds from infected pods usually carry at least one species of *Colletotrichum*.

The phoma-and-phomopsis leaf-spotting complex is a secondary disease in both savanna ecosystems and has not yet been detected in the humid tropics (Table 1). At present, bacteriosis caused by *Pseudomonas fluorescens* Biotype II is viewed as a site-specific problem of importance as a seed-borne pathogen. Centrosema mosaic virus (CeMV) is viewed similarly, because, at present, it is important at only one site (Table 1). Little leaf has caused severe damage in small plots under cutting.

Leaf-eating insects, principally Chrysomelidae and other Coleoptera, cause significant damage to *Centrosema* across the major ecosystems of tropical America. Judging from visual ratings, the greatest damage occurs during the wet season in both well-drained savanna ecosystems and during the dry season in the poorly drained savannas and forest ecosystems. *Centrosema acutifolium* and *C. macrocarpum* may be more damaged than some other species, at least in areas of South America where well-adapted species have been compared (Pizarro, 1986).

Further monitoring at major screening sites is needed to determine whether some diseases and pests will build up in ecosystems where they are, at present, unimportant. Differences in the importance of diseases and pests in different ecosystems necessitates research on most of them. Currently, most research on the status of diseases and pests is being done at CIAT. Ideally, it should be done in the ecosystem where the particular disease or pest is most important.

**Relative Importance of Various Diseases Among *Centrosema* Species**

*Centrosema* species vary in their relative susceptibility to various diseases. No case has yet been found of a disease being important to all
promising species. Bacteriosis is the most host-specific disease, and *C. acutifolium* is the species most susceptible to it (Table 2). Cercospora leaf spot is most important to *C. pubescens*; pseudocercospora leaf spot to *C. brasilianum*; and cylindrocladium leaf spot to *C. acutifolium*. Anthracnose is slightly more important to *C. brasilianum* and *C. pubescens* than to other species because of its association with rhizoctonia foliar blight and tendency to cause pod anthracnose on these species. Phoma-and-phomopsis leaf-spot complex is more important to *C. acutifolium* than to *C. pubescens* or *C. macrocarpum*. For several years, differential susceptibility among *Centrosema* species to *Rhizoctonia* spp. has been observed, *C. brasilianum* being the most susceptible (CIAT, 1982 to 1984b; de Alvarez and Lenné, 1986).

*Centrosema brasilianum* and *C. macrocarpum* are more affected by little leaf, and *C. macrocarpum* by centrosema mosaic virus, than are other species. In both cases, observations are site specific and care must be taken in their interpretation. Controlled experiments are required to confirm field observations.

**Variability Within *Centrosema* Species for Resistance to Diseases**

*Rhizoctonia foliar blight*

Field experiments at several sites have given hope that susceptibility to rhizoctonia foliar blight may vary within *Centrosema* species. In Florida, Sonoda et al. (1971) observed apparent differences in susceptibility within *C. plumieri* and other species. However, in tropical South America, screening of *C. brasilianum* has shown that most accessions are moderately to severely blighted (CIAT, 1981 to 1986; Lenné et al., 1985; Schultze-Kraft and Belalcázar, 1988). More than 150 accessions have been tested in these field trials.

Some of the experiments have shown poor agreement among replications (CIAT, 1985). Small-plot evaluations of reaction to rhizoctonia foliar blight among *C. brasilianum* accessions, using only natural inoculum, are not of great value in selecting resistant accessions. An improved field screening methodology is, at present, being developed.

Development of artificial inoculation, using liquidized frozen mycelium, has greatly improved the uniformity of results of studies on 190
Table 2. Relative importance\(^a\) of various diseases\(^b\) among promising species of *Centrosema* in tropical America.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cercospora leaf spot (C. canescens)</td>
<td>C. brasilianum</td>
</tr>
<tr>
<td>Pseudocercospora leaf spot (P. bradburyae)</td>
<td>I to S</td>
</tr>
<tr>
<td>Cylindrocladium leaf spot (C. colhounii)</td>
<td>NI</td>
</tr>
<tr>
<td>Anthracnose (Colletotrichum spp.)</td>
<td>S</td>
</tr>
<tr>
<td>Phoma-and-phomopsis leaf-spot complex (Phoma spp.; Diaporthe phaseolorum)</td>
<td>NI</td>
</tr>
<tr>
<td>Rhizoctonia foliar blight (Rhizoctonia spp.)</td>
<td>I</td>
</tr>
<tr>
<td>Bacteriosis (Pseudomonas fluorescens Biotype II)</td>
<td>NI</td>
</tr>
<tr>
<td>Little leaf or phyllody</td>
<td>S to I</td>
</tr>
<tr>
<td>Centrosema mosaic virus (CeMV)</td>
<td>S to I</td>
</tr>
</tbody>
</table>

\(^a\) I = important; S = secondary; NI = not important. A certain amount of weighting was given to I and S to indicate more nearly the level of importance of any given disease.

\(^b\) Only better known and/or widely distributed diseases are included.

SOURCE: Modified from Lenné et al., 1983.
reaction of *Centrosoema* spp. seedlings to *Rhizoctonia* spp. isolates (CIAT, 1986). In several studies, variation in reaction to *Rhizoctonia* species among accessions of *C. brasilianum, C. macrocarpum, C. pubescens,* and *C. acutifolium* has been noted. Most accessions of *C. macrocarpum* are inherently highly susceptible (Olaya H. and Lenné, 1986). In selection for resistance to rhizoctonia foliar blight within *C. brasilianum,* both field evaluation and artificial inoculation will be necessary. The major problem with artificial inoculation studies is choosing the isolate which would represent the disease in the ecosystem and/or site for which *C. brasilianum* is being selected. A range of isolate virulence should be included.

**Bacteriosis**

Accessions of *C. acutifolium* in Santander de Quilichao, Colombia, varied in reaction to *P. fluorescens* Biotype II (CIAT, 1981 and 1982; Guevara Gómez, 1982; Schultze-Kraft et al., 1987). CIAT 5112 and 5118 were highly susceptible, while CIAT 5568 was more resistant. Controlled artificial inoculation studies confirmed results obtained in the field (Guevara Gómez, 1982). Some accessions have continued to show high resistance across major ecosystems.

**Centrosoema mosaic virus (CeMV)**

*Centrosoema macrocarpum* accessions differed in reaction to CeMV in Santander de Quilichao and Carimagua, Colombia, during 1984 and 1985 (CIAT, 1985 and 1986). Considerable variability was also observed among plants within accessions. Screening under controlled conditions is clearly necessary.

**Other diseases**

Variability has been observed at several sites in reaction to cercospora leaf spot, anthracnose, little leaf, and various other diseases within promising species such as *C. brasilianum, C. macrocarpum, C. pubescens,* and *C. acutifolium.* Controlled screening for disease resistance is needed to support field results.
Variability Among Important Pathogens

Variability within the *Rhizoctonia* spp. complex

Studies on more than 200 *Rhizoctonia* isolates have shown the presence of at least three species: *R. solani*, *R. zeae*, and BNR (CIAT, 1987; de Alvarez and Lenné, 1986; Olaya H., 1985). Olaya H. and Lenné (1986) showed that *R. solani* and BNR were more virulent and common than *R. zeae*. Isolates vary in growth rate, color, zonation, sclerotial characters, mycelial texture, and virulence. Multinucleate isolates of *R. solani* have been classified as AG-1, AG-2, and AG-4, with AG-1 and AG-4 being more common. Further variation within these groups was detected from isozyme bands (Olaya H., 1985). Of a collection of 180 isolates of *Rhizoctonia* spp., only 44% were *R. solani*, 56% being BNR (Olaya H. and Lenné, 1986). In comparative pathogenicity trials, high levels of virulence were registered for isolates of both *R. solani* and BNR (de Alvarez and Lenné, 1986; Olaya H. and Lenné, 1986).

Because foliar blight of *Centrosera* is caused by a variable complex of *Rhizoctonia* species and types, studies of resistance under controlled conditions are complex and long term. Priority should be given to determining the most common types of *Rhizoctonia* in specific sites to obtain resistance information as soon as possible. Studies on the effect of environmental conditions on population dynamics should also be given priority.

Variability within *Colletotrichum* spp.

Both *C. gloeosporioides* and *C. truncatum* are involved in leaf-and-pod anthracnose of *Centrosera* spp. Although both species can be isolated from the same lesions, particularly from pods, *C. gloeosporioides* is more commonly isolated from leaves (Lenné et al., 1983). Some variation in virulence has been found within *C. gloeosporioides*. Most isolates of *C. truncatum* are not pathogenic to seedlings. No evidence of variability has yet been observed among other *Centrosera* pathogens.
Seed-Borne Pathogens

General studies

Seed microflora of Centrosea includes species of Aspergillus, Chaetomium, Fusarium, Mucor, Penicillium, Rhizopus, Trichoderma, and bacteria. The occurrence of Chaetomium, Penicillium, and Trichoderma offers potential for natural biological control. In addition, several important pathogens of Centrosea spp. are found, including the bacterium Pseudomonas fluorescens Biotype II, Colletotrichum spp., and centrosea mosaic virus (CeMV).

Pseudomonas fluorescens Biotype II

Treatment of C. acutifolium seeds with chemicals such as copper hydroxide (Kocide®) and carboxin (Vitavax®) were successful in lowering infection with this bacterium, but not in eliminating it (Salas and Lenné, 1985). Further work is planned, using dry heat which successfully eliminates another Pseudomonas species from rice seed (R. Zeigler, personal communication).

Colletotrichum spp.

The association of Colletotrichum spp. with seed of Centrosea spp. (Lenné, 1981a) is important, not only for pathogen movement, but also because it retards germination (Lenné and Sonoda, 1978). Both benomyl (Benlate®) and captafol (Difolatan®) were successful in eliminating C. gloeosporioides and C. truncatum from C. pubescens seed (J. M. Lenné, unpublished data).

Centrosea mosaic viruses

Studies made on CenMV in New Guinea found no evidence of seed infection (Shaw, 1968). Low levels of seed infection, however, have been detected by enzyme-linked immunosorbent assay (ELISA) for CeMV in Colombia (A. Niessen, personal communication). Further work is necessary to define infection levels and species of Centrosea involved but, at present, this virus is not causing serious damage unless introduced into sites with high aphid activity.
Options for Disease and Pest Management

Options for disease and pest management include chemical, biological, and cultural control (sanitation and grazing management); strategic association; and resistance (Lenné, 1983; Lenné et al., 1980). Resistance is the most practical and economical option for pasture plants. All Centrosema germplasm is screened for reaction to local pests and pathogens at major screening sites of CIAT and the International Tropical Pastures Evaluation Network (RIEPT). Backup greenhouse screening is necessary for some pathogens and pests. The chemical basis of resistance to several pathogens has been observed in Centrosema spp. Accessions of C. schottii (syn. C. haitiense), C. pubescens, and C. virginianum produced phytoalexins and phenolic compounds when inoculated with R. solani (Markham and Ingham, 1980; Sukumaran and Gnanamanickam, 1980). These compounds included tectorigenin, cajanin, kievitone, phaseololidin, and coumestrol.

The use of chemicals to control diseases and pests is uneconomic in most cases. In addition, cattle intolerance to residues, toxicity to insect pollinators, and problems of resurgence of pests and diseases are important biological constraints. Pesticides, however, have some value in management of seed-borne pathogens where economic injury levels are lower and toxic residues are of less concern.

Plants growing under higher fertility often show greater resistance to diseases (Leath and Ratcliffe, 1974), but results to date do not encourage use of specific fertilizers as an option for management of Centrosema diseases (CIAT, 1984b; Lenné, 1983). Biological control agents of many Centrosema pests have been identified, but this option is largely unexplored for tropical pasture plants. Some work has been done on natural control agents of Rhizoctonia species in the Llanos. During 1981-1986, decrease or lack of buildup in the incidence and severity of foliar blight during the wettest period of the year were found to be associated with high populations of Trichoderma spp., Gliocladium roseum, Penicillium spp., and various bacteria (CIAT, 1982; de Alvarez and Lenné, 1983). Antagonism of the above-mentioned fungi and bacteria to isolates of R. solani was demonstrated in vitro. Buildup of these microorganisms could explain natural decreases in foliar blight.

To date, neither sanitation by burning nor strategic association have been investigated for controlling Centrosema diseases. The effect of grazing management on foliar blight and yield of C. brasiliense CIAT
5234 has been studied (de Alvarez and Lenné, 1986). Losses of dry matter, ranging from 34% to 54%, have been greatest under continuous grazing and in association with Andropogon gayanus. The losses probably occurred because, firstly, the grass favors disease development (possibly because of competition for nutrients and light and/or by creating a more favorable microclimate for disease development); and, secondly, the grazing animal itself apparently aids dissemination of Rhizoctonia through the pasture.

Research Priorities

The following research priorities can be defined in order of importance for diseases and insect pests of Centrosema.

Rhizoctonia foliar blight

Improved methodology for evaluating resistance under field conditions should be studied immediately. Isolate variability is already being examined to provide representative isolates for greenhouse screening. The value of associated antagonistic fungi and bacteria as natural biological control agents of foliar blight also needs to be evaluated under field conditions. Further work is needed on epidemiology and the effect of grazing and association on foliar blight incidence and severity.

Centrosema mosaic virus

Of high priority is a comparative study of the similar mosaic-causing viruses recorded on Centrosema spp. Information available from previous studies can be of use when investigating CeMV in Colombia. Care must be taken when moving seed, especially that of C. macrocarpum, as CeMV is seed borne. Further work on CeMV must also involve the evaluation of Centrosema germplasm for resistance.

Cercospora leaf spot

A confusing complex of Cercospora spp. has been described on Centrosema spp. throughout the world. Because the last detailed treatment of this genus was made more than 30 years ago (Chupp,
Diseases and pests of Centrosema

1953), comparative work is needed to determine whether we are actually dealing with four different diseases. Before initiating any breeding program, such a study is essential.

Phoma-and-phomopsis complex

Further work is necessary to elucidate the importance of these fungi and the relationships between them. This is particularly important in the Cerrados where soybean cultivation is increasing. The Phomopsis state of Diaporthe phaseolorum is an important pathogen of this crop.

Potentially plant-parasitic nematodes

The importance of the recently found nematode species in Centrosema-based pastures needs urgent evaluation.

Mycoplasma-like organisms

Little leaf seems to be a problem of small plots and not of large grazing experiments. This observation requires further investigation as does the site-specific nature of this disease.

Insect pests

Very little specific information is available about insect pests of Centrosema. Research on specific pests causing significant damage must increase as the distribution and importance of Centrosema increase. Studies of priority are the relative importance of individual pests, their distribution, and the damage they cause. Such data will help develop appropriate control strategies and to establish priorities for plant-breeding programs. Research on the ladybird beetle (Epilachna indica) in Malaysia deserves priority.

Acknowledgments

The senior author would like to thank the Commonwealth Mycological Institute, Kew, Surrey, U.K., for access to their unpublished data of diseases recorded on Centrosema.
References


Diseases and pests of Centrosema


Diseases and pests of Centrosema


Diseases and pests of Centrosema

International Conference on Plant Pathogenic Bacteria, August 16-23, 1981 at CIAT, Cali, Colombia. CIAT series no. 03E-2(82). Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia, and Agricultural Editor's Office, College of Agriculture, University of Missouri, Columbia, MO, USA. p. 35-38.


———; Vargas H., A.; and Torres G., C. 1983. Descripción de las enfermedades de las principales leguminosas forrajeras tropicales: guía de estudio. Serie 04SP-03.03. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. 50 p.


Diseases and pests of Centrosema


Diseases and pests of Centrosema


### Appendix 1. Diseases\textsuperscript{a} of *Centrostepa* spp. in tropical America.

<table>
<thead>
<tr>
<th>Pathogen</th>
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<th>Host species</th>
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<td><strong>Fungi</strong></td>
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<td><em>Cercospora canescens</em> Ell. &amp; Mart.</td>
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<td><em>C. acutifolium</em></td>
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<td>Béreau, 1981</td>
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<tr>
<td></td>
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<td><em>C. arenarium</em></td>
<td>Colombia, Ecuador, French</td>
<td>CIAT, 1981 to 1986</td>
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<td></td>
<td></td>
<td><em>C. brasilianum</em></td>
<td>Guiana, Peru, Venezuela,</td>
<td>Chupp, 1953</td>
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<tr>
<td></td>
<td></td>
<td><em>C. pascuorum</em></td>
<td>Central American countries</td>
<td>Lenné, 1981a</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>C. plumieri</em></td>
<td></td>
<td>Lenné et al., 1983</td>
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<td></td>
<td></td>
<td><em>C. pubescens</em></td>
<td></td>
<td>J. M. Lenné, pers. surv.</td>
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<tr>
<td></td>
<td></td>
<td><em>C. schiedeanum</em></td>
<td></td>
<td>Norse, 1974</td>
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<td>Schultze-Kraft and</td>
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<td>Keller-Grein, 1985</td>
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<td>Sonoda and Lenné, 1979</td>
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<td><em>C. centroseiae</em> Chupp &amp; Muller</td>
<td>Leaf spot</td>
<td><em>C. virginianum</em></td>
<td>Venezuela</td>
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<tr>
<td><em>C. centroseamatis</em> Chupp &amp; Muller</td>
<td>Leaf spot</td>
<td><em>C. pubescens</em></td>
<td>Puerto Rico</td>
<td>CM1\textsuperscript{b}, unpubl. rec.</td>
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<td><em>C. pubescens</em></td>
<td>Mexico, Puerto Rico</td>
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<td><em>C. virginianum</em></td>
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<tr>
<td><em>Colletotrichum gloeosporioides</em> (Penz.) Sacc.</td>
<td>Leaf-and-pod anthracnose</td>
<td><em>C. arenarium</em></td>
<td>Bolivia, Brazil, Colombia,</td>
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<td><em>C. brasilianum</em></td>
<td>Ecuador</td>
<td>Lenné et al., 1983</td>
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<td></td>
<td></td>
<td><em>C. macrocarpum</em></td>
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<td><em>C. truncatum</em> (Schw.) Andrus &amp; Moore</td>
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<td><em>C. acutifolium</em></td>
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<td>J. M. Lenné, pers. surv.</td>
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<td><em>C. pascuorum</em></td>
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<td><em>C. plumieri</em></td>
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<td><em>C. pubescens</em></td>
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<td></td>
<td></td>
<td><em>C. schiedeanum</em></td>
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<td></td>
<td></td>
<td><em>C. virginianum</em></td>
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\textsuperscript{b}CM1 = Central Mexico 1, an experimental line of *Centrostepa* resistant to anthracnose disease.
<table>
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<tr>
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<th>Host species</th>
<th>Country</th>
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<td><em>Colletotrichum</em> sp.</td>
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<td>French Guiana</td>
<td>Béreau, 1981</td>
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<td></td>
<td></td>
<td><em>C. pubescens</em></td>
<td></td>
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</tr>
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<td><em>Curvularia</em> sp.</td>
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<td><em>C. pubescens</em></td>
<td>Colombia</td>
<td>J. M. Lenné, pers. surv. Sonoda and Lenné, 1979</td>
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<td></td>
<td></td>
<td><em>C. sp.</em></td>
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<td><em>Cylindrocladium colhounii</em> Peer.</td>
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<td></td>
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<td><em>C. brasilianum</em></td>
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<td><em>C. macrocarpum</em></td>
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<td></td>
<td><em>C. pubescens</em></td>
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<td><em>Diaporthe phaseolorum</em> (Cooke &amp; Ellis) Sacc.</td>
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<td><em>Phakopsora pachyrhizi</em> Syd.</td>
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<td><em>C. pubescens</em></td>
<td>Puerto Rico</td>
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<td></td>
<td></td>
<td><em>C. macrocarpum</em></td>
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<th>Host species</th>
<th>Country</th>
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<td><em>Phomopsis</em> state of <em>Diaporthe phaseolorum</em> (Cooke &amp; Ellis) Sacc.</td>
<td>Leaf spot</td>
<td>C. <em>acutifolium</em>&lt;br&gt;C. <em>macrocarpum</em>&lt;br&gt;C. <em>pubescens</em></td>
<td>Brazil, Colombia</td>
<td>CIAT, 1985&lt;br&gt;J. M. Lenné, pers. surv.</td>
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<td>Tar spot</td>
<td>C. <em>virginianum</em></td>
<td>Venezuela</td>
<td>Standen, 1952</td>
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<td><em>Pseudocercospora</em> <em>bradburyae</em> (Young) Deighton&lt;br&gt;(syn. <em>Cercospora</em> <em>bradburyae</em> Young)</td>
<td>Leaf spot</td>
<td>C. <em>acutifolium</em>&lt;br&gt;C. <em>arenarium</em>&lt;br&gt;C. <em>brasilianum</em>&lt;br&gt;C. <em>macrocarpum</em>&lt;br&gt;C. <em>pascuorum</em>&lt;br&gt;C. <em>plumieri</em>&lt;br&gt;C. <em>pubescens</em>&lt;br&gt;C. <em>schiedeanum</em>&lt;br&gt;C. <em>virginianum</em></td>
<td>Barbados, Bolivia, Brazil,&lt;br&gt;Colombia, Ecuador, Peru,&lt;br&gt;Puerto Rico, Dominican&lt;br&gt;Republic, Trinidad,&lt;br&gt;Venezuela, Central&lt;br&gt;American countries</td>
<td>CIAT, 1986&lt;br&gt;Chupp, 1953&lt;br&gt;Leather, 1968&lt;br&gt;Lenné et al. 1983&lt;br&gt;J. M. Lenné, pers. surv.&lt;br&gt;Sonoda and Lenné, 1979&lt;br&gt;Schultze-Kraft and Keller-Grein, 1985</td>
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<td>J. M. Lenné, pers. surv.&lt;br&gt;Lenné, 1979</td>
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<td>Disease</td>
<td>Host species</td>
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<td><em>Uromyces neurocarpi</em> Diet.</td>
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<td>and dieback</td>
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<td></td>
<td><em>C. pubescens</em></td>
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<td>Schultzze-Kraft and</td>
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<td><em>C. acutifolium</em></td>
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<td>Keller-Grein, 1985</td>
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<td>Lenné, 1981a</td>
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<td>Witches' broom</td>
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<td></td>
<td><em>C. pubescens</em></td>
<td></td>
<td>Keller-Grein, 1985</td>
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<td><em>Helicotylenchus</em> sp. nov</td>
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<td>Lenné, 1981b</td>
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<td><em>Pratylenchus brachyurus</em>&lt;br&gt;Luc &amp; de Quiran 1960</td>
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<td><em>C. acutifolium</em>&lt;br&gt;<em>C. brasillianum</em>&lt;br&gt;<em>C. macrocarpum</em>&lt;br&gt;<em>C. pubescens</em></td>
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a. Excluding viruses.
b. CMI = Commonwealth Mycological Institute.
Appendix 2. Diseases\textsuperscript{a} of *Centrosera* spp. in other regions and countries.

<table>
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<tr>
<th>Pathogen</th>
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<td><em>Alternaria macrospora</em> Zimm.</td>
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<td><em>C. pubescens</em></td>
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<td>Uganda</td>
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<td></td>
<td>Pacific</td>
<td>Australia</td>
<td>R. Davis, pers. comm.</td>
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<td><em>Ascochyta</em> sp.</td>
<td>Leaf spot</td>
<td><em>C. pubescens</em></td>
<td>Africa</td>
<td>Uganda,</td>
<td>CMI, unpubl. rec.</td>
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<td></td>
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<td>Zimbabwe</td>
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<td><em>Botryodiplodia theobromae</em> Pat.</td>
<td>Dieback</td>
<td><em>C. pubescens</em></td>
<td>Asia</td>
<td>Malaysia</td>
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<td></td>
<td></td>
<td></td>
<td>Africa</td>
<td>Ghana</td>
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<td>Sooty mold</td>
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<td>Congo(?)</td>
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<td><em>Oidium</em> sp.</td>
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<td>R. Davis, pers. comm.</td>
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<td><em>Periconia bryooides</em> Persoon ex Schweinitz</td>
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<td><em>Phoma minutella</em> Sacc. &amp; Penz.</td>
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<td><em>P. sorghina</em> (Sacc.) Boer., Dorenb. &amp; van Kest.</td>
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<td>Pathogen</td>
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<td>Region</td>
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<td>R. J. Johnson, 1960; Singh, 1973</td>
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<td>Fiji</td>
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Appendix 2. (Continued)

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<td>North America</td>
<td>USA</td>
<td>Sonoda and Lenné, 1979</td>
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<td>Williams and Liu, 1976</td>
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<td>J. Hopkinson, pers. comm.</td>
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<td><em>Rosellinia bunodes</em></td>
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<td>(Berk. &amp; Broome) Sacc.</td>
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<td><em>Sclerotium barkeri</em> Syd.</td>
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<td><em>C. pubescens</em></td>
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<td>Singh, 1973; Thompson and Johnson, 1953</td>
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<th>Pathogen</th>
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<th>Region</th>
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<th>Sources</th>
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<td>Singh, 1973; Thompson and Johnson, 1953</td>
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<td>Cyst nematode</td>
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<td>Merny and Cadet, 1978</td>
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<td>Brizuela 1961</td>
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<td><em>M. incognita</em> (Kofoid &amp; White)</td>
<td>Root-knot</td>
<td><em>C. plumieri</em></td>
<td>Africa</td>
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<td>Luc and de Guiran, 1960</td>
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<td>Chitwood 1949</td>
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<td><em>C. pascuorum</em></td>
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<td><em>C. sp.</em></td>
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<td>Philippines</td>
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<td><em>Meloidogyne</em> spp.</td>
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a. Excluding viruses.
b. CMI = Commonwealth Mycological Institute.
### Appendix 3. Viruses recorded on *Centrosea* spp. throughout the world.

<table>
<thead>
<tr>
<th>Virus</th>
<th>Group</th>
<th>Particle length (nm)</th>
<th>Distribution</th>
<th>Host range</th>
<th>Transmission</th>
<th>Sources</th>
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<tbody>
<tr>
<td>Centrosea mosaic virus (CeMV)</td>
<td>Potyvirus</td>
<td>700</td>
<td>Colombia</td>
<td><em>Centrosea spp.</em>&lt;br&gt;<em>Macropitillum</em> sp.&lt;br&gt;<em>Diosclea</em> sp.&lt;br&gt;<em>Crotalaria</em> spp.&lt;br&gt;<em>Desmodium distortum</em>&lt;br&gt;<em>Glycine max</em>&lt;br&gt;<em>Phaseolus vulgaris</em> var. <em>Bountiful</em>&lt;br&gt;<em>Bountiful</em> and <em>Double White</em></td>
<td><em>Aphididae</em>&lt;br&gt;<em>Aphis</em> spp.&lt;br&gt;<em>Myzus persicae</em>&lt;br&gt;(Not transmitted by seed)&lt;br&gt;(Seed transmission at low levels)</td>
<td>Shaw, 1968&lt;br&gt;F. Morales, pers. comm.&lt;br&gt;CIAT, 1985 and 1986</td>
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<td>Cowpea mosaic virus</td>
<td>Comovirus</td>
<td>30</td>
<td>Cuba</td>
<td><em>Centrosea spp.</em>&lt;br&gt;<em>Vigna unguiculata</em>&lt;br&gt;<em>Rhynchosia pyramidalis</em></td>
<td><em>Chrysomelidae</em>&lt;br&gt;(Not transmitted by seed)</td>
<td>Diaz, 1974&lt;br&gt;Kvicala et al., 1972</td>
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<td>Cowpea severe mosaic virus serotype I (CpSMV)</td>
<td>Comovirus</td>
<td>?</td>
<td>Brazil</td>
<td><em>Centrosea pubescens</em>&lt;br&gt;<em>Calopogonium mucunoides</em>&lt;br&gt;<em>Vigna unguiculata</em></td>
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<td>Lin et al., 1982</td>
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<tr>
<th>Virus</th>
<th>Group</th>
<th>Particle length (nm)</th>
<th>Distribution</th>
<th>Host range</th>
<th>Transmission</th>
<th>Sources</th>
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<tr>
<td>Blackeye cowpea mosaic virus (BICMV)</td>
<td>Potyvirus</td>
<td>?</td>
<td>Brazil</td>
<td>Centrosema pubescens Vigna unguiculata</td>
<td>Seed transmitted</td>
<td>Lin et al., 1981</td>
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<tr>
<td>Cowpea potyvirus (unclassified)</td>
<td>Potyvirus</td>
<td>700-750</td>
<td>Brazil</td>
<td>Centrosema brasilianum Vigna unguiculata</td>
<td>Aphididae Aphis craccivora (Not transmitted by seed)</td>
<td>Lima et al., 1981</td>
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<tr>
<td>Cucumber mosaic virus (CMV)</td>
<td>Cucumovirus</td>
<td>30</td>
<td>Guadeloupe</td>
<td>Centrosema pubescens Macropitium atropurpureum</td>
<td></td>
<td>Migliori et al., 1978</td>
</tr>
<tr>
<td>Groundnut crinkle virus (GCV)</td>
<td>Carlavirus</td>
<td></td>
<td>Côte d'Ivoire</td>
<td>Arachis spp. Centrosema pubescens</td>
<td>(Not transmitted by aphids)</td>
<td>Dubern, 1981</td>
</tr>
<tr>
<td>Groundnut eyespot virus</td>
<td>Potyvirus</td>
<td></td>
<td>Côte d'Ivoire</td>
<td>Arachis spp. Centrosema pubescens</td>
<td>Aphididae Aphis craccivora</td>
<td>Dubern and Dollet, 1978</td>
</tr>
<tr>
<td>Yellow mottle virus</td>
<td>Geminivirus</td>
<td></td>
<td>Colombia</td>
<td>Centrosema spp.</td>
<td></td>
<td>J. M. Lenné, pers. observ.</td>
</tr>
</tbody>
</table>

<sup>a</sup> Needs Groundnut Rosette Assistor Virus.
Chapter 8

SEED PRODUCTION OF CENTROSEMA SPECIES

J. E. Ferguson, J. M. Hopkinson, L. R. Humphreys, and R. P. de Andrade*

Abstract

Reproductive physiology and seed formation of *C. pubescens*, a short-day plant, are reviewed, and the information available for other *Centrosema* species is summarized.

Seed-crop management involves the selection of suitable geographic regions and specific sites, good agronomic practices at establishment, use of physical support, and integrated weed control. Seed may be harvested by handpicking and threshing, direct combining, crop desiccation (either by mowing, followed by natural drying, or by using chemical desiccants) prior to combine harvesting, and suction harvesting.

Seed of *C. pubescens* is produced as an opportunistic byproduct from plantation agriculture. Attempts by specialist seed growers in north Queensland and central Brazil to produce seed have failed because of agronomic problems and competition from cheaper imports. Thus, seed supply of new cultivars of novel species may not occur spontaneously after cultivar release. Factors which will favor the evolution of commercial seed supplies of new cultivars are identified and discussed.

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Seed production research is meager, and must be increased as cultivars are being released. Priorities for future research include the definition of flowering control mechanisms; identification of favored geographic regions for commercial seed production; seed-crop management, especially intercropping *Centrosera* with annual grain and perennial tree crops, and the use of support systems other than conventional trellises; and seed technology to promote longevity in storage and reduce hard-seededness before planting.

**Introduction**

Demand for seed of common *Centrosera pubescens* to establish tropical pastures began in Queensland, Australia, in the mid-1950s (Allen, 1958). It was probably greatest in the mid-1970s when it was associated with pasture expansion in the Brazilian Amazon region. *Centrosera schiedeanum* cv. Belalto was released in Queensland, Australia, in 1971 (Barnard, 1972). Two cultivars of *C. pascuorum*, cvs. Cavalcade and Bundey, were released in Northern Territory, Australia, in 1984 (New releases . . ., 1985). Several other species such as *C. acutifolium*, *C. brasilianum*, and *C. macrocarpum*, are regarded as highly promising in pasture evaluation experiments in tropical America.

The available literature on seed production is skewed by a predominance of reports on initial seed multiplication on experiment stations with a relative dearth of reports on commercial experience. This paper reviews the available literature on seed production, provides concepts and guidelines for the future development of seed supplies, and identifies priorities for future research.

**Reproductive Physiology**

**Control of flowering**

The control of flowering in *Centrosera* was reviewed by Ison and Hopkinson (1985). Common *C. pubescens* is a short-day plant: flowering is accelerated when natural daylength is artificially shortened. In Taiwan, plants became vegetative with increased daylength (Wang, 1961). Similar flowering dates of *C. pubescens* grown at 20° and 27° S led Bowen (1959) to conclude, “this indicates the absence of a photoperiodic effect.” However, such behavior is also compatible with a
short-day critical photoperiod close to the daylength which occurs at the autumn equinox, when daylength is not latitude-sensitive. In Bali, on March 22, Ison (1984), by dissection and microscopic examination, recorded floral initiation in this indeterminate plant; the period to first blooming occupied 23-29 days. The critical photoperiod does not appear to be extended by cool temperatures, as occurs in some varieties of *Stylosanthes guianensis* var. *guianensis* (Ison and Humphreys, 1984), because floral initiation was simultaneous at sites between 10 and 1000 m in altitude (Ison, 1984). The juvenile period, that is, before seedlings respond to inductive conditions (if present), did not exceed 108 days in Bali.

Flowering time of *C. pubescens* at different sites (Table 1) shows considerable variation within the early mid-autumn period, and is probably favored by warm temperatures following initiation (Ison and Hopkinson, 1985). Some of the variation in Table 1 may also be explained by genetic variation between races of common centro (R. J. Clements, personal communication). The synchrony of flowering within the crop is much better than in the quantitative short-day plant *Macroptilium atropurpureum*. This is evident from the duration and pattern of yield formation from sequential handpicking of the two crops in the Philippines (Javier and Mendoza, 1976). Field observation indicates that flowering is also promoted by mild water stress.

Accessions of *C. pubescens* varied 50 days in their time of first flowering at Fort Pierce (Kretschmer, 1977), where *C. schiedeanum* cv.

Table 1. Flowering time of common *Centrosema pubescens* at different sites.

<table>
<thead>
<tr>
<th>Site</th>
<th>Latitude</th>
<th>Date of first flowering</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fort Pierce, FL, USA</td>
<td>27° N</td>
<td>November 1</td>
<td>Kretschmer, 1977</td>
</tr>
<tr>
<td>Taipei, Taiwan</td>
<td>25° N</td>
<td>November 27</td>
<td>Wang, 1961</td>
</tr>
<tr>
<td>Ajuchitlán, Mexico</td>
<td>18° N</td>
<td>October 29</td>
<td>Sánchez, 1978</td>
</tr>
<tr>
<td>Tarapoto, Peru</td>
<td>7° S</td>
<td>May 6</td>
<td>Silva and López, 1985</td>
</tr>
<tr>
<td>Bali (3 sites), Indonesia</td>
<td>9° S</td>
<td>April 14-20</td>
<td>Ison, 1984</td>
</tr>
<tr>
<td>Ayr, Qld., Australia</td>
<td>20° S</td>
<td>April 4-14</td>
<td>Bowen, 1959</td>
</tr>
<tr>
<td>Itagual, SP, Brazil</td>
<td>23° S</td>
<td>May 6</td>
<td>Serpa and Dias, 1983</td>
</tr>
<tr>
<td>Ormiston, Qld., Australia</td>
<td>27° S</td>
<td>April 4-14</td>
<td>Bowen, 1959</td>
</tr>
</tbody>
</table>
Belalto flowered 10 days after common C. pubescens. *Centrosea brasiliannum* CIAT 5234 flowered 30 days before *C. pubescens* at Tarapoto, Peru. Accessions of the annual *C. pascuorum* varied by as many as 75 days in flowering time (Clements, this volume; Clements and Williams, 1980). Although *C. virginianum* lines in subtropical sites flower erratically at different times of the year, the species flowers predominantly during shortening days (Clements, 1977). Schultze-Kraft et al. (1985) report that *C. macrocarpum* shows short-day characteristics. These studies suggest both the need for controlled experiments to determine flowering control, and the availability of considerable genetic diversity in flowering time which can be used in plant improvement programs.

**Seed formation**

Santipracha (1980) studied seed formation in *C. pubescens* at the warm lowland site of Hat Yai, Thailand (7º N). Seeds were first germinable 25 days after blooming, but maximum germinability was attained about 35 days after blooming, coinciding with the attainment of maximum seed weight and seed vigor. Hard-seededness became evident at 38 days (when seed-moisture content was 37%) and increased to 85% of seeds at 45 days as they dried to 13% moisture. Early formed pods contain more seeds than later formed pods (Serpa, 1974), but seed yield is highly correlated with pod numbers.

Field observations suggest that seed formation of *C. pubescens* is adversely affected by cool temperatures or frost, and that sites selected for seed production need to be warmer than for crops of *Desmodium intortum*, *Neonotonia wightii*, or *M. atropurpureum*. In the cases of *C. acutifolium* and *C. macrocarpum*, moisture stress during seed formation is adverse.

**Management for Seed Production**

The predominant source of commercial seed of common *C. pubescens* is the rubber and oil-palm plantations in tropical lowland regions. The major suppliers are Indonesia, Sri Lanka, Philippines, and Thailand, with occasional production in Papua New Guinea and Malaysia (Big demand for centro seed, 1962). Because seeds are an opportunistic byproduct from a legume cover crop, there is little or no purposeful management for seed production. Although no data are available, seed yields and volumes appear to vary widely between years and locations.
Efforts to develop commercial seed cropping (Table 2) are confined to *C. pubescens* in north Queensland, Australia, and in the Brazilian states of São Paulo and Minas Gerais; to *C. schiedeanum* cv. Belalto in north Queensland, Australia; and to *C. pascuorum* in north Queensland and Northern Territory, Australia. Despite the lack of published, confirmatory, information, the following management strategies appear relevant to seed production:

**Selection of geographic region and specific site**

Seed crops must not be randomly located but carefully chosen (Hopkinson and Reid, 1979). Having chosen a suitable region, specific sites must have good soil drainage, light to medium soil texture, low incidence of weeds, and be suitable for mechanization.

**General agronomic practices for legume establishment**

Good agronomic practices to achieve a satisfactory base plant population and vigorous growth usually include adequate land preparation, a high seeding rate, use and appropriate placement of composite fertilizer at planting, and inoculation with rhizobia. Additional options include row planting and selective herbicide application at both preemergence and postemergence.

**Crop support system**

Seed crops of *Centrosema* spp. may be grown with or without physical support (Tables 2 and 3). A comparative study of *C. pubescens* seed crops grown with and without support showed that the use of trellises increased yield by 29% and the use of a sorghum framework increased yield by 13% (Ribeiro, 1980). Much greater yield increases have been obtained by using support systems for *C. acutifolium* and *C. brasilianum* (Table 3). Grass stakes have been found to be an acceptable alternative to more expensive trellises.

Specialist growers of common *C. pubescens* seed in northern Australia do not use a support system (Wright, 1972) because these crops are combine harvested. Verhoeven (1958) reported seed yields as high as 340-680 kg/ha. In plantation agriculture, centro is also grown without support, but, because the seed is an opportunistic byproduct, the need for support is usually not considered.
Table 2. Summary of seed yield of *Centrosemia* spp. according to crop culture and harvest method.

<table>
<thead>
<tr>
<th>Species, cultivar, or accession</th>
<th>Country and location</th>
<th>Crop support, type, and culture</th>
<th>Harvest method</th>
<th>Actual seed yield (kg/ha)</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. pubescens</em> common</td>
<td>Australia</td>
<td>Pure sward, with irrigation</td>
<td>Windrowed, then combined</td>
<td>340-680</td>
<td>Verhoeven, 1958</td>
</tr>
<tr>
<td></td>
<td>Ayr region</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Brazil</td>
<td>Sward</td>
<td>Handpicking</td>
<td>450</td>
<td>de Otero, 1961</td>
</tr>
<tr>
<td></td>
<td>(Itaguai?)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ecuador</td>
<td>Trellis support</td>
<td>Handpicking</td>
<td>408-1343</td>
<td>Farfán, 1974</td>
</tr>
<tr>
<td></td>
<td>Puerto Viejo</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Boliche</td>
<td>Trellis support</td>
<td>Handpicking</td>
<td>43-891</td>
<td>Torre, 1975</td>
</tr>
<tr>
<td></td>
<td>Mexico</td>
<td>Trellis support</td>
<td>Handpicking</td>
<td>347</td>
<td>F. Avalos, pers. comm.</td>
</tr>
<tr>
<td></td>
<td>Ajuchitlán</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Philippines</td>
<td>Pure sward</td>
<td>Handpicking, 2 passes in 10 days</td>
<td>486</td>
<td>Javier and Sasis, 1969</td>
</tr>
<tr>
<td></td>
<td>Los Baños</td>
<td>Pure sward</td>
<td>Mower cut, then machine threshed</td>
<td>436</td>
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<td></td>
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<tr>
<td></td>
<td>Peru</td>
<td>Trellis support</td>
<td>Handpicking, various passes</td>
<td>521</td>
<td>Silva and López, 1985</td>
</tr>
<tr>
<td></td>
<td>Tarapoto</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Venezuela</td>
<td>Trellis support</td>
<td>Handpicking, various passes</td>
<td>77</td>
<td>Cordero and Montes, 1977</td>
</tr>
<tr>
<td></td>
<td>Maracay</td>
<td></td>
<td></td>
<td></td>
<td></td>
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(Continued)
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<th>Species, cultivar, or accession</th>
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<th>Harvest method</th>
<th>Actual seed yield (kg/ha)</th>
<th>Sources</th>
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<tbody>
<tr>
<td><em>C. pubescens</em> common</td>
<td>Venezuela Maracay</td>
<td>Pure stand</td>
<td>Handpicking, various passes</td>
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<td></td>
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<td>Pure stand, semicommercial</td>
<td>Handpicking, various passes</td>
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<td><em>C. pubescens</em> IPEACS</td>
<td>Brazil Itagual</td>
<td>Expt. 1</td>
<td>Handpicking</td>
<td>Ribeiro, 1980</td>
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<tr>
<td></td>
<td></td>
<td>Sward</td>
<td>a. once only</td>
<td>428</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>b. various passes</td>
<td>608</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trellis support</td>
<td>a. once only</td>
<td>478</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>b. various passes</td>
<td>863</td>
<td></td>
</tr>
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<td></td>
<td>Expt. 2</td>
<td>Trellis support</td>
<td>530</td>
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<tr>
<td></td>
<td></td>
<td>Sward</td>
<td>a. once only</td>
<td>286</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>b. various passes</td>
<td>530</td>
<td></td>
</tr>
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<td></td>
<td></td>
<td>Sorghum crop</td>
<td></td>
<td>367</td>
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<td></td>
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<td></td>
<td></td>
<td>557</td>
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<td><em>C. schiedeanum</em> cv. Belalto</td>
<td>Australia Walkamin</td>
<td>Pure sward, with irrigation</td>
<td>Direct combining</td>
<td>0-350</td>
<td>J. M. Hopkinson, unpubl. data</td>
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<tr>
<td><em>Centrosema</em> hybrid CIAT 438</td>
<td>Colombia Santander de Quilichao Palmira</td>
<td>Trellis support</td>
<td>Handpicking</td>
<td>466-877</td>
<td>CIAT, 1978</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trellis support</td>
<td>Handpicking</td>
<td>90</td>
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<td></td>
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<td>1450</td>
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<td>Harvest method</td>
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<td><em>Centrocheta</em> hybrid CIAT 438</td>
<td>Peru Tarapoto</td>
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<td>Handpicking</td>
<td>340</td>
<td>Silva and López, 1985</td>
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<tr>
<td><em>C. acutifolium</em> CIAT 5277</td>
<td>Colombia Quilichao</td>
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<td>Handpicking</td>
<td>132</td>
<td>C. Wickham and J. E. Ferguson, unpubl. data</td>
</tr>
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<td></td>
<td>Carimagua Quilichao</td>
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<td>Handpicking</td>
<td>62 ± 17</td>
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<td></td>
<td>Valledupar</td>
<td>Trellis support</td>
<td>Handpicking</td>
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<td>Handpicking</td>
<td>224</td>
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<tr>
<td><em>C. brasilianum</em> CIAT 5234</td>
<td>Peru Tarapoto</td>
<td>Trellis support</td>
<td>Handpicking various passes</td>
<td>1247</td>
<td>Silva and López, 1985</td>
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<tr>
<td></td>
<td>Brazil Planaltina</td>
<td>Trellis support</td>
<td>Handpicking various passes</td>
<td>80</td>
<td>R. P. de Andrade, unpubl. data</td>
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<td>Colombia Quilichao</td>
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<td>Handpicking various passes</td>
<td>211</td>
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<td></td>
<td>Carimagua</td>
<td>Trellis support</td>
<td>Handpicking various passes</td>
<td>153</td>
<td>J. E. Ferguson, unpubl. data</td>
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<tr>
<td></td>
<td>Valledupar</td>
<td>Trellis support</td>
<td>Handpicking various passes</td>
<td>769</td>
<td>J. E. Ferguson, unpubl. data</td>
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<td>Species, cultivar, or accession</td>
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<td>Harvest method</td>
<td>Actual seed yield (kg/ha)</td>
<td>Sources</td>
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<td>-------------------------------</td>
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</tr>
<tr>
<td><em>C. brasilianum</em></td>
<td>Mexico Iguala</td>
<td>Trellis support</td>
<td>Handpicking various passes</td>
<td>1390</td>
<td>A. Peralta, pers. comm.</td>
</tr>
<tr>
<td>CIAT 5234</td>
<td>Brazil Planaltina</td>
<td>Trellis support</td>
<td>Handpicking various passes</td>
<td>271</td>
<td>R. P. de Andrade, unpubl. data</td>
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<tr>
<td>CIAT 5824</td>
<td>Planaltina</td>
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<td>Handpicking various passes</td>
<td>324</td>
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</tr>
<tr>
<td><em>C. macrocarpum</em></td>
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<td>Trellis support</td>
<td>Handpicking</td>
<td>284</td>
<td>Silva and López, 1985</td>
</tr>
<tr>
<td>CIAT 5065</td>
<td>Brazil Planaltina</td>
<td>Trellis support</td>
<td>Handpicking</td>
<td>42</td>
<td>R. P. de Andrade, unpubl. data</td>
</tr>
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<td></td>
<td>Mexico Iguala</td>
<td>Trellis support</td>
<td>Handpicking</td>
<td>505</td>
<td>A. Peralta, pers. comm.</td>
</tr>
<tr>
<td>Colombia</td>
<td>Quilichao</td>
<td>Trellis support</td>
<td>Handpicking various passes</td>
<td>253</td>
<td>J. E. Ferguson, unpubl. data</td>
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<tr>
<td>Mean of 5 accessions</td>
<td>Carimagua</td>
<td>Trellis support</td>
<td>Handpicking various passes</td>
<td>101</td>
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</tr>
<tr>
<td>Mean of 2 accessions</td>
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<td>Trellis support</td>
<td>Handpicking various passes</td>
<td>93</td>
<td>J. E. Ferguson, unpubl. data</td>
</tr>
<tr>
<td>CIAT 5713</td>
<td>Australia Katherine</td>
<td>Pure stand, with irrigation</td>
<td>Suction combining</td>
<td>1000</td>
<td>New releases . . . . , 1985</td>
</tr>
<tr>
<td></td>
<td>Walkamin</td>
<td>Pure stand</td>
<td>Direct combining</td>
<td>500</td>
<td>B. H. English, pers. comm.</td>
</tr>
<tr>
<td>Species, cultivar, or accession</td>
<td>Country and location</td>
<td>Crop support, type, and culture</td>
<td>Harvest method</td>
<td>Actual seed yield (kg/ha)</td>
<td>Sources</td>
</tr>
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<td>--------------------------------</td>
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<td>---------</td>
</tr>
<tr>
<td></td>
<td>N.T., various sites</td>
<td>Nonirrigated, pure stand</td>
<td>Manual harvest</td>
<td>250 (approx.)</td>
<td>Stockwell et al., 1986</td>
</tr>
<tr>
<td></td>
<td>Walkamin</td>
<td>Pure stand</td>
<td>Direct combining</td>
<td>450</td>
<td>B. H. English, pers. comm.</td>
</tr>
</tbody>
</table>

**COMMERCIAL CONDITIONS**

<p>| <em>C. pubescens</em> common          | Australia Ingham    | Mixed pasture (centro and molasses) | a. Windrowed, then combined  | 146 (average) | Gude, 1959 |
|                                |                     |                                | b. Direct heading above 8&quot;   |               |           |
|                                | North Queensland    | Pure stand and mixed pastures  | Combined                    | 140-180       | Teitzel and Burt, 1976 |
| Mareeba                        | Pure stand (3 consec. years) | Direct combining            | 109 1st year 355 2nd year 68 3rd year | J. W. Wright, pers. comm. |</p>
<table>
<thead>
<tr>
<th>Species, cultivar, or accession</th>
<th>Country and location</th>
<th>Crop support, type, and culture</th>
<th>Harves method</th>
<th>Actual seed yield (kg/ha)</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. pubescens</em> common</td>
<td>Brazil</td>
<td>Pure stand</td>
<td>Direct combining</td>
<td>80-150</td>
<td>R. P. de Andrade, unpubl. data</td>
</tr>
<tr>
<td></td>
<td>São Paulo (state)</td>
<td>Pure stand</td>
<td>Direct combining</td>
<td>300</td>
<td>R. P. de Andrade, unpubl. data</td>
</tr>
<tr>
<td></td>
<td>Janaúba</td>
<td>Trellis support</td>
<td>Handpicking, various passes</td>
<td>200-400</td>
<td>Hare and Waranyuwat, 1980</td>
</tr>
<tr>
<td></td>
<td>Thailand</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Centrosema</em> hybrid CIAT 438</td>
<td>Peru</td>
<td>Trellis support</td>
<td>Handpicking, various passes</td>
<td>75-98</td>
<td>Pérez et al., 1987</td>
</tr>
<tr>
<td></td>
<td>Tarapoto</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. schiedeanum</em> cv. Belalto</td>
<td>Australia</td>
<td>Pure stand</td>
<td>Direct combining</td>
<td>107</td>
<td>J. M. Hopkinson, unpubl. data</td>
</tr>
<tr>
<td></td>
<td>Cooktown</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3. The effect of different forms of support on seed yield of *Centrosema acutifolium* CIAT 5277 and *C. brasilianum* CIAT 5234 at Santander de Quilichao, Colombia, 1986-1987.

<table>
<thead>
<tr>
<th>Form of support</th>
<th>Seed yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>C. acutifolium</em> CIAT 5277</td>
</tr>
<tr>
<td>Unsupported sward</td>
<td>95</td>
</tr>
<tr>
<td>Trellis 1.8 m high</td>
<td>401</td>
</tr>
<tr>
<td>2.5 m high</td>
<td>313</td>
</tr>
<tr>
<td>Stakes of king grass</td>
<td>424</td>
</tr>
<tr>
<td>(<em>Pennisetum</em> hybrid)</td>
<td></td>
</tr>
</tbody>
</table>

SOURCE: J. E. Ferguson, unpublished data.

In other countries, *Centrosema* spp. may be provided with complete or partial physical support. The objectives of support are usually to facilitate handpicking the pods and to increase flower density and/or pod set. Effective support may result in higher seed yields, especially where the climatic regions are only marginally favorable. Most experiment stations that multiply seed of *Centrosema* spp. on a small scale use trellis support (Table 2).

Physical support may be provided by systematically constructed trellises or fence lines; natural vegetation, including weeds or residues; grass component in mixed pasture (Gude, 1959); another legume component in a mixed seed crop (J. M. Hopkinson, unpublished data); perennial grass stem stakes (Table 3); or associated annual crops such as maize (Verhoeven, 1958), *Crotalaria juncea*, pigeonpea, sorghum, or rice.

**Integrated weed control**

Broad-leaved weeds can be a problem in first-year stands, while invasion by grasses and volunteer legumes can increase with time. The actual weed species, economic effects, and control thresholds are specific to location and cultivar. Unless a full range of weed control practices is applied accordingly, competition within seed areas and/or contamination of seed lots by weed species will reduce seed yields, increase seed costs, reduce stand life, and reduce seed supply. Useful selective herbicides are 2,4-D (Bailey, 1969), neburon (Riepma, 1965), alachlor, bentazon, dinoseb, fluazifop-butyl, metolachlor, pendimethalin, and trifluralin.
Insect control

Insects such as lepidopterous larvae and thrips, can damage buds, flowers, and developing pods. Depending on the value of the seed crop, insecticides such as malathion, monocrotophos, and aldicarb can be applied. Seeds can be protected during storage by products such as carbomyl or malathion.

Alternative use

Seed crop areas may also provide limited grazing and hay-making opportunities. The implications, both agronomic and economic, again will be specific to cultivar and location, the required practices being defined by local research or by trial and error.

Seed Harvesting

There are four basic strategies for harvesting seed. These are handpicking and threshing; direct combining; crop desiccation, followed by combining and pickup; and suction-harvester follow-up.

Handpicking and threshing

This refers to the manual collection of mature seed pods, followed by threshing and separation of seeds. Hand harvesting is characterized by high rates of seed recovery and high seed quality, because mature pods may be selected. The availability, cost, and management of manual labor is an important consideration. This is highly variable, ranging from favorable and traditional to impossible and uneconomic. This method is used when the crop is provided with physical support (Table 2), in plantation agriculture, and in small-scale onfarm production by graziers (Goodchild, 1955). Pickers, often family groups or contractors, move or pass through those areas having a reasonable density of pods, collecting the mature pods as they go. These are then delivered to a central area for threshing and drying. Because mature pods dehisce when dry, the pods are dried in the sun to promote shattering. Seed drying occurs at the same time. Additional threshing can be applied by manual beating or vehicular movement. Seed is then swept up, winnowed in the breeze, dried completely, and packaged.
Repeated handpicking usually gives greater yields than single-pass operations (Table 2). For example, additional passes through the crop resulted in yield increases of 42% and 85% in unsupported seed crops, and 50% and 80% in supported crops (Ribeiro, 1980). C. Wickham and J. E. Ferguson (unpublished data) obtained an increase of 70% in the case of a crop with trellis support.

**Direct combining**

The conventional grain combine has been used directly in common *C. pubescens* seed crops (Gude, 1959; Wright, 1972). Recent combine models have the advantages of high power and greater capacity to cope with the mature-crop structure which requires the combine to cut and treat the total mass of stems, leaves, and pods. The judgment of an experienced combine operator is essential to the success of this method, and sites must be suitable for the safe operation of the combine.

**Crop desiccation followed by combining and pickup**

This method has advantages over direct combining, depending on crop condition, climatic conditions at harvest, uniformity of seed maturation, and combine capacity.

There are two approaches to crop desiccation: the first is mechanical mowing, followed by natural drying *in situ* or in windrows for 4-7 days, depending on weather conditions (Gude, 1959; Javier and Sasis, 1969; Verhoeven, 1958). Verhoeven (1958) emphasized the need for covering the power takeoff drive mechanism, not using a swathe board, and cutting with overlap. The second approach is chemical desiccation, using paraquat, and allowing about 2-5 days for subsequent drying in windrows (Wright, 1972). A conventional crop combine with a pickup attachment can then efficiently collect, thresh, and separate the seeds, once the crop mass is sufficiently dry.

**Suction-harvester follow-up**

A suction harvester is most relevant in the cases of seed crops with high seed yield, high-value seeds, and where machines are readily available. An alternative harvest method is first applied (e.g., direct combining or crop desiccation followed by combining and pickup) in order to capture the standing seed yield, to reduce the crop mass, and expose the soil surface to the suction harvester. There may also be a
need for additional mowing, raking, and, possibly hay baling. Suction harvesters may be tractor drawn and may or may not have a seed-separation capability. This method is usually associated with an increased task of conditioning the seed to remove soil particles of similar size to the seed. Basic seed multiplication areas of *C. pascuorum* cv. Cavalcade have been suction harvested (New releases . . ., 1985).

**Seed Conditioning**

The relatively large seed size of *Centrosema* species (21,000-44,000 seeds/kg), combined with their rounded, oblong shape, favors the use of conventional seed-conditioning equipment. The basic seed conditioner is an air-screen cleaner which separates seed on the basis of size and shape. If necessary, additional equipment such as a gravity separator or indent cylinder, can be used to achieve further separation based on differences in specific gravity or length, respectively, between crop seeds and other particles. Consequently, it is relatively easy to achieve seed lots with high pure-seed content (more than 95%) and low content (less than 4%) of inert matter and weed seeds.

With small seed lots in the field, natural wind-winnowing and the use of a small hand-screen can effectively remove dust and most foreign matter.

**Physiological Aspects of Seed Quality**

Maximum germination, at 20-30 °C, following treatments to reduce hard-seededness, is normally about 80%. Mature seeds of *C. pubescens* contain a significant proportion (33%-50%) of hard seeds, that is, seeds which do not imbibe water (Bass, 1984; Cabrales and Bernal, 1983). Hot-water treatment (80 °C for 20 minutes) is reported to be more effective than acid treatment (5 minutes in cool H₂SO₄) in reducing hard-seededness (Cabrales and Bernal, 1983). Sulfuric acid treatment is more efficient than dry heat (65 °C for 4 hours), abrasion, and hot water (75 °C for 10 minutes) (de Almeida et al., 1979). Win et al. (1975a) showed that germination was increased by acid treatment that lasted for as long as 20 minutes.

Bass (1984) reported that, in most storage conditions studied over a 16-year period, hard-seededness tended to increase by about 50%, while
significant decreases occurred at conditions of -12 °C at 70% r.h. and 32 °C at 50% r.h. In storage conditions of -12 °C and 70% r.h., germination could be maintained for 16 years. Win et al. (1975b) reported that germination was maintained during short-term (6 months) storage at 20 °C and 40% r. h.

Development of Seed Supplies for Pastures

Over the last 40 years, common centro has been recognized as having pasture potential, but seed was supplied only as an opportunistic byproduct of plantation agriculture. Attempts at seed cropping by specialist growers in both northern Australia and central Brazil have not been successful, mainly because of competition from cheap imported seed, but also because of agronomic problems such as poor synchrony of flowering, weed invasion, and low seed yields. *Centrosema schiedeanum* cv. Belalto was released in Queensland, Australia, in 1971 (Barnard, 1972), but a commercial seed supply has not evolved because of competition from cheap imported *C. pubescens* seed and insufficient demand from graziers. Two cultivars of *C. pascoorum* were released in the Northern Territory, Australia, in 1984, and their commercial seed supply is only just beginning.

While the prospects for commercial seed production of some cultivars appear favorable, the general case for *Centrosema* spp. is difficult. Certain prerequisites have to be met for progressive achievement of seed supplies at prices attractive to graziers. These prerequisites are:

**Emphasis on seed-yield potential as a requirement when releasing new cultivars**

New cultivars must have a reasonable seed-yield potential, as demonstrated by proven ability to flower, and set high seed yields under semicommercial conditions. An example of a progress report of a seed-yield profile for *C. acutifolium* CIAT 5277 is presented in Table 4. (Seed-yield data for various *Centrosema* species, from both experimental and commercial conditions, are presented in Table 2.) It must be noted that yields under experimental conditions are artificially high because of small areas and uneconomic management and harvesting practices. However, they provide an indication of potential seed yield. Under commercial conditions, seed yields are governed by many factors and are highly variable. Although, as yet unconfirmed, 236
Seed production of Centrosema species

Table 4. An evolving profile of seed yield (kg/ha) of Centrosema acutifolium CIAT 5277 at four locations in Colombia.

<table>
<thead>
<tr>
<th>Year</th>
<th>Quilichao 40°N</th>
<th>Carimagua 30°N</th>
<th>El Viso 30°N</th>
<th>Valledupar 10°N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n^b Mean</td>
<td>n Mean</td>
<td>n Mean</td>
<td>n Mean</td>
</tr>
<tr>
<td>1983-84</td>
<td>1 335</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1984-85</td>
<td>5 68</td>
<td>2 163</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1985-86</td>
<td>6 217</td>
<td>4 68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1986-87</td>
<td>7 117</td>
<td>6 24</td>
<td>1 150</td>
<td>1 238</td>
</tr>
<tr>
<td>Average</td>
<td>147 62</td>
<td></td>
<td>150</td>
<td>238</td>
</tr>
</tbody>
</table>

a. Data from seed-multiplication areas (0.01-2.0 ha) with trellis support and handpicking with a varying number of passes.
b. Number of independent observations (that is, data from different seed-multiplication areas).

SOURCE: J. E. Ferguson, unpublished data.

Seed crops of perennial species offer higher seed yields during the first two years. The seed-yield data of different Centrosema species are as follows:

Common *C. pubescens* and *Centrosema* hybrid CIAT 438 have a potential seed yield of 800-1000 kg/ha. Commercial yields from manual harvesting of crops supported by trellises range from 200-400 kg/ha in Thailand to 75-98 kg/ha in Peru. Combine harvesting of commercial sward crops in Queensland, Australia, and Brazil has yielded 150-300 kg/ha. Thus, commercial yields are only 20%-40% of potential yields. Mechanical-harvesting efficiency can be improved by a combination of high-powered combines and suction harvesting to raise yield levels to about 500 kg/ha.

*Centrosema pascuorum*, an annual species, has a high potential seed yield, with more than 1000 kg/ha. Yields of 500-900 kg/ha by direct combining are reported from northern Australia and, in one case, of 1000 kg/ha by suction harvesting.

*Centrosema brasilianum* flowers early and prolifically, and has a high potential seed yield over a range of climatic conditions, with reports as high as 1200-1400 kg/ha. Hand harvesting frequently provides seed yields of 200-500 kg/ha. Mechanical harvesting ought to be feasible but has not yet been attempted.

*Centrosema acutifolium* appears sensitive to short days and flowering is somewhat erratic, resulting in highly variable seed yields. Potential
seed yield is about 700 kg/ha. At low-latitude locations in Colombia, seed yields appear moderate, that is, 150-200 kg/ha.

*Centrosema macrocarpum* also appears sensitive to short days and may have a relatively long juvenile period. This species is regarded as cross pollinating (Escobar and Schultze-Kraft, this volume). Potential seed yield is about 500 kg/ha. The few observations available from Colombia indicate that 100-250 kg/ha can be obtained by hand harvesting.

**Effective release and promotion of new cultivars**

New cultivars should be released formally. The release process (Ferguson, 1985) should include the multiplication of a minimal volume of basic seed, selective distribution to various seed growers, a realistic analysis of constraints to future adoption, and organized technical promotion efforts.

**High levels of demand from graziers for seeds**

Graziers must be made aware of the potential of new cultivars. This will require onfarm demonstration trials, promotion programs, and economic data. Graziers must be convinced of a new cultivar’s value so to create enough demand for seed to encourage investment and production by specialized seed growers.

**Support from public institutions after release**

Because seed of common centro is derived as a low-cost byproduct from plantations, any new cultivar of *C. pubescens* (or similar *Centrosema* species) will have to compete with an existing source of relatively cheap seed. Examples of failure to establish a commercial seed supply because of such competition are those of *C. schiedeanum cv.* Belalto in Australia and common centro in Brazil. Thus, seed supply of new cultivars will evolve spontaneously only under certain circumstances. Most new cultivars will require some public sector support after release in order to develop a seed supply.

Indirect support should come from onfarm demonstrations and pasture-promotion programs. Direct support could involve seed-production research; seed multiplication; technical assistance to new seed growers; initiatives to stimulate commercial seed production, for
example, seed-production contracts with novice seed growers, and seed-sharing agreements; programs ensuring quality, including seed-certification programs if necessary; and import controls to protect new cultivars from cheap and/or diseased seed of low-performance cultivars.

Research Priorities

Definition of flowering control mechanisms

Research on common centro indicates that flower induction and synchrony are influenced by the combined effects of decreasing photoperiod, increasing moisture stress, and, possibly, decreasing temperature. Studies on other species are needed, including research in controlled environments and inferential (or deductive) research from field observations at various locations.

Identification of favored geographic regions for commercial seed production

Seed crops must be located in suitable climatic and edaphic regions which may be separated from areas of use in pastures. These should be identified. Crop performance should be studied in alternative regions, and recommendations made on the basis of a constantly updated analysis of regional adaptation in terms of such characteristics as seed yield and disease incidence as was done for C. acutifolium in Colombia (Table 4). Within suitable geographic regions, seed-crop management practices should be studied. Crop-support practices which can compensate for climatic inadequacies should also be investigated.

Seed crop management and harvesting

Cropping systems should yield high quantities of seed at low cost. Where hand harvesting is feasible, studies are needed on intercropping with perennial tree crops and using stem stakes of forage grasses or broken branches of local trees. Where combining is feasible, intercropping with annual crops should be studied. For example, in Brazil, the seed of Calopogonium mucunoides was successfully produced in association with rice (Bendito calopogônio!, 1986; K. Matsumoto, personal communication; A. H. Zimmer, personal communication). Opportunistic combining of Centrosema seeds from a grass-legume pasture is another option deserving study (Gude, 1959).
The use of a wider range of herbicides would help achieve integrated weed control. Individual species may react differently to particular herbicides, and this requires further research. The timing of clearing cuts or withdrawal of grazing animals needs defining in relation to flowering and seed-maturity times. Research to provide fertilizer recommendations is needed, and the comparative economics of alternative harvest methods in different cropping systems should be studied.

Seed technology

As new cultivars are developed, their seed physiology needs to be studied, with emphasis on germination, hard-seededness (including methods of reducing hard-seededness), and longevity of seed in storage.

References


Seed production of Centrosema species


Seed production of Centrosema species


Verhoeven, G. 1958. Tropical legume seed can be harvested commercially. Queensl. Agric. J. 84:77-82.


Chapter 9

GENETICS AND BREEDING OF *CENTROSEMA*

J. W. Miles, R. J. Clements, B. Grof, and A. Serpa* 

Abstract

At least two basic chromosome numbers exist in *Centrosema*: $n = (C.\ virginianum$ and $C.\ arenicola)$ and $n = 22$ (and perhaps also $n = 20$) for other species. A rigorous evaluation of reproductive behavior in *Centrosema* spp. is lacking. Extensive outcrossing appears to occur in some species (for example, *C. macrocarpum*), while most species are highly, but not exclusively, self-pollinating. Artificial hybridization within species of *Centrosema* is usually easy. Some interspecific crosses have been successful.

Information on genetics of agronomic traits is limited. No single-gene Mendelian trait is known in any species. Wide genetic variation is documented in several *Centrosema* spp., and substantial progress in breeding projects has been demonstrated. Breeding objectives have included forage yield, seed yield, and stoloniferous growth habit. Conventional pedigree-breeding methods have been the most commonly used. The efficacy of other methods such as natural selection under grazing or recurrent population improvement, ought to be more fully assessed. *Centrosema* breeding programs have been conducted in Brazil, Colombia, and Australia. Only one of these has resulted in the release of a commercial cultivar.

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Introduction

*Centrosea* has probably received more attention from plant breeders than any other tropical forage legume genus. This reflects the commercial importance of the genus (particularly *C. pubescens*), and the deficiencies of commercial cultivars selected directly from natural germplasm.

In this paper, we review current biological knowledge relevant to the design of *Centrosea* breeding programs. The objectives, methods, and results of ongoing or concluded projects are discussed. We seek to highlight areas where additional information is necessary to improve the effectiveness and efficiency of future *Centrosea* breeding projects.

Cytology and Chromosome Counts

Chromosome numbers of 16 *Centrosea* species have been reported (Table 1). There are serious discrepancies in the record. At least two factors may contribute to this lack of agreement. One is that *Centrosea* chromosomes are small and difficult to count. The second is that the taxonomy of *Centrosea* has been confused, and there may have been incorrect identification of species in some cases. For example, the material seen by Fritsch (1972) may have been *C. pubescens* rather than *C. virginianum* as was reported.

Two camera lucida drawings of *Centrosea* chromosomes have been published. The first of these (Turner and Irwin, 1961) showed \( n = 11 \) for *C. coriaceum*, while the second (Lewis et al., 1962) showed \( 2n = 18 \) for *C. virginianum*. J. B. Hacker's photographs and camera lucida drawings of the chromosomes of *C. grazielae*, *C. pubescens*, and *C. angustifolium* (all \( 2n = 22 \)) and of *C. virginianum* \( (n = 9) \) (Figure 1) substantiate his extensive data (Table 1).

The other extensive data set is that of Hutton (1985) who reported that *C. pubescens* (3 accessions), *C. macrocarpum* (6 accessions), *C. schiedeanum* (1 accession), and *C. acutifolium* (3 accessions) all had \( 2n = 20 \) somatic chromosomes and normal pairing at meiosis with the formation of 10 bivalents. These counts disagree with those of Hacker but agree with the earlier reports for *C. pubescens* by Frahm-Leliveld (1953 and 1957), as well as with an unpublished report by L. Nascimento from the Universidade Federal Rural do Rio de Janeiro, 246
Table 1. Summary of published chromosome counts for *Centrosema* spp.

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of accessions</th>
<th>Chromosome number (2n)</th>
<th>Country of origin of material examined</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. acutifolium</em></td>
<td>3</td>
<td>20</td>
<td>Colombia, Brazil</td>
<td>Hutton, 1985</td>
</tr>
<tr>
<td><em>C. angustifolium</em></td>
<td>1</td>
<td>22</td>
<td>Brazil</td>
<td>Hacker cited in Clements et al., 1983</td>
</tr>
<tr>
<td><em>C. arenicola</em></td>
<td>1</td>
<td>18</td>
<td>USA</td>
<td>J. B. Hacker, unpublished data</td>
</tr>
<tr>
<td><em>C. bracteosum</em></td>
<td>1</td>
<td>20</td>
<td>Brazil</td>
<td>Bandel, 1964</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>20</td>
<td>Brazil</td>
<td>Coleman and de Menezes, 1980</td>
</tr>
<tr>
<td><em>C. brasiliannum</em></td>
<td>1</td>
<td>20</td>
<td>Brazil</td>
<td>Coleman and de Menezes, 1980</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>22</td>
<td>Brazil</td>
<td>Hacker cited in Clements et al., 1983</td>
</tr>
<tr>
<td><em>C. coriaceum</em></td>
<td>1</td>
<td>22</td>
<td>Brazil</td>
<td>Turner and Irwin, 1961</td>
</tr>
<tr>
<td><em>C. grandiflorum</em></td>
<td>2</td>
<td>22</td>
<td>Brazil</td>
<td>Hacker cited in Clements et al., 1983</td>
</tr>
<tr>
<td><em>C. grazielae</em></td>
<td>3</td>
<td>22</td>
<td>Brazil</td>
<td>Hacker cited in Clements et al., 1983</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>1</td>
<td>22</td>
<td>Colombia</td>
<td>Hacker cited in Clements et al., 1983</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>20</td>
<td>Colombia</td>
<td>Hutton, 1985</td>
</tr>
<tr>
<td><em>C. pascuorum</em></td>
<td>6</td>
<td>22</td>
<td>Brazil, Ecuador</td>
<td>Hacker cited in Clements et al., 1983</td>
</tr>
<tr>
<td><em>C. plumieri</em></td>
<td>1</td>
<td>20</td>
<td>Côte d’Ivoire</td>
<td>Frahm-Leliveld, 1957</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>22</td>
<td>Dominican Rep., Fiji</td>
<td>Hacker cited in Clements et al., 1983</td>
</tr>
<tr>
<td><em>C. pubescens</em></td>
<td>2</td>
<td>20</td>
<td>Indonesia</td>
<td>Frahm-Leliveld, 1953</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>20</td>
<td>Côte d’Ivoire</td>
<td>Frahm-Leliveld, 1957</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>22</td>
<td>Brazil, Mexico, Venezuela, Guatemala, Guyana</td>
<td>Hacker cited in Clements et al., 1983</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>20</td>
<td>Colombia, Venezuela</td>
<td>Hutton, 1985</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>20</td>
<td>Brazil</td>
<td>L. Nascimento, unpublished data</td>
</tr>
<tr>
<td><em>C. sagittatum</em></td>
<td>3</td>
<td>22</td>
<td>Brazil, Argentina</td>
<td>Hacker cited in Clements et al., 1983</td>
</tr>
<tr>
<td><em>C. schiedeanum</em></td>
<td>1</td>
<td>22</td>
<td>Costa Rica</td>
<td>Hacker cited in Clements et al., 1983</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>20</td>
<td>Colombia</td>
<td>Hutton, 1985</td>
</tr>
<tr>
<td><em>C. schottii</em></td>
<td>3</td>
<td>22</td>
<td>Colombia, Mexico</td>
<td>Hacker cited in Clements et al., 1983</td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>2</td>
<td>18</td>
<td>USA</td>
<td>Lewis et al., 1962</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>22</td>
<td>Cuba</td>
<td>Fritsch, 1972</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>18</td>
<td>Brazil, Mexico, Venezuela, Honduras, Bolivia, Paraguay</td>
<td>Hacker cited in Clements et al., 1983</td>
</tr>
</tbody>
</table>

---

a. Material previously identified as *C. sp. aff. acutifolium*.

b. Original source unknown.

c. Material previously identified as *C. sp. aff. pubescens*. 
Figure 1. Chromosomes in *Centrosema* spp. (unpublished photographs by J. B. Hacker).
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Brazil. Counts of $2n = 20$ for some other *Centrosema* species have also been reported (Table 1).

It is difficult to resolve these differences. There appear to be at least two basic chromosome numbers in the genus. One group of species (*C. virginianum* and *C. arenicola*) possesses 18 somatic chromosomes (if Fritsch's count of $2n = 22$ is reassigned to *C. pubescens*). The second group has 22 chromosomes as documented by J. B. Hacker, and perhaps also 20. Photographs or drawings are needed to substantiate the $2n = 20$ counts.

Reliable chromosome counts would help resolve some doubtful points of taxonomic classification within the genus. They would also aid in the prediction of interspecific cross-compatibility.

Reproductive Behavior

Knowledge of reproductive behavior is relevant to the design of efficient plant-breeding programs. Unfortunately, the published record does not contain a single measure of outcrossing rate in any *Centrosema* species. Most species are assumed to be self-pollinated.

Hutton (1960) provided indirect evidence of predominant self-pollination in “common” *C. pubescens*. By examining well-developed, but unopened, flower buds collected in the early morning, he showed that anthesis had already occurred: pollen was found on the stigma and there was pollen-tube growth. Hutton and others have observed little or no phenotypic variation within commercial lines of common centro.

Battisin (1983) also observed cleistogamous pod development from *C. pubescens* and *C. pascuorum* flower buds that never opened. She noted, however, that this does not preclude the existence of some degree of outcrossing as most flowers do open normally. She provided other evidence of self-fertility in *C. pascuorum* and *C. vexillatum*: flowers of both species set seeds normally when enclosed in cellophane bags. Additional evidence of self-pollination in *C. pascuorum* was the total absence of insect visitation to *C. pascuorum* flowers, whereas flowers of *C. pubescens*, *C. brasilianum*, *C. vexillatum*, and *C. virginianum* were frequently visited by bumblebees (*Bombus* spp.).

Accessions of several *Centrosema* spp., however, apparently do not set seed if there is no mechanical manipulation of the flower to effect transfer of pollen from anthers to stigma. Greenhouse-grown plants of
C. macrocarpum, for example, fail entirely to set seed (Escobar Berón et al., 1985). However, self-sterility is not involved because self-fertilization from artificial pollination is readily achieved (Escobar Berón et al., 1985).

Insect visitation to flowers of most Centrosema spp., for example, C. virginianum (Buswell, 1919), provides a mechanism for pollen transfer. Escobar Berón et al. (1985) found that marked pollen of C. macrocarpum was readily transported by insects. Evidence of some natural outcrossing is provided by the observation of phenotypic variability within germplasm accessions produced from field-grown seed (Penteado, 1986 and n.d., for C. acutifolium; Schultze-Kraft and Belalcázar, 1988, for C. brasiliánum; R. Schultze-Kraft, personal communication, for C. macrocarpum).

It is highly desirable to have reliable estimates of outcrossing rate for all agronomically important Centrosema spp., as well as estimates of the degree to which outcrossing rate varies with genotype and environmental conditions. Obtaining such estimates requires reliable genetic markers which have not yet been identified.

Hybridization

A fundamental step in any plant-breeding program is the creation of novel genotypes through the recombination of genes from distinct individuals. Artificial hybridization is readily achieved in Centrosema. The large flowers are easily manipulated. Grof (1970) describes pollination procedures in detail. The hermaphroditic flowers are emasculated in the well-developed bud stage in the afternoon and pollinated either immediately or (preferably) in the following morning. High relative humidity is needed for successful pollination (Grof, 1970; Hutton, 1985). Certain genotypes are more difficult to hybridize than others. Crosses that are unsuccessful in one direction can often be achieved easily in the other (Grof, 1970; Hutton, 1985).

Hutton (1985) and R. J. Clements (unpublished data summarizing 1326 intraspecific crosses) obtained about 25%-30% success in artificial pollination in compatible Centrosema crosses. This is not much less than the 39.4% set reported by Serpa and Dias (1983) for open-pollinated C. pubescens flowers on field-grown plants. Clements (1977) reports an average pod set of only 20% for open-pollinated, field-grown C. virginianum plants at peak flowering. Pod set in the field and success
rate for artificial pollination may vary greatly during the year (Clements, 1977; Serpa and Dias, 1983) and by genotype (Clements, 1977).

The Available Gene Pool

Cross-compatibility among individuals defines the set of genotypes among which genes can be recombined, that is, the gene pool available to a breeding program. Normally, the available gene pool coincides more or less with the limits of the recognized species. In *Centrosera*, some gene pools comprise more than a single recognized taxonomic species, making a great range of genetic variability potentially available to the breeder. Only in *C. virginianum* has sterility been reported for intraspecific hybrids (Clements, 1983b). Successful interspecific hybrid combinations are summarized in Table 2.

<table>
<thead>
<tr>
<th>Female parent</th>
<th>Male parent</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. pubescens</em> x <em>C. macrocarpum</em></td>
<td>B. Grof, unpublished data Hutton, 1985</td>
<td></td>
</tr>
<tr>
<td><em>C. pubescens</em> x <em>C. acutifolium</em></td>
<td>Grof, 1970 Hutton, 1985 Serpa, 1974 and 1977</td>
<td></td>
</tr>
<tr>
<td><em>C. acutifolium</em> x <em>C. pubescens</em></td>
<td>M. L. Escandón and J. M. Miles, unpublished data&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td><em>C. pubescens</em> x <em>C. schiedeanum</em></td>
<td>Hutton, 1985</td>
<td></td>
</tr>
<tr>
<td><em>C. schiedeanum</em> x <em>C. pubescens</em></td>
<td>R. J. Clements, unpublished data B. Grof, unpublished data</td>
<td></td>
</tr>
<tr>
<td><em>C. schiedeanum</em> x <em>C. macrocarpum</em></td>
<td>R. J. Clements, unpublished data&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td><em>C. grandiflorum</em> x <em>C. macrocarpum</em></td>
<td>R. J. Clements, unpublished data&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td><em>C. pubescens</em> x <em>C. grandiflorum</em></td>
<td>R. J. Clements, unpublished data&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td><em>C. acutifolium</em> x <em>C. schiedeanum</em></td>
<td>M. L. Escandón and J. W. Miles, unpublished data&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td><em>C. brasiliannum</em> x <em>C. “tetragonolobum”</em></td>
<td>M. L. Escandón and J. W. Miles, unpublished data&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Preliminary: identity of putative F<sub>1</sub>s not confirmed.
<sup>b</sup> F<sub>1</sub> fertility not known.
Grof (1970) and Serpa (1974 and 1977) reported successful interspecific hybridization, using parent material identified as C. pubescens, C. brasiliánum, and C. virginianum. The accession Q 8216, identified as C. brasilíánum (Grof, 1970), was subsequently found to be a common form of C. pubescens. The accession IRI 1534 (syn. Q 8998), identified as C. virginianum (Grof, 1970), is a most unusual plant. It has white flowers, a red-green calyx with greatly reduced calyx teeth, pale non-speckled seeds, a strongly stoloniferous growth habit, and dark shiny leaflets with acute apices (R. J. Clements, unpublished data). It is closest in form to C. acutifolium, but is a poor seed producer and may perhaps be an interspecific hybrid with some C. pubescens ancestry. It was collected in 1962 at Araraquara, São Paulo state, Brazil, but in a recent visit to the collection site, R. Schultz-Kraft (personal communication) was not able to find it again. Until a more definite identification is made, IRI 1534 is considered to be an unusual form of C. acutifolium, and the hybrids reported by Grof and Serpa involving IRI 1534 as a parent are considered to be C. pubescens x C. acutifolium.

Hutton (1983 and 1985) used C. macrocarpum, C. acutifolium, and C. schiedeanum as males in crosses to C. pubescens. Several accessions of each species were used in this series of crosses. The progeny were fully fertile in the F₁, F₂, and F₃ generations. B. Grof (unpublished data) has also produced hybrids between C. schiedeanum cv. Belalto and C. pubescens, between C. pubescens and C. macrocarpum, and additional hybrids between C. pubescens and C. acutifolium. M. L. Escándon and J. W. Miles (unpublished data) have successfully used C. acutifolium as a female parent in crosses with C. pubescens and have crossed C. acutifolium with C. schiedeanum.

R. J. Clements (unpublished data) has crossed C. pubescens CPI 93039 with C. grandiflorum CPI 78358. The hybrid appears sterile.

Thus, it appears that, from a purely plant-breeding point of view, C. pubescens, C. acutifolium, C. macrocarpum, C. schiedeanum, and perhaps C. grandiflorum can be considered a single, fully intercompatible gene pool. R. J. Clements (unpublished data), from 332 attempted interspecific crosses, found no other successful hybridization than within the previously mentioned group of species close to C. pubescens. M. L. Escándon and J. W. Miles (unpublished data) have attempted more than 1200 interspecific crosses. Apart from crosses within the same C. pubescens group, the only successful crosses were C.
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*brasilianum* x *C. "tetragonolobum"* and (perhaps) *C. brasilianum* x *C. angustifolium*.

A clear delineation of the gene pools readily accessible to a *Centrosema* breeding project is desirable. A project with this aim has recently begun at CIAT. Aside from their practical value, results of this work will help solve taxonomic questions.

**Genetics, Heritability, and Genotype-Environment Interactions**

Plant breeding is based on genetic differences among individuals within gene pools. Breeding projects with *Centrosema* have been designed to generate new cultivars rather than to generate basic genetic information. However, any breeding project provides some information on the inheritance of plant characters.

There is no report of a phenotypic character inherited in a simple Mendelian fashion in any *Centrosema* species. There is, however, ample evidence of intraspecific genetic variation for quantitative traits of agronomic significance such as dry-matter yield, earliness to flower, seed yield, seed-yield components, disease reaction, seed size, hardseededness, and *Rhizobium* specificity (Clements, 1977, 1983a, and 1983b; Clements et al., 1984; Clements and Williams, 1980; Franco et al., 1973; Kretschmer, 1977; Mogrovejo J., 1981; Monteiro and Martins, 1983; Serpa, 1976; Serpa and da Silva, 1984; Serpa and De-Polli, 1975; Schultze-Kraft, 1986; Schultze-Kraft and Belalcázar, 1988; Schultze-Kraft et al., 1987; Schultze-Kraft and Keller-Grein, 1985).

Commercial seed lots of common *C. pubescens* are genetically variable. Bowen and Kennedy (1961) found lines within common centro with heritable differences in their reaction to particular *Rhizobium* strains. Serpa (1966) found large differences in germination percentage and rate among lines selected from the Brazilian commercial cv. Deodoro. Serpa and Cunha Filho (1970) detected differences in taproot length and nodule number among sister lines of *C. pubescens* after three generations of selfing and selection for vigor and high seed yield in lines derived directly from cv. Deodoro without artificial hybridization. Reaction to artificial inoculation with anthracnose (*Colletotrichum* sp.) has also been shown to differ among lines derived from cv. Deodoro (Serpa et al., 1977). In none of these examples has the genetic nature of the variation within *C. pubescens* populations been investigated.
Clements (1983b) characterized the genetic variation for herbage yield in *C. virginianum* through the analysis of two separate six-parent diallel crosses in the F₁ and F₂ generations. One diallel set was made from a random set of accessions and the second diallel from accessions selected for herbage and seed yield. There was more genetic variation among the unselected than among the selected parents. Most variation in the unselected set was attributable to general combining-ability effects, and no important effect of interaction between genotype and environment (either site or year) was detected. The diallel formed with the selected set of parents gave contrasting results: less total genetic variation, an important specific combining-ability effect (indicating a greater proportion of nonadditive genetic variance), and a large genotype-environment effect. Clements pointed out that these results agree with a common trend in quantitative genetic analyses, namely that selection diminishes additive genetic variance and decreases the consistency of genotype performance across environments. That the contrasting result stemmed from selection for yield and not from any peculiarity in the selected accessions is suggested by the fact that 95% of the total genetic variation for cotyledon height (a nonselected attribute) resulted from additive genetic effects (Clements and Ludlow, 1977).

Both Grof (1970, for *C. pubescens* and *C. pubescens* x *C. acutifolium*) and Clements (1983b, for *C. virginianum*) reported heterotic effects in the early generations following hybridization. Some of this heterosis was recoverable in advanced generation lines.

Evidence of genetic variation within *Centrosema* gene pools is also provided by the response to selection. Reliable documentation of the results of selection or breeding projects is surprisingly scarce. *Centrosema pascuorum* lines superior to their parents in forage and seed yield have been obtained (Clements et al., 1986). Two *C. virginianum* lines selected for herbage yield and winter survival from a series of biparental crosses were shown to be superior to any other bred lines or introductions (including original parental accessions) with respect to second-year herbage yield, and superior to their parents with respect to winter survival (Clements and Thomson, 1983).

Hutton (1985) compared selected F₃ lines with his original *C. pubescens* and *C. macrocarpum* parents in a small-plot field trial on a highly acid Oxisol. His data suggest that a small proportion of the F₃'s retains the high adaptation to acid-soil conditions of the *C. macrocarpum* parent.
In the programs of Grof (1982) and Serpa and da Silva (1984), the extent of breeding progress is uncertain because the bred lines have not been compared directly with the original parental genotypes.

**Breeding Objectives**

Improved forage yield, its distribution during the year, and its persistence over time, are probably the most commonly mentioned objectives of past *Centrosema* breeding programs (Table 3), often in combination with one or more additional attributes.

Serpa's selection and breeding program in *C. pubescens* and *C. pubescens x C. acutifolium* for Brazilian conditions has sought characters such as lower rates of hard-seededness, improved *Rhizobium* compatibility, high N$_2$-fixation rate, anthracnose resistance, and high herbage and seed yields.

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**Table 3. Summary of objectives of five *Centrosema* breeding projects.**

<table>
<thead>
<tr>
<th>Species</th>
<th>Country</th>
<th>Objectives</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. pubescens</em></td>
<td>Brazil</td>
<td>Forage yield</td>
<td>Serpa, 1966, 1974, and 1976</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Seed yield</td>
<td>Serpa and Cunha Filho, 1970</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low hard-seededness and <em>Rhizobium</em> compatibility with N$_2$ fixation</td>
<td>Serpa and De-Polli, 1975 and 1980</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Seedling vigor</td>
<td>Serpa et al., 1977</td>
</tr>
<tr>
<td><em>C. pubescens</em></td>
<td>Australia</td>
<td>Forage yield</td>
<td>Grof, 1970 and 1982</td>
</tr>
<tr>
<td></td>
<td>Colombia</td>
<td>Seed yield</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cool-season yield</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stoloniferous habit</td>
<td></td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>Australia</td>
<td>Forage yield</td>
<td>Clements and Thomson, 1983</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Seed yield</td>
<td>Clements and Ludlow, 1977</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Winter survival</td>
<td></td>
</tr>
<tr>
<td><em>C. pascuorum</em></td>
<td>Australia</td>
<td>Forage yield</td>
<td>Clements et al., 1986</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Seed yield</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flowering date</td>
<td></td>
</tr>
<tr>
<td><em>C. pubescens x C. macrocarpum</em></td>
<td>Colombia</td>
<td>Forage yield</td>
<td>Hutton, 1983 and 1985</td>
</tr>
<tr>
<td></td>
<td>Brazil</td>
<td>Seed yield</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acid-soil tolerance</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disease resistance</td>
<td></td>
</tr>
</tbody>
</table>

a. These programs used *C. pubescens x C. acutifolium* hybrids, at least in part.
Grof’s selection program in *C. pubescens* x *C. acutifolium* sought genotypes with better yield, particularly in the cool season, and with strongly stoloniferous growth which was assumed to confer greater persistence under grazing.

Hutton (1983 and 1985) sought a combination of attributes not present in those *C. pubescens* accessions available when the program was initiated: adaptation to acid, infertile soils; high forage and seed yields; and a strongly stoloniferous growth habit.

High seed yield, often mentioned as a *Centrocoma* breeding goal (Clements, 1977; Clements et al., 1986; Clements and Thomson, 1983; Hutton, 1983 and 1985), is important for persistence and for reducing the price of commercial seed.

Clements’ breeding projects were initiated in species where no commercial cultivars previously existed. As Clements and Thomson (1983) noted, experience with existing commercial cultivars would have made it easier to set objectives and thus would have greatly improved the chances of success. During the evaluation of germplasm accessions, breeding objectives can often be formulated, even in the absence of a standard commercial cultivar. Such may be the case for *C. brasilianum* for the savanna regions of South America where susceptibility of most accessions to web blight (caused by *Rhizoctonia solani*) and sucking insects are critical limitations. Forage yield losses of 30%-50% from web blight have been documented (CIAT, 1986).

**Choice of Parents**

The choice of parents is critical in any breeding program. No amount of effort invested in evaluation and selection in progeny of a cross can yield new combinations of genes not present in the original parents.

The earlier in the breeding program that reliable assessment of the breeding value of potential parents can be made, the fewer resources are wasted on evaluating inferior crosses. However, the earlier such an assessment is made, the less reliable it is. There is no fully satisfactory solution to this dilemma (Baker, 1984; Simmonds, 1979).

Parental selection is further complicated in *Centrocoma* by the possibility of exploiting interspecific hybrids. Where fertile crosses are easily obtained such as *C. pubescens* x *C. macrocarpum* or *C. pubescens*
x C. acutifolium, and where each species offers desirable attributes not available in the other, there is no reason to treat interspecific cross-combinations differently from intraspecific crosses.

Where fertility barriers are involved, attempts to recombine traits from different species must be approached with caution. Experience in other genera suggests that the efforts expended on interspecific crosses are not usually productive, at least in the short term, for example, Trifolium spp. (Williams, 1983). Most Centrosema spp. are likely to be variable for quantitative traits. In many cases, closely compatible species further broaden the range of easily accessible genetic variation. Only in very exceptional cases will the breeder need to resort to difficult interspecific crosses to achieve his objectives.

**Breeding Methods**

Pedigree-breeding methods have commonly been applied to Centrosema spp. (Clements and Thomson, 1983; Grof, 1982; Hutton, 1983 and 1985; A. Serpa, unpublished data). In Clements’ C. pascuorum program (Clements et al., 1986), the pedigree method was modified to include two generations of single-seed descent. This was an important factor in the very rapid advance to highly inbred, selected lines.

Clements has attempted several less conventional breeding procedures in his C. virginianum program (Clements, 1976). In addition to the traditional pedigree approach, he formed two composite crosses, one from 16 parents (CC16) and one from a selected subset of 7 parents (CC7: one of the parents was included twice to make a balanced set of 8 parents) with the objective of combining genes from more than a single pair of parental lines prior to the initiation of selection. Both composites were formed with a hierarchical mating design beginning with crosses between pairs of accessions to form F1s, the formation of double crosses from crosses between pairs of F1s, the formation of quadruple crosses, and so on. The number of individuals used was sufficient to ensure that the final composite population would, with 95% probability, include all genes present in the original set of parents.

Several different procedures were used to manage the wide genetic variation resulting from these composite crosses. CC16 was planted in a grass-legume mixture and grazed until the initial legume population was nearly depleted. Surviving plants were dug up and transplanted to pots in the greenhouse for seed multiplication, without recombination. The
resulting seed was bulked and again planted in a grazed pasture for a second "cycle" of natural selection. Two cycles of selection have been completed. Although a rigorous evaluation of the results of this natural selection procedure has not been made, survival seems to have improved over generations as the presumably more poorly adapted genotypes have been eliminated from the population.

The composite formed from the seven selected *C. virginianum* parents (CC7) was planted as one of seven *C. virginianum* populations for evaluation under grazing. It appears to have improved over 8 years relative to the genetically homogeneous entries (Clements, this volume; Jones and Clements, 1987).

The CC16 population was also advanced by single-seed descent to the F₅ generation (R. J. Clements, unpublished data). The resulting 1054 lines have not yet been evaluated.

As Cameron et al. (1984) pointed out, recurrent selection may be more efficient and effective than pedigree selection in achieving the combination of complex, quantitative characters required for a successful forage-legume cultivar. Even in highly self-pollinated *Centrosera* spp. it ought to be feasible to mount effective recurrent selection programs. An effective recurrent selection program can be based on the evaluation of between 200 and 500 families (for example, S₁ families) in each cycle with an overall proportion selected of 0.10 to 0.20 (Baker, 1984). Using bulk pollen, this would require about 67 to 167 hand pollinations per cycle (assuming 30% success and 10 seeds per successful pollination). Where outcrossing is suspected (for example, in *C. macrocarpum*), recurrent population improvement may be even more appropriate. If outcrossing is not complete, the recombination phase may require a reliable seedling marker trait so that outcrossed individuals can be easily identified in open-pollinated progenies.

Where specific traits are sought which cannot be found in the available germplasm collections, the breeder may resort to the artificial induction of mutations. Penteado (1982) reported that a diverse set of *C. pubescens* accessions responded similarly to gamma radiation and that an appropriate acute dose for mutation induction is in the range of 20 to 25 krad.

New biotechnologies such as in vitro selection, anther culture, or protoplast fusion may improve the efficiency and effectiveness of breeding programs. However, these technologies are, as yet, scarcely used routinely in the improvement of major crop species. Their application to *Centrosera* improvement is unlikely in the short term.
Evaluation Techniques

A bottleneck in breeding programs is the reliable evaluation of genotypes over the range of variability in the target environment. Evaluation is particularly complex for plants intended for grazed grass-legume pastures where the ultimate criterion of merit is animal, rather than plant, performance (Jones and Walker, 1983).

The large number of genotypes generated by a breeding program must be reduced drastically before testing under grazing. Usually, this selection is done on the basis of the performance of individuals (spaced plants) in the early generations and families (small plots) in more advanced generations. *Centrosema* spp. require large plots with wide borders. Although significant interaction for herbage yield between genotypes and conditions of evaluation such as spacing, establishment method, defoliation method, and association, has been measured in many pasture species, genetic correlations have been found to be high (England, 1975; Sedcole and Clements, 1973). Genetic gains are realized, even for complex traits such as yield, through selection in the early generations under artificial conditions. This appears particularly true in the early stages of the breeding program when the range of genetic variation is great. In any case, the breeder usually has little choice to indirect selection as he rarely has sufficient prior knowledge of the importance of genotype interactions with conditions of evaluation for his particular genetic populations. Nor does he have the resources to evaluate hundreds or thousands of breeding lines under "real-life" grazed pasture conditions.

Genotype interaction with site or year can further decrease the precision of evaluation and selection. Clements (1983b) found large genotype interactions with both location and year in progenies of highly selected accessions of *C. virginianum*, but not for the progenies of unselected parents. He concluded that such interactions will become of increasing concern as the breeding program progresses from the stage of unselected germplasm accessions to selected and highly adapted populations. Several authors have proposed methods for choosing an efficient set of testing sites where genotype-location interactions are important (Abou-El-Fittouh et al., 1969; Byth et al., 1976; Horner and Frey, 1957; Shorter et al., 1977). One obvious limitation to all of these is that identification of efficient testing sites requires extensive prior data on genotype response to a wide range of sites. A practical method of dealing with genotype-location and genotype-year interactions is to test as widely as possible over a well-defined target environment, limiting
the range of the target environments if excessive genotype-location interaction precludes further breeding progress.

Laboratory or greenhouse techniques may decrease the time required for, or refine the precision of, genotype evaluation, provided the results achieved are well correlated with field performance. Clements and Ludlow (1977) found that cotyledon-node height of *C. virginianum* seedlings measured in the greenhouse correlated well with differences in winter survival, thus providing a quick, reliable screening technique. However, Serpa et al. (1977) found no correlation between reaction to anthracnose as measured on artificially inoculated seedlings in the greenhouse and the observed reaction of field-grown plants.

Hutton (1983 and 1985) attempted to evaluate tolerance to acid, low-fertility soil conditions by measuring performance of seedlings grown in solution culture in sterile sand. However, he found poor correlation between performance in solution culture and performance in soil in pots or in the field. Seedling screening in the greenhouse in deep (17 cm) trays containing an infertile, acid Oxisol was claimed to provide a reliable, rapid means of identifying acid-soil tolerant genotypes in segregating populations (Hutton, 1985).

**Results of Current or Concluded *Centrosema* Breeding Projects**

Five *Centrosema* breeding projects are publicly documented. Several additional undocumented breeding activities will be described here. We shall attempt to analyze each project, not only in terms of its effectiveness relative to its own stated objectives, but also in terms of whether simple germplasm collection and evaluation procedures may have achieved the same objective.

To date, only Clements’s *C. pascuorum* breeding program, among all the *Centrosema* breeding projects, has resulted in the formal release of a named cultivar, that is, Cavalcade (New releases . . . , 1985). The project was initiated with what normally would be considered a woefully inadequate germplasm base. However, some of the six available accessions showed sufficient promise in multisite trials that, with no additional germplasm forthcoming, breeding was commenced. A relatively small program involving only 13 biparental crosses and testing only in the F₂, F₄, and F₆ generations in only one or two sites resulted in seven promising F₆ families which were subsequently subjected to more
widespread agronomic testing. Because single-seed descent generation advance was judiciously used, the entire breeding program took only 6 years. One of the resulting lines proved to be far superior to either of its parents both in herbage yield (22% better) and, particularly, seed yield (118% better).

The breed lines of *C. pascuorum* compared favorably in the multisite trials with two other successful forage legume cultivars (*Macroptilium atropurpureum* cv. Siratro and *Stylosanthes hamata* cv. Verano). These results demonstrate the dramatic genetic gains that are possible in the earliest stages of plant-breeding programs in essentially undomesticated species. The final test remains of whether cv. Cavalcade becomes a successful and widely used forage legume. After the program was completed, a wider range of collections became available. Some of these have compared favorably with cv. Cavalcade (Thomson et al., n.d.).

Clements’s *C. virginianum* project is probably the best documented *Centrostepa* breeding project (Clements and Thomson, 1983). As with the *C. pascuorum* project, the initiation of breeding in *C. virginianum* was arguably premature as only a small germplasm collection was available at the time. While no commercial cultivar has resulted from this program to date, the project has produced lines superior to any available germplasm accession at the main test site even though the collection grew from 21 to over 170 accessions during the 10-year period. It seems unlikely that the same resources invested in augmenting the collection of naturally occurring germplasm would have had the same positive result as breeding. An additional benefit of this program, which would not have come from an equally large program of germplasm collection and evaluation, has been the generation of a considerable body of information on the genetics and breeding of *C. virginianum*, much of which will be relevant to other *Centrostepa* spp.

Evidence of the efficacy of natural selection under grazing is provided by the results of a comparison of two *C. virginianum* accessions, six pedigree-derived lines, and a seven-parent composite cross population (Jones and Clements, 1987). Over 9 years, the composite population improved, relative to all other *C. virginianum* lines, in contribution to total forage dry matter on offer, in stolon length, in number of rooted points, and in number of roots.

Hutton (1983 and 1985) aimed at producing interspecific hybrids which combined the high forage and seed yields and stoloniferous growth habit of *C. pubescens* with adaptation to low-fertility, acid-soil conditions as exhibited by *C. macrocarpum* and *C. acutifolium*. Good
progress has been made within the limitations imposed by the germplasm available at the time the project was initiated. Unforeseen disease problems may have reduced the intensity of selection for the desired agronomic characters. His material should now be tested against new, superior collections of *C. macrocarpum*, *C. acutifolium*, and *C. brasiliananum*.

Grof (1970), working mainly within a *C. pubescens x C. acutifolium* population, sought to produce a stable cultivar with vigorous initial growth, high cool-season yield, strong stoloniferous growth habit, and resistance to diseases and insects to replace commercial centro. Pedigree selection among spaced plants in the F$_2$ through to F$_5$ generations was conducted at the CIAT research station in Palmira, Colombia. One F$_3$ line, designated CIAT 438 in 1973, has proved highly adapted to the region where selection was performed and in Peru (Grof, 1982; Reátegui et al., 1985). CIAT 438, from the cross *C. pubescens* Q 8216 x *C. acutifolium* IRI 1534 (syn. Q 8998), is referred to throughout this volume as *Centrosera* hybrid CIAT 438. However, it is morphologically almost indistinguishable from *C. pubescens*. It is difficult to assess from the published data the genetic gain achieved in this breeding program because none of the bred lines was compared directly with the original parents. CIAT 438 is certainly a very successful line and is superior in several respects to commercial centro (CIAT, 1979). However, the parents themselves are also superior to commercial centro (Grof, 1970; Grof and Harding, 1970).

Serpa’s *Centrosera* breeding program began with selection for permeable seeds within a heterogeneous population of *C. pubescens* identified as “Deodoro” which originated at the Deodoro Experiment Station of the former Brazilian Instituto de Pesquisa Agropecuária do Centro-Sul (IPEACCS). Additional selection within this population for forage and seed yields, anthracnose resistance, nitrogen fixation, and seeding vigor resulted in three lines far superior to the original population. Pedigree selection in crosses among these lines and a cross reported as *C. pubescens x C. virginianum* (Serpa, 1977) (probably *C. pubescens x C. acutifolium*) resulted in additional promising material. In 1980, a population, named as *Centrosera* Itaguaí Sintético 80 (CIS-80), was formed by mixing seed from 37 plants selected either from the original Deodoro population or from the intra- or interspecific crosses. In small-plot trials CIS-80 was markedly superior to standard check accessions in seedling vigor and forage yield (Serpa and da Silva, 1984). This population is presently being multiplied for testing under commercial conditions.
In addition to these more or less concluded breeding projects, several additional *Centrosema* breeding activities are currently in progress.

Following agronomic evaluation of a collection of some 350 accessions of *C. pubescens* and related species in Queensland (Australian subtropics), Clements initiated a crossing program with the objective of combining tolerance to drought and cold with early flowering. Two single crosses, involving four parents have been made. The intention is to form the double cross, and then backcross to the most drought-tolerant accession before initiating selection.

Grof has initiated a series of exploratory interspecific crosses involving accessions of *C. pubescens*, *C. macrocarpum*, and *C. acutifolium*.

A breeding project with the aim of developing *Rhizoctonia*-resistant lines of *C. brasielianum* has begun at CIAT with the evaluation of potential parental accessions. Two seven-parent diallel crosses are being formed to study the inheritance of resistance.

An interspecific hybridization program is currently underway at CIAT to study cross-compatibility relations among *Centrosema* spp. More than 1200 interspecific crosses have been attempted to date (20 February 1987). Only 27 of these crosses (2.2%) have yielded seed, and only a fraction of this seed was of hybrid origin; the remainder was from accidental selfing. This is less than one-third of the success rate (7.5%) of 790 intraspecific crosses made under the same conditions, and is much less than the success rates reported by Hutton (1985) and R. J. Clements (unpublished data) in their intraspecific hybridization programs. Additional evidence of interspecific incompatibility is a much lower average seed set for the interspecific crosses (7.8 seeds per pod) than for the intraspecific crosses (13.9 seeds per pod).

**Conclusions**

Several *Centrosema* breeding projects have achieved notable success. There is, however, an urgent need to clearly delineate the available gene pools. Some interspecific crosses have been successful and several breeding programs have been based on interspecific hybridization. However, a systematic evaluation of species compatibilities is only beginning. A thorough cytological examination of the genus would be helpful in clearing up past inconsistencies.
We know little about breeding systems in *Centrosema* spp. and the relation these have with environmental factors. Progress in this area depends on the identification of a reliable genetic marker. The demonstration of outcrossing in *Centrosema* spp., along with a good marker may allow the implementation of unconventional breeding schemes involving massive genetic recombination as have been proposed for *Stylosanthes* spp. (Miles, 1985).

Knowledge of the expected response to selection for any particular attribute would be extremely useful in the design of future breeding projects. It is doubtful, however, whether special studies designed solely to obtain estimates of genetic parameters are justified. Applied breeding programs can provide information on heritabilities, correlations between traits, and the interaction of genotype with environmental conditions. Breeding programs often can be deliberately designed to generate such information at little additional cost.

The importance of disease resistance in *Centrosema* breeding programs will probably increase, particularly in tropical America. Information on sources of resistance, its inheritance, and the interactions between pathogens and the *Centrosema* host will be needed.

The critical limiting factor in *Centrosema* breeding is a clear understanding of the plant attributes contributing to better growth and persistence of the plant and to better or more efficient animal performance, and the availability of simple techniques to assess these attributes. Only with well-defined and relevant breeding objectives can an improvement program have a reasonable chance of creating useful new cultivars. Only if large plant populations can be evaluated reliably and economically will substantial genetic progress toward these breeding goals be achieved.

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Genetics and breeding of Centrostepa


Genetics and breeding of Centrosema


Genetics and breeding of Centrosema


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Chapter 10

ESTABLISHMENT AND MANAGEMENT OF CENTROSEMA PASTURES

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Abstract

Most published work on the establishment and management of Centrosema pastures refers to the commercial cultivars of C. pubescens. Nevertheless, many establishment and management practices can be applied to other Centrosema species now being evaluated for their forage value. These practices are discussed such as the scarification and inoculation of seed which are important for rapid establishment, techniques for seedbed preparation, sowing techniques and rates, and fertilization. The advantages of undersowing annual crops are emphasized.

Regular replacement of original plants, by vegetative spread and/or the emergence of new seedlings, is essential for persistence of Centrosema. There is considerable intraspecific and interspecific variation in characters influencing persistence in the genus. Grass-legume compatibility also influences persistence, the Centrosema species appearing to be more compatible with tufted than with stoloniferous grasses. The proportion of Centrosema in mixed swards is affected by different grazing pressures and grazing systems.

Priorities for future research are suggested.

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Introduction

The genus *Centrosema* comprises about 35 recognized species of herbaceous tropical legumes (Williams and Clements, this volume). One species, *C. pubescens*, has dominated the published literature and has received more attention than all other species of the genus combined. *Centrosema pubescens* was one of the first tropical legumes to be used as a cover crop in plantation agriculture and as a forage species in the humid tropics. Recent research in tropical America and Australia has identified a number of other species with forage potential. Commercial lines of *C. schiedeleanum* (cv. Belalto) and *C. pascuorum* (cvs. Cavalcade and Bundey) are now available, and accessions of *C. acutifolium*, *C. macrocarpum*, and *C. brasilianum* are in advanced testing under grazing.

The purpose of this review is to discuss establishment and management practices for *Centrosema* pastures.

Establishment practices

Seed treatment

Scarification and inoculation of seed are of particular importance in sown pastures.

**Scarification.** In common with many other legumes, species of *Centrosema* have a high proportion of hard seeds. In *C. pubescens*, this may represent 60% of the sample (Bogdan, 1977). Hard-seededness is an adaptive feature which, in nature, prevents the possible loss of all sown seeds if a germination event is followed by adverse conditions in areas of unreliable rainfall. Germination is delayed by the impermeability of the seed coat, a genetically controlled feature in *C. pubescens* (Serpa, 1966). However, in sown pastures, if germination and plant establishment are to be rapid and uniform, dormancy caused by hard-seededness must be broken by scarification.

Seed can be scarified in many different ways. Skerman (1977) listed five methods that have been successfully used to break hard-seededness in *C. pubescens*. They are mechanical treatment; immersion in concentrated sulfuric acid (24 or 36 N) for 7 minutes, followed by a thorough washing in water; immersion in warm glycerin at 30 °C for 272
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2 hours; hot-water treatment at 77 °C for 15 minutes; and Osram irradiation for 16 hours or more. Other methods are described by Phipps (1973) who also reported considerable variation in response among treatments. Immersion of seed in boiling water for one second or storage in a freezer at -17 °C for 16 days increased germination by 66% and 57%, respectively, over that of unscarified seed. Immersion in liquid nitrogen (-196 °C), however, increased germination by no more than 34%. These procedures are also suitable for other species of the genus. For example, both mechanical scarification and concentrated sulfuric acid treatment have been used successfully at CIAT for large quantities of seed of C. acutifolium, C. brasiliannum, and C. macrocarpum.

Inoculation. Species of Centrosema are unlikely to realize their full potential for nitrogen fixation unless seed is inoculated with selected strains of Rhizobium (Sylvester-Bradley et al., this volume). Inoculation gives the legume a marked advantage in speed of establishment, which is of special relevance when sown with vigorous tropical grasses. Bowen and Kennedy (1961) found heritable variation in the capacity of C. pubescens to nodulate. In Brazil, Colozza and Werner (1982) reported that inoculation of C. pubescens resulted in appreciable increases in dry-matter yield, nodule weight, and nitrogen content compared with uninoculated control plants. In soil-core screening trials in the Eastern Plains (Llanos Orientales) of Colombia, accessions of C. pubescens, C. brasiliannum, C. macrocarpum, and C. pubescens x C. macrocarpum hybrids yielded significantly more nitrogen when inoculated (CIAT, 1984). Strong responses to inoculation were also observed with accessions of C. acutifolium (CIAT, 1986). Recommended strains of Rhizobium for species of Centrosema are available from collections at the Division of Tropical Crops and Pastures of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia and at CIAT in Colombia.

Traditionally, peat-based inoculants have been used but recent studies (CIAT, 1985) indicate that freeze-dried inoculum may have considerable potential for the tropics. Peat-based inoculants are more perishable, expensive to produce, and are susceptible to desiccation on the seed surface. Mortality of freeze-dried Rhizobium inoculum on seed of C. macrocarpum was only 12% after three days compared with 99.9% for peat-based inoculum.

Pelleting of inoculated seed with lime has often been recommended for tropical legumes despite their adaptation to soils of low pH and symbiosis with acid-tolerant Rhizobium. The practice was developed originally to overcome nodulation failures with temperate legumes on
acid, low-calcium soils. Norris (1971) found no support for the routine practice of lime-pelleting tropical legumes, and good results were usually obtained in field trials on Podzolic soils in Australia by simply applying inoculum with a sticky substance. Even in the commercial cultivar of *C. pubescens*, Odu et al. (1971) found that maximum nitrogen fixation occurred at a pH value of 6.4; higher pH values suppressed nodulation.

However, in acid soils where aluminum or manganese toxicities occur, lime pelleting may have a beneficial effect on nodulation in the commercial cultivar of *C. pubescens* (Dereiner and Aronovich, 1966). Nodulation in this line appears to be more vulnerable to nutrient toxicity than the growth of the host plant (Murphy et al., 1984). High aluminum concentrations in solution culture delayed the appearance of nodules and reduced both nodule number and weight, but had no effect on plant dry weight. For other species of *Centrosera* collected on acid, infertile soils in tropical America, lime pelleting has given negative results and the procedure is not recommended (R. Sylvester-Bradley, personal communication). However, for purposes of preinoculation or for protection of *Rhizobium* where seed is sown with fertilizers such as superphosphate, pelleting with materials such as rock phosphate or ground charcoal, is useful (R. Sylvester-Bradley, personal communication).

**Preparation of the seedbed**

The degree of seedbed preparation necessary for good establishment is influenced by many factors, including edaphic and climatic conditions, the availability and type of machinery, and economic considerations. Methods range from complete soil preparation to minimum tillage (CIAT, 1986).

Species that are relatively slow to establish such as *C. pubescens*, will benefit most from a thorough preparation of the seedbed when climate and soil conditions permit. This may necessitate plowing, followed by various passes with a disc harrow to break up large soil clods, and rolling to produce a firm, level seedbed. On the highly weathered soils of the humid and subhumid tropics, overpreparation, particularly on sloping land (even with a slope as slight as 0.5%), increases erosion risk and cost of establishment—the main constraint to adopting legume-based pastures (J. M. Spain, unpublished data). In the savannas of central Brazil, pastures are often sown after annual crops such as upland rice or maize (Kornelius et al., 1979). In this situation, only
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minimal land preparation is required for pasture establishment because
the soil was already thoroughly prepared for the preceding crop.

Centrosema acutifolium, C. brasilianum, C. macrocarpum, C.
pubescens, and hybrids between the latter species have been successfully
established on roughly prepared seedbeds (CIAT, 1987). In soils of good
structure where weed potential is low such as in the Oxisols and Ultisols
of the tropical American savannas, disc harrowing or chisel plowing,
together with partial, not full, vegetation control, has given good
results. These methods are much more economic than complete land
preparation, but are suitable only where well-adapted, aggressive species
are sown (Spain, 1983).

In Australia, C. pubescens has been sown directly into ash, following
the clearing and burning of mesophyll vine forest (Teitzel and
Burt, 1976). However, windrowed cut timber and preparing a weed-free
seedbed is recommended. In wet tropical climates, weeds are a major
problem in pasture establishment and there is regrowth of woody
plants. Weeds can be controlled by mechanical means or by herbicides.
In Indonesia, preemergence applications of ametryn (1.0 to 3.2 kg/ha),
diuron (1.6 kg/ha), or linuron (1.0 kg/ha) have given good weed control
in cover crops of C. pubescens under oil palm (Lumbantobing and
Syamsuddin, 1984). Alternatively, the postemergence application of
0.34 kg a.i./ha of 2,4-D or 0.11 kg/ha of diquat when plants of C.
pubescens were at least 5 weeks old had no adverse long-term effects in
the wet tropics of Australia (Teitzel and Burt, 1976). Other herbicides,
shown by Mastrocola et al. (1983) to have no effect on dry-matter yield
or nodulation in C. pubescens, include bentazon and chloroxuron.
However, costs are an important limitation to herbicide use in pasture
establishment.

In the savannas of tropical South America, leaf-cutting ants of the
Atta genus are major pests at establishment. Although insecticides can
be used, repeated, expensive applications are required—implicating
serious ecological problems. Chemical control is probably suitable only
for small experimental areas and is most effective against species of Atta
that concentrate in large colonies. Early land preparation can be
beneficial in controlling both ants and weeds (J. M. Spain, unpublished
data). In savanna, land should be prepared at the end of the wet season
and left rough and fallow during the dry season. This practice will also
reduce competition with other farm activities and increase nutrient
availability at sowing time.

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Methods of sowing

Pasture species may be sown directly into a prepared seedbed, undersown in annual crops, or established in existing vegetation such as native pasture. In all cases, seed may be broadcast or drilled in rows. In the Brazilian savannas, where crops and pastures are commonly integrated, Kornelius et al. (1979) successfully established *C. pubescens* in upland rice. The advantages of undersowing annual crops such as upland rice or maize, have been summarized by Thomas (1975):

The cost of establishment will be absorbed by the crop enterprise.

Undersowing offers protection to the soil against erosion and accretion may result.

The crop can protect the establishing pasture against adverse conditions such as high temperatures.

A thorough weeding can be undertaken before the pasture is sown.

The nutritional quality of crop residues used for animal feed is improved.

In the year following the crop-break, production from undersown pastures is higher than from directly sown swards in that year.

The sowing of *Centrostepa* spp. into existing vegetation has been reported by Risopoulos (1966) from Zaire where *C. pubescens* was sown into *Imperata cylindrica*, following the use of a tandem-disc harrow. Velásquez and Bryan (1975) established *C. pubescens* and *C. plumieri* in an 8-year-old stand of *Digitaria decumbens* in the Orinoco Delta, Venezuela, after two passes with a rotovator or disc harrow. For good establishment in these conditions, it is necessary to reduce competition from the existing vegetation. This can be done by burning, heavy grazing, herbicide treatment, soil disturbance, or a combination of these methods.

Although seed of *Centrostepa* species has been sown by broadcasting or drilling in rows, there is insufficient information available to conclude that one method is superior to the other. Andrade and Ferreira (1981) found in Brazil that strip or furrow planting *C. pubescens* gave better results than broadcasting. Equipment used for sowing crops can be easily adapted for drilling *Centrostepa* species (Zimmer et al., 1983). Fertilizer can be placed close to the seed. In contrast, Akinola (1981) in Nigeria found that yields of *C. pubescens*
were higher in associations with *Brachiaria decumbens* when broadcast than when drilled in rows. In the Brazilian savannas, seed of *C. macrocarpum*, *C. brasilianum*, *C. acutifolium*, and *C. pubescens* × *C. macrocarpum* hybrids has been successfully broadcast with both *Andropogon gayanus* and *Brachiaria decumbens*. After 50 days, plant densities for species of *Centrosema* averaged 8/m² (Thomas, 1985). In this environment, rolling to consolidate the seedbed after broadcasting is crucial to good establishment.

The optimal drilling depth for *Centrosema* species will be affected by soil texture and seed size. *Centrosema pubescens* seed can be sown to depths of 5 cm without significantly reducing plant emergence (Adegbola, 1964; Dudar, 1982; Pedrosa and da Rocha, 1977). This depth should be satisfactory for *C. brasilianum* since its seed size is similar to *C. pubescens*. The smaller seeded *C. pascuorum* should not be sown so deeply. *Centrosema acutifolium* and *C. macrocarpum* have larger seeds and, theoretically, could be drilled deeper than 5 cm, although no data exist to substantiate this.

**Time of sowing**

The best time for sowing is determined principally by the distribution of rainfall (Spain, 1983; Zimmer et al., 1983). In areas where early rainfall is reliable, there are advantages to early sowing; where early rainfall is unreliable, later sowing will be safer. Late sowing may expose soil and young seedlings to high intensity rainfall, risking erosion and plant damage, and there will be less grazing time in the establishment year. In Thailand, Nada and Sirikiratayanond (1979) found that planting *C. pubescens* first, followed by planting a grass later, gave a higher legume proportion, but the delay in sowing the grass markedly increased weed invasion. In Venezuela, Valenti and Guzmán (1984) obtained their best results by sowing, simultaneously, *C. pubescens* with *Cynodon plectostachyus* or *Panicum maximum*, rather than at different times, because there was a lower weed population.

**Sowing rates**

Seed size varies among different species of *Centrosema*. The larger seeded *C. acutifolium* and *C. macrocarpum* have about 21,500 seeds/kg, *C. pubescens* 40,000 seeds/kg, *C. brasilianum* 43,500 seeds/kg, and *C. pascuorum* 48,000 seeds/kg. Humphreys (1980) recommends seed rates
ranging from 3 to 5 kg/ha for the commercial cultivars of *C. pubescens* when large quantities of relatively cheap seed are available. Clements et al. (1984) used 4 kg/ha of viable seed, mechanically scarified to 65%-90% soft seed, for experimental plantings of 25 accessions of *C. pascuorum, C. brasilianum, C. schottii, C. virginianum*, and *C. schiedeanum*. In Colombia, seed rates of 3 kg/ha for *C. brasilianum* and 4 kg/ha for both *C. acutifolium* and *C. macrocarpum* have been used for establishing seed multiplication areas (J. E. Ferguson, personal communication). Since seed of these species is not at present commercialized and in relatively short supply, a 50% reduction in seed rates is recommended for their establishment in grass-legume pastures for grazing. These values represent minimal seed rates and can be increased when seed becomes more plentiful and less costly. In trials in Brazil, where seed cost was not a consideration, *C. brasilianum* and *C. pubescens x C. macrocarpum* hybrids were established in associations for grazing with 4 kg/ha seed and *C. acutifolium* and *C. macrocarpum* with 6 kg/ha seed (D. Thomas, unpublished data).

**Fertilizer application**

Response to fertilizer is site specific and recommendations are best made on the basis of local experience (Salinas et al., this volume). The amount of fertilizer to be applied depends on soil type, pasture grown, and the history of nutrient application in the paddock. Chemical analyses of soils and plants are useful guides. Even when species are selected for adaptation to low soil-fertility conditions, as in tropical South America, it is unrealistic to expect them to grow and persist without some fertilizer. Farmers in the Third World, however, are often reluctant to apply fertilizer directly to pastures, so alternative strategies such as integration with crops, must be considered.

Plants differ in their capacity to extract nutrients from the soil and in their growth response to applied fertilizer. There is considerable variation in *Centrosema* in soil adaptation (Salinas et al., this volume). In Florida, commercial centro responds markedly to lime, even to as much as 3000 kg/ha (Snyder and Kretschmer, 1983). In Colombia, *C. plumieri* required 6 t/ha of lime to produce only 1698 kg/ha of dry matter on an Oxisol (Spain, 1979). In contrast, species such as *C. acutifolium*, *C. arenarium, C. brasilianum*, and *C. macrocarpum*, require only small quantities of calcitic or dolomitic limestone as sources of calcium (Ca) or magnesium (Mg) at establishment. Many phosphatic fertilizers also supply sufficient Ca for maximum growth.

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In general, phosphorus (P) is the most limiting nutrient for establishment (Jamieson, 1969; Kornelius et al., 1979; León and Toledo, 1982; Meléndez et al., 1976; Salinas et al., this volume; Spain, 1983). Recommendations vary from 10 to 40 kg of P/ha, depending on the native fertility and the P-fixation capacity of the soil. Tropical soils usually have low reserves of potassium (K) and it is necessary to apply 20 to 25 kg of K/ha at establishment. Good grazing management can subsequently ensure an efficient recycling of nutrients such as P and K, reducing the need for maintenance applications of these fertilizers (Spain and Salinas, 1985). Responses to other macronutrients such as sulfur, have been reported for C. pubescens (Couto and Sanzonowics, 1983). Deficiencies of micronutrients such as zinc, copper, boron, and molybdenum, may be found in sandy soils and those with low organic-matter content, but are site specific. The residual effect of micronutrients is usually high and, under good management conditions, maintenance applications may not be required for many years.

Banding of soluble P fertilizer will give an advantage over broadcast application where the rate applied, calculated on an area basis, is less than that for near maximum growth (Salinas, 1984). This is of practical significance as the P requirement during establishment is higher than that in the maintenance phase (Fox et al., 1974).

Management factors

Persistence

Persistence of individual plants in a sward will depend on such morphological attributes as the number and position of new growing points and on storage reserves. The potential life of the perennial plant may also be shortened by pest or disease activity (Lenné and Lapointe, this volume). Since the expected life of a perennial pasture is greater than the longevity of its individual plants, regular replacement of original plants is essential for persistence. This may occur either through vegetative spread or seedling recruitment. Mechanisms for vegetative perennation include crown enlargement, growth and nodal rooting of stolons, and the development of new plants from rhizomes. The cycle of seed formation, soil-seed reserves, and seedling recruitment is an important alternative pathway for persistence in both annuals and perennials.
Little is known about the relative importance of plant morphology and seedling recruitment in the persistence of *Centrosema* species, although for annual species such as *C. pascuorum*, the need for seedling recruitment is self-evident. Consequently, any discussion on mechanisms for persistence are mostly speculative.

There is considerable interspecific and intraspecific variation within *Centrosema* in many characters which are believed to influence persistence. The commercial cultivar of *C. pubescens* has only a slight tendency to root at the nodes while *C. schiedeanum* cv. Belalto has a greater capacity for such rooting and so survives better under grazing (Teitzel and Burt, 1976). Many accessions of *C. macrocarpum* such as CIAT 5065, in association with *A. gayanus* do not survive well under grazing, possibly because of a low seed-set and the stolons fail to root at the nodes (D. Thomas, unpublished data). Recently, new accessions of *C. macrocarpum* have been collected that show a greater capacity to root at the nodes and a higher potential seed yield. Hybrids formed between *C. macrocarpum* and *C. pubescens* also have a high seed yield potential (CIAT, 1984). Acid-soil tolerance was inherited from the parent lines of *C. macrocarpum*, enabling the seed-production potential of the parent lines of *C. pubescens* to be realized.

Morphological deficiencies in *C. brasillianum* are compensated by a free-seeding habit and good seedling recruitment under grazing (B. Grof, personal communication). *Centrosema acutifolium* is a species which combines a strong capacity for nodal rooting with good seed production (CIAT, 1985).

One interesting exception to the usual growth habit in *Centrosema* species, is *C. arenarium* which is an erect and nontrailing plant. It also has basal buds which are protected from defoliation and trampling, a good seed-set at equatorial latitudes, and relatively low animal acceptability may result in potentially good persistence of this species under grazing (R. Schultze-Kraft, personal communication).

By selecting plants with desirable morphological characteristics, good seed production, and resistance to pests and diseases, a potential for persistence is also selected. However, in practice, persistence will also be influenced by other factors such as grazing management, fertilizer application, and the choice of the companion grass.

**Grass-legume compatibility**

Species of *Centrosema* have been grown with many different companion grasses. In general, tufted grasses have proved to be more compatible than aggressive stoloniferous types.

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Experience in Brazil, Colombia, Costa Rica, Ecuador, USA (Florida), Malaysia, Peru, and Sri Lanka (de Mattos et al., 1978; Grof, 1981; Hudgens, 1973; Kretschmer, 1971; Pedreira et al., 1975; Toledo and Morales, 1979; Waidyanatha et al., 1984; Wong and ‘t Mannetje, 1981) indicates that *C. pubescens* associates well with *Panicum maximum* and *Hyparrhenia rufa*. Other grasses reported to combine well with *C. pubescens* are *Paspalum plicatulum, P. guenoarum, Setaria anceps, Pennisetum purpureum* (Pedreira et al., 1975), *Hemarthria altissima* (Gomes, 1978), *Dichanthium caricosum* (Partridge, 1979), *Brachiaria militiformis* (syn. for *B. subquadripire* under coconuts (Waidyanatha et al., 1984), and *Andropogon gayanus* (Giraldo and Toledo, 1986). In Brazil and Colombia, *C. acutifolium* and *C. brasilianum* have also shown compatibility with *Andropogon gayanus* (Grof, 1986; Thomas, 1985). Grasses that are less compatible include *Digitaria decumbens*, *Cynodon dactylon* (Pedreira et al., 1975), and *Brachiaria humidicola* (Smith and Whiteman, 1985).

The capacity of *C. pubescens* to combine with *Brachiaria mutica* and *B. decumbens* appears to be influenced by light intensity. In full daylight, *C. pubescens* did not associate well in Brazil or Colombia with *B. decumbens* (Grof, 1981; Pedreira et al., 1975), but under coconuts where light intensities were lower, associations were successfully maintained for over 6 years in Indonesia (Rika et al., 1981). Similarly, in Belize, without shade, *C. pubescens* did not combine well with *Brachiaria mutica* (Lazier, 1980). Nevertheless, in the Solomon Islands, under coconuts, good legume contents were reported by Smith and Whiteman (1985) in mixtures of *B. mutica* and *C. pubescens*. The proportional decrease in photosynthesis with reduced light intensity under coconuts is much greater for tropical grasses which have a C4-dicarboxylic acid pathway for CO₂ fixation. Thus, under shading, the competitive balance swings in favor of the legume.

**Tolerance to fire**

The capacity to survive fire is important to pasture legumes in savanna regions where frequent burning occurs either as a management practice or by accident. Little is known about the tolerance of *Centrosema* species to fire. Lourenço et al. (1976) in São Paulo, Brazil, analyzed the effects of controlled burning at the end of the rainy season on an association of *Hyparrhenia rufa* and four legumes, including *C. pubescens*. Observations made 60 and 120 days after burning showed that *C. pubescens* was not as tolerant to fire as were *Neonotonia*

Mechanisms which enable plants to survive grazing or drought appear to be relevant to fire tolerance. In *Stylosanthes* species, the capacity of individual plants for surviving a hot burn depends on the protection afforded to the buds within the crown or in the root system (Williams and Gardener, 1984). In some surviving plants, the shoots had grown from root tissue 37 mm below the soil surface. Mott (1982) showed that the presence of a large seed store in the soil was also a successful means of surviving fire, although a great deal of seed is destroyed by burning. Stockwell et al. (1986) reported significant destruction of *C. pascuorum* seed by fire in small plots in the Northern Territory, Australia.

**Effects of stocking rate or grazing pressure**

Marked changes often occur in the botanical composition of pastures when stocking rate, and hence grazing pressure, is varied. The effects of stocking rate on the trends in botanical composition of tropical pastures have been described by Roberts (1980). For example, in associations under high grazing pressures, the species which are least able to withstand defoliation, or are slow to recover after grazing, will eventually be eliminated. If the remaining species are of lower feeding value or less acceptable to cattle than those which they replace, liveweight gain per head at high stocking rates will fall until it stabilizes at the lower production level of the remaining components.

In the establishment year, grazing too heavily or too early can reduce the productive life of pastures containing *C. pubescens* (Teitzel and Burt, 1976). This legume, with its relatively poor establishment vigor and high animal acceptability, is especially vulnerable to heavy, selective grazing. Light, short, intermittent grazing is recommended during the establishment period. This recommendation is probably applicable to other species of the genus.

Subsequent to the establishment year, the few data available suggest that the proportion of *C. pubescens* in mixed pastures is reduced by high stocking rates or grazing pressures. In Brazil, Lourenço et al. (1981) subjected a mixture of *Panicum maximum* and *C. pubescens* to a range of stocking rates varying from 2.0 to 3.6 animals/ha in summer and 1.3 to 2.4 animals/ha in winter. An increase in stocking rate led to a decline in the proportion of legume over time. In Ecuador, a pasture
Establishment and management of Centrosema pastures

containing two grasses and two legumes, including *C. pubescens*, was grazed at forage allowances that ranged from 1.6 to 8.3 kg of dry matter on offer per day for each 100 kg of body weight (Santillán, 1983). Although legume yield and content were less sensitive to low forage allowances than to other factors such as length of rest period, moderate forage allowances such as 5.0 kg of dry matter per day for each 100 kg of body weight, were recommended. In this trial, conducted over a 2-year period, no attempt was made to separate the two legume species and the specific effects on *C. pubescens* were not described. In Colombia, in an association of *Andropogon gayanus* and *Centrosema* hybrid CIAT 438, Giraldo and Toledo (1986) reported that legume contents were greater with high to moderate forage allowances (4 or 6 kg of green dry matter/day for each 100 kg of body weight) than with low forage allowance (2 kg of green dry matter/day for each 100 kg of body weight). In the Solomon Islands, under coconuts, Smith and Whiteman (1985) observed that *C. pubescens* disappeared from an association with *Brachiaria humidicola* over a 3-year period when grazed at a stocking rate of 4.5 animals/ha. At the lower stocking rates of 3.0 and 3.6 animals/ha, the legume persisted but at a reduced level.

Data for other perennial species of *Centrosema* are limited. In the Colombian Llanos, the content of two accessions of *C. acutifolium* (CIAT 5277 and CIAT 5568) in association with *Andropogon gayanus* was reduced from 54% to 38% when rotationally grazed at a high stocking rate (CIAT, 1987). In the Cauca Department of Colombia, in a bimodal rainfall regime, increasing stocking rate from 2.4 to 3.6 animals/ha reduced the legume content of accessions of *C. acutifolium* and *C. macrocarpum* associated with *Andropogon gayanus* (Table 1). There were differences between introductions of *C. macrocarpum*, with accession CIAT 5434 persisting better than CIAT 5065 after 2 years of grazing. In the Australian humid sub tropics, a good legume content in *C. virginianum-Setaria sphacelata* pastures was maintained at a stocking rate of 1.5 animals/ha, but the legume did not persist at 2.3 animals/ha (Jones and Clements, 1987). There appears to be no information available for annual species such as *C. pascuorum*. One can only suggest that management be directed toward ensuring a high seed production and buildup of soil-seed reserves, the principal persistence mechanism in these species.

It is not possible to make hard and fast recommendations for the optimal stocking rate or grazing pressure for *Centrosema* as a whole because it varies with species, accession, companion grass, and location. Furthermore, most of the work so far conducted has been of relatively
Table 1. Effect of stocking rate and grazing frequency on legume content in mixtures containing *Andropogon gayanus* and *Centrosema* species after 2 years of grazing in Quilichao, Colombia.

<table>
<thead>
<tr>
<th>Legume</th>
<th>CIAT accession no.</th>
<th>Legume content (% DM) at stocking rate (animals/ha)</th>
<th>Legume content (% DM) at grazing frequency (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2.4</td>
<td>3.6</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5434</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>5065</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td><em>C. acutifolium</em></td>
<td>5568</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>5277</td>
<td>17</td>
<td>4</td>
</tr>
</tbody>
</table>

a. Animals of 300 kg liveweight.
b. Paddocks were grazed for 3.5 days, every 2, 4, or 6 weeks.

SOURCE: CIAT, unpublished data.

short duration. Trials need to be conducted at different representative sites within a given ecosystem over long periods of time to determine the effects of grazing management on the maintenance of pasture productivity and legume persistence. Stocking rate or grazing pressure can interact with the grazing system (Table 2), thereby requiring their inclusion in the design of grazing trials, at least at higher grazing pressures. Spain et al. (1985) have proposed a flexible management system for advanced evaluation of associations of tropical pasture species, incorporating both grazing pressures and grazing system. The methodology is currently being tested at a number of locations in the

Table 2. The interaction between stocking rate and grazing frequency and its effect on legume content in mixtures of *Andropogon gayanus* and *Centrosema macrocarpum* or *C. acutifolium* after 2 years of grazing in Quilichao, Colombia.

<table>
<thead>
<tr>
<th>Stocking rate (animals/ha)</th>
<th>Legume content (% DM) at grazing frequency (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>2.4</td>
<td>17</td>
</tr>
<tr>
<td>3.6</td>
<td>1</td>
</tr>
</tbody>
</table>

a. Animals of 300 kg liveweight.
b. Paddocks were grazed for 3.5 days, every 2, 4, or 6 weeks.

SOURCE: CIAT, unpublished data.
Establishment and management of Centrosema pastures

American tropics. *Centrosema acutifolium*, *C. macrocarpum*, and *C. brassilianum* are included in trials at two locations in Colombia where preliminary results are promising (CIAT 1985, 1986, and 1987).

**Effects of grazing system**

There is considerable debate in the literature on the merits of continuous versus rotational grazing (*t* Mannetje et al., 1976). There is little information on the effects of grazing systems for *Centrosema* species. The few trials that are being conducted are in their preliminary stages (CIAT, 1987). As previously mentioned, any consideration of the effects of a grazing system must take note of possible interactions with stocking rate or grazing pressure. Continuous grazing systems are relatively inexpensive and easier to operate than rotational systems.

One of the difficulties in developing systems of rotational grazing is that innumerable variations are possible in the number of paddocks and length of grazing and rest periods. Differences exist between species and accessions: the cycle length of an optimal rotation for one grass-legume mixture may not be suitable for a different grass-legume mixture. The differential effects of grazing frequency on *C. macrocarpum* and *C. acutifolium* are illustrated in Table 1.

In Ecuador, Santillán (1983) used a central-composite response surface design to compare the effects of a range of grazing days (1 to 28) and rest days (0 to 56) on a compound mixture of grasses and legumes which included *C. pubescens*. After 2 years, grazing days had a negligible effect on legume proportion, but length of the rest period had a very large effect. Legume production was favored by a shortening of the rest period, and moderate rest periods of the order of 28 days were recommended. The importance of the length of rest period is particularly relevant to annual *Centrosema* species where adequate flowering and seed production is essential to persistence. The use of *Centrosema* species in other management systems is discussed by Lascano et al., this volume.

**Future Research**

In recent years, many species of *Centrosema* other than *C. pubescens* have shown good forage potential. Clearly, there is a need to conduct
more research on establishment practices and the effects of management factors with these “new” species.

Detailed studies are probably not necessary on scarification methods. Much can be extrapolated from existing experience, and current methods appear to be applicable to a range of *Centrosera* species. Inoculation studies should continue, with basic research being conducted at major centers. New strains and technology can be later tested, away from the major centers, in regional evaluation trials.

Weeds are a major problem at establishment, especially in forest ecosystems. Research is required to identify effective and low-cost weed-control options for these regions. The use of wick-type herbicide applicators has given good results in these areas and should be pursued further (P. Argel, personal communication). The undersowing of annual crops offers a number of advantages for pasture establishment and should be investigated with different *Centrosera* species. Fertilizer studies are required to define the nutrient requirements for both establishment and maintenance of productivity for “new” accessions on the more important soils. This is of special importance, given the extreme range in soil adaptation which exists within *Centrosera*. Information is also required on the best way to apply fertilizer, and whether split applications have merit.

Perhaps the greatest gap in our knowledge of *Centrosera* concerns the effects of management factors. Basic information on pasture response to management factors is needed to provide a framework for developing a strategy of grazing management that is applicable to a wide range of climatic and edaphic conditions. Persistence is strongly influenced by stocking rate or grazing pressure. However, the importance of the grazing system is, at present, unclear. Some species are likely to persist better under intermittent grazing than under continuous grazing. Therefore, long-term experiments designed to test the effect of grazing systems and their interaction with stocking rate or grazing pressures should be undertaken. If noncontinuous grazing systems are necessary, the optimal combinations of grazing and rest periods will need to be defined.

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Chapter 11

NUTRITIVE VALUE OF
CENTROSEMA AND
ANIMAL PRODUCTION

C. E. Lascano, J. K. Teitzel, and Eng Pei Kong*

Abstract

The nutritive value of *Centrosema* spp. is as high as, or higher than, that of other tropical pasture legumes of economic importance. Variation exists in forage quality between and within species of *Centrosema* according to, for example, protein content, digestibility, and palatability. *Centrosema* spp. appear not to have antiquality factors such as tannins, at levels that significantly depress digestibility or affect plant acceptability.

In the humid tropics, with soils of medium natural fertility, *C. pubescens*-based pastures can produce an annual 500-600 kg of liveweight gain/ha with appropriate grazing management and correction of mineral deficiencies or imbalances. This high level of animal production can also be obtained with *C. macrocarpum*, *C. acutifolium*, and *C. brasiliannum* adapted to acid soils of low natural fertility in the humid tropics. In the wet-dry tropics, with soils of low fertility, the potential annual animal production from *Centrosema* species is 200-300 kg/ha.

The use of *Centrosema* spp. in production systems is very diverse, ranging from use as a supplement to native pastures in extensive cattle production systems to very intensive cropping and plantation agriculture systems. In addition, grass-*Centrosema* spp. pastures can

*Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia; Queensland Department of Primary Industries, South Johnstone, Qld., Australia; and Malaysian Agricultural Research and Development Institute (MARDI), Kluang, Johor, Malaysia, respectively.*
also be integrated with nitrogen-fertilized, prostrate-grass pastures to minimize seasonal fluctuations in forage availability, resulting from such environmental stresses as cold or dry periods.

Introduction

The nutritive value of a forage plant is dependent on the quantity eaten and the degree to which the plant supplies essential nutrients to the animal. Because intake and nutrient composition vary with climatic conditions, soil fertility, and plant maturity, it is very difficult to rank forage species in terms of nutritive value unless grown under the same environment. Similarly, it is difficult to realistically compare the various animal-production data from grazing trials conducted in different locations, on different soil types, with different fertilizer inputs, and different grazing-management treatments. Nevertheless, this chapter attempts to summarize information on the quality of Centrosema forage, on animal production from pastures based on Centrosema, and on integration of these pastures in different production systems.

Quality of Centrosema Forage

Differences between Centrosema and other tropical legumes

The nutritive value of C. pubescens (commercial centro) is well documented in the literature. Centro usually has high protein content (17%-25%) but medium digestibility (50%-55%). However, only a few studies have compared the nutritive value of Centrosema spp. forage with that of other tropical legumes grown under the same conditions. In Table 1, studies are summarized in which several tropical legumes have been compared in terms of crude protein (CP) and in vitro dry-matter digestibility (IVDMD) of tissue of similar age. The study of Abaunza Amador (1982) included Centrosema hybrid CIAT 438 which had high levels of protein (30%) but medium digestibility (54%) in leaf tissue compared with the other legumes in the experiment. Similarly, Reid et al. (1973) found that centro had lower digestibility than Macroptilium atropurpureum and Pueraria phaseoloides. Other Centrosema species such as C. macrocarpum and C. arenarium, have shown high protein levels and digestibility coefficients, particularly when compared with
Table 1. Crude protein (CP) and in vitro dry-matter digestibility (IVDMD) of some legume species, including *Centrosema*, at similar maturity stages.

<table>
<thead>
<tr>
<th>Legume</th>
<th>CP (%)</th>
<th>IVDMD (%)</th>
<th>Maturity stage</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Centrosema pubescens</em></td>
<td>—</td>
<td>57</td>
<td>Mean of cuttings</td>
<td>Reid et al., 1973</td>
</tr>
<tr>
<td><em>Desmodium intortum</em></td>
<td>—</td>
<td>54</td>
<td>every 5, 8, 12, and 16 weeks</td>
<td></td>
</tr>
<tr>
<td><em>Macroptilium atropurpureum</em></td>
<td>—</td>
<td>62</td>
<td>16 weeks</td>
<td></td>
</tr>
<tr>
<td><em>Pueraria phaseoloides</em></td>
<td>—</td>
<td>62</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Centrosema</em> hybrid (438)²</td>
<td>30</td>
<td>54</td>
<td>Mean of leaf cuttings every 3, 6, 9, 12, and 15 weeks</td>
<td>Abaunza Amador, 1982</td>
</tr>
<tr>
<td><em>Zornia</em> sp. (9648)</td>
<td>31</td>
<td>71</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Stylosanthes guianensis</em></td>
<td>24</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>S. hamata</em> (147)</td>
<td>23</td>
<td>69</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>S. capitata</em> (1315)</td>
<td>21</td>
<td>59</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>D. ovalifolium</em> (350)</td>
<td>17</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Aeschynomene histrix</em></td>
<td>31</td>
<td>66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(9690)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>P. phaseoloides</em> (9900)</td>
<td>28</td>
<td>59</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. macrocarpum</em> (5065)</td>
<td>30</td>
<td>66</td>
<td>Leaf cuttings in mature stage</td>
<td>CIAT, 1984</td>
</tr>
<tr>
<td><em>C. arenarium</em> (5236)</td>
<td>24</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>D. ovalifolium</em> (350)</td>
<td>17</td>
<td>44</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Rhynchosia reticulata</em></td>
<td>22</td>
<td>46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(8173)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Dioclea guianensis</em> (9311)</td>
<td>18</td>
<td>43</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>21</td>
<td>56</td>
<td>Green leaf cuttings, average 3 years</td>
<td>Jones and Clements, 1987</td>
</tr>
<tr>
<td><em>Vigna parkeri</em></td>
<td>26</td>
<td>61</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Values in parentheses are CIAT accession numbers.

Legumes high in tannins such as *Desmodium ovalifolium*, *Rhynchosia reticulata*, and *Dioclea guianensis* (CIAT, 1984). More recent results (Jones and Clements, 1987) have shown that *Vigna parkeri* had higher protein levels, digestibility, and P levels than *C. virginianum*.

The mineral composition of common *C. pubescens* has also been widely studied and results indicate that the concentration of most important elements in centro meet animal requirements (Wilson et al., 1981). Obviously, this changes with soil-fertility status within or between sites. In other studies (Abaunza Amador, 1982), P and S levels in leaves of *Centrosema* hybrid CIAT 438 averaged 0.26% and 0.30%, respectively, being higher than in *Stylosanthes* spp. (0.17% of P and 0.25% of S) and *D. ovalifolium* (0.15% of P and 0.18% of S).
Very few studies on voluntary intake of Centrosema spp. compared with other tropical legumes are reported in the literature. In one study conducted at CIAT, intake of mature C. macrocarpum CIAT 5065 fed to sheep housed in metabolism crates was 15% higher than that of Stylosanthes macrocephala CIAT 1643 and 41% higher than S. guianensis var. pauciflora CIAT 1283, also in a mature stage (Villaquirán and Lascano, 1986). The higher voluntary intake of C. macrocarpum was associated with a greater proportion of leaf (43%) relative to that of S. macrocephala (17.5%) and S. guianensis var. pauciflora (35%). In vivo dry-matter digestibility was also higher in C. macrocarpum (64.5%) than in the other two legumes (46% and 55.5% for S. macrocephala and S. guianensis var. pauciflora, respectively).

Differences among species of Centrosema

Again, very few studies have been reported in which the nutritive value of different species of Centrosema have been compared under similar conditions. In a recent survey of nine Centrosema species (Table 2), the crude-protein content of young leaf tissue was high in all species, ranging from 22.6% in C. acutifolium CIAT 5568 to 29.6% in C. pubescens CIAT 5189. In vitro digestibility values were also very high, ranging from 60.2% in C. acutifolium CIAT 5568 to 72.2% in C. macrocarpum CIAT 5065 and 74.6% in C. acutifolium CIAT 5277. The

Table 2. Crude-protein (CP) content, in vitro dry-matter digestibility (IVDMD), and tannin contents of leaves of immature Centrosema forage.

<table>
<thead>
<tr>
<th>Species</th>
<th>CIAT accession no.</th>
<th>CP (%)</th>
<th>IVDMD (%)</th>
<th>Tannins (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. acutifolium</td>
<td>5277</td>
<td>24.9</td>
<td>74.6</td>
<td>0.10</td>
</tr>
<tr>
<td>C. acutifolium</td>
<td>5568</td>
<td>22.6</td>
<td>60.2</td>
<td>2.10</td>
</tr>
<tr>
<td>C. arenarium</td>
<td>5236</td>
<td>25.7</td>
<td>63.3</td>
<td>0.19</td>
</tr>
<tr>
<td>C. brasilianum</td>
<td>5234</td>
<td>27.3</td>
<td>71.6</td>
<td>0.12</td>
</tr>
<tr>
<td>C. macrocarpum</td>
<td>5065</td>
<td>26.4</td>
<td>72.2</td>
<td>0.23</td>
</tr>
<tr>
<td>C. pascuorum</td>
<td>5230</td>
<td>27.1</td>
<td>63.8</td>
<td>0.11</td>
</tr>
<tr>
<td>C. pubescens</td>
<td>5189</td>
<td>29.6</td>
<td>66.7</td>
<td>0.11</td>
</tr>
<tr>
<td>C. schiedeanum</td>
<td>5920</td>
<td>25.9</td>
<td>71.1</td>
<td>—</td>
</tr>
<tr>
<td>C. &quot;tetragonolobum&quot;</td>
<td>15087</td>
<td>28.0</td>
<td>64.8</td>
<td>4.00</td>
</tr>
<tr>
<td>C. vexillatum</td>
<td>15055</td>
<td>27.8</td>
<td>64.8</td>
<td>4.00</td>
</tr>
</tbody>
</table>

a. Samples taken 6 months after planting.
b. Vanillin-HCl method.

SOURCE: CIAT, unpublished data.
high in vitro digestibility values observed were associated with low levels of tannins, which are known to depress the digestibility of a number of tropical legumes (Ford, 1978; Hutton and Coote, 1966; Lascano and Salinas, 1982). The low tannin concentration of some Centrosema species (C. arenarium and C. macrocarpum) has also been associated with a high rate of ruminal degradation of their nitrogen fraction as compared with legumes high in tannins such as D. ovalifolium, R. reticulata, and Dioecia guianensis (CIAT, 1984).

From other results, summarized in Table 3, it is inferred that some species of Centrosema have digestibility coefficients and protein content as high as, or higher than, those of common C. pubescens. The digestibility of C. brasilianum, C. acutifolium, C. macrocarpum, C. arenarium, and C. plumieri is higher than that of centro. Protein values reported for Centrosema species range from 15% to 34% with the lower extreme in C. pascuorum and higher extreme in Centrosema hybrid.

In samples of Centrosema forage taken from the Eastern Plains (Llanos Orientales) of Colombia in pastures under the same grazing management, protein levels of C. acutifolium CIAT 5277 were similar to C. macrocarpum CIAT 5452 but consistently higher than in C. brasilianum CIAT 5234. These differences were associated with heavy infestation of C. brasilianum with rhizoctonia foliar blight (Rhizoctonia spp.) during the rainy season (CIAT, 1987).

The mineral content of C. pascuorum, C. acutifolium, C. brasilianum, and C. macrocarpum is similar to that of centro (Clements et al., 1984; R. Schultze-Kraft, personal communication).

**Differences among accessions of individual Centrosema species**

With “new” Centrosema species being evaluated and selected in Australia and Colombia there has been continued interest in determining differences in nutritive value between accessions or ecotypes. One early study in Australia with 19 accessions of C. virginianum indicated significant differences between accessions in leaf and stem digestibility (Clements, 1977). In a later study, Clements et al. (1984) evaluated 10 accessions of C. pascuorum in northern Australia and found little difference in protein and mineral content between accessions.
Table 3. Crude-protein (CP) content and in vitro dry-matter digestibility (IVDMD) of *Centrosema* species.

<table>
<thead>
<tr>
<th>Species</th>
<th>CP (%)</th>
<th>IVDMD (%)</th>
<th>Observations</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. pubescens</em></td>
<td>17-25</td>
<td>45-65</td>
<td>Range of values from literature review</td>
<td>Abaunza Amador, 1982</td>
</tr>
<tr>
<td><em>Centrosema</em> hybrid (438)*</td>
<td>26-34</td>
<td>46-61</td>
<td>Leaf cuttings from 3 to 15 weeks regrowth</td>
<td>Reid et al., 1973</td>
</tr>
<tr>
<td><em>C. plumieri</em></td>
<td>—</td>
<td>59-70</td>
<td>Whole plant cuttings from 4 to 20 weeks regrowth</td>
<td></td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>—</td>
<td>54-59</td>
<td>Leaf cuttings</td>
<td>Clements, 1977</td>
</tr>
<tr>
<td><em>C. pascuorum</em></td>
<td>15</td>
<td>—</td>
<td>Whole plant cuttings, average of 10 accessions</td>
<td>Clements et al., 1984</td>
</tr>
<tr>
<td><em>C. brasilianum</em></td>
<td>23-29</td>
<td>48-56</td>
<td>Leaf cuttings of 3 months regrowth, range in 7 ecotypes</td>
<td>Belalcázar and Schultze-Kraft, 1986</td>
</tr>
<tr>
<td><em>C. arenarium</em> (5236)</td>
<td>24</td>
<td>60</td>
<td>Leaf cuttings of 6 months regrowth</td>
<td>CIAT, 1984</td>
</tr>
<tr>
<td><em>C. macrocarpum</em> (5065)</td>
<td>25</td>
<td>58</td>
<td>Leaf cuttings, mature plant</td>
<td>Villaquirán and Lascano, 1986</td>
</tr>
<tr>
<td><em>C. brasilianum</em> (5234)</td>
<td>20</td>
<td>42</td>
<td>Whole plant cuttings of legumes in association with grasses and under grazing</td>
<td>CIAT, 1987</td>
</tr>
<tr>
<td><em>C. macrocarpum</em> (5452)</td>
<td>25</td>
<td>46</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. acutifolium</em> (5277)</td>
<td>30</td>
<td>47</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. pubescens</em> (centro)</td>
<td>26</td>
<td>52</td>
<td>Average of 8 harvest at 3-month intervals for crude protein and 1 harvest for IVDMD (leaf tissue)</td>
<td>Schultze-Kraft et al., 1985</td>
</tr>
<tr>
<td><em>C. acutifolium</em></td>
<td>25</td>
<td>58</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. brasilianum</em></td>
<td>23</td>
<td>58</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>24</td>
<td>55</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. pubescens</em></td>
<td>26</td>
<td>54</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. arenarium</em></td>
<td>25</td>
<td>56</td>
<td>Tissue of 3 months regrowth</td>
<td>R. Schultze-Kraft, pers. comm.</td>
</tr>
<tr>
<td><em>C. brachypodium</em></td>
<td>26</td>
<td>57</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
In Colombia, Schultze-Kraft et al. (1985) evaluated eight accessions of *C. macrocarpum* and found that CP ranged from 25% to 28% and IVDMD ranged from 49% to 53% in 3-month-old leaves. Schultze-Kraft and Belalcázar (1988) evaluated 130 accessions of *C. brasilianum* and found that CP levels in tissues 3.5-months old ranged from 11.8% to 19.6% with values following a normal distribution. Most of the accessions (75%) fell within a range of 15.8% to 19.6% protein. In another study, Belalcázar and Schultze-Kraft (1986) determined CP and IVDMD in the leaf tissue of seven ecotypes of *C. brasilianum*, representing the wide geographic distribution of the species. Protein levels were low in *C. brasilianum* CIAT 5234 (22.5%) compared with the other six ecotypes which averaged 27.4%. The in vitro dry-matter digestibility during the wet season was lowest (43.7%) in CIAT 5588 which was very susceptible to *Rhizoctonia*; the rest of the ecotypes averaged 49.7% digestibility. The P and Ca levels were similar in all seven ecotypes, averaging 0.27% and 0.68%, respectively.

In *C. acutifolium*, Schultze-Kraft et al. (1987) found that in tissue of similar age, variety “orinocense” ecotypes such as accession CIAT 5277, have consistently averaged higher digestibility (66%) and protein content (29%) than variety “matogrossense” ecotypes such as CIAT 5568, (57% and 24%, respectively). Such consistent difference is probably explained by the higher concentrations of tannins in the var. “matogrossense” (CIAT 5568 in Table 2).

In general, according to the scattered data available, *Centrosema* forage has as high as, or higher, nutritive value than that of other tropical legumes. As a genus, *Centrosema* appears to have higher nutrient concentration and digestibility than *Stylosanthes* spp. and *Desmodium* spp. which are of economic importance in many tropical and subtropical areas. It also appears that variation exists in protein level and digestibility between and within species of *Centrosema*. However, it is doubtful that such differences per se would be reflected in animal performance when the legumes are in mixtures with grasses. Other attributes such as intake associated with plant acceptability by the grazing animal and nitrogen fixation, would be more related to animal production in grazing situations.

From the evidence available, *Centrosema* forage does not have antiquality factors such as tannins, at levels that depress digestibility or affect palatability. This suggests that breeding to increase nutritive value of *Centrosema* spp. ought not be of high priority in current programs.
Palatability of *Centrosema* Forage

The term "relative palatability" has been used by several authors to refer to the general acceptability of forage species by grazing animals when given a choice of selection. In this context, only few studies, usually involving “cafeteria” type grazing experiments, have been published for *Centrosema* species. In an early study of Warmke et al. (1952), 11 tropical legumes were evaluated for relative palatability in a “cafeteria” trial. Among the legumes included, centro ranked fourth in preference, indicating no problems of acceptability. More recently, Abaunza Amador (1982) found that *Centrosema* hybrid CIAT 438 had a lower relative preference than *Stylosanthes capitata*, but higher than *Desmodium ovalifolium* and *Dioclea guianensis*.

Palatability studies that included other species of *Centrosema* have been conducted at CIAT and some of the results have been published by Lascano et al. (1985). In these studies, during both the dry and wet seasons, the palatability indexes of *C. macrocarpum* CIAT 5065 have been higher than the indexes of other legumes in the test (*Desmodium ovalifolium*, *Centrosema arenarium*, *Dioclea guianensis*, *Calopogonium caeruleum*, and *Rhynchosia reticulata*). However, *C. arenarium* CIAT 5236 received lower preference than *D. ovalifolium* CIAT 350 which is of known low palatability, but higher acceptability than *D. guianensis*, *C. caeruleum*, and *R. reticulata*. In another “cafeteria” test (CIAT, 1986), the relative preference for *C. acutifolium* CIAT 5568 was much higher in the dry and wet seasons than it was for *Zornia* sp., *Z. glabra*, *Desmodium velutinum*, *Stylosanthes guianensis*, *S. viscosa*, *Tadehagi* sp., and *Flemingia macrophylla*. The high relative acceptability of *C. acutifolium* was confirmed in a subsequent “cafeteria” test which included a number of legume species: *D. ovalifolium*, *D. heterocarpon*, *D. strigillosum*, *Tadehagi* sp., *Phyllodium* sp., and *Dendrolobium* sp. (R. Schultze-Kraft, personal communication).

From the evidence available, it appears that there are differences in palatability between *Centrosema* species. There are highly palatable species such as *C. pubescens*, *C. macrocarpum*, and *C. acutifolium*, but unpalatable species such as *C. arenarium*.

Further studies on palatability of *Centrosema* spp. are needed, because the resulting information will prove valuable for identifying potential alternative uses of new *Centrosema* species in different pasture and production systems.
Grazing Selectivity in Pastures Based on *Centrocoma* spp.

It is usually accepted that, in a number of grass-legume pastures, animals preferentially graze the legume during the dry season of the year (Böhnert et al., 1985; Gardener, 1980; Hunter et al., 1976) or when the quality of the companion grass declines (Lascano et al., 1981).

Grazing studies in small plots have shown that *Centrocoma* hybrid CIAT 438, in association with *Andropogon gayanus*, *Brachiaria decumbens*, and *Panicum maximum* and under common grazing, was consumed more toward the end of the grazing period (11% in the diet) than at the beginning (1.4%) (Lascano et al., 1981). In a grazing trial currently in progress in the Colombian Llanos, *C. acutifolium* CIAT 5277 and CIAT 5568 in association with *A. gayanus* have been preferentially grazed in the dry season, regardless of grazing-management treatment (CIAT, 1987). Legume proportion in the diet during the rainy season averaged 5% across stocking rates and increased to 76% during the dry season. Similar results have been observed in another location in a grazing trial with *A. gayanus-C. macrocarpum* CIAT 5713 and *A. gayanus-C. acutifolium* CIAT 5568 and CIAT 5277. The selection index (that is, the percentage of legume in diet over the percentage of legume on offer) for *C. acutifolium* was 0.14 in a period of maximum rainfall and increased to 2.1 in the dry season. Similarly, the selection index for *C. macrocarpum* was 0.90 in the wet season and increased to 1.4 in the dry period of the year (CIAT, 1987). The higher selection index for *C. macrocarpum* during the rainy season as compared with *C. acutifolium* may reflect higher palatability, but also higher proportion in the forage on offer.

Differences in selectivity under grazing may be expected when comparing cattle and sheep. A pasture mixture of *A. gayanus-C. acutifolium* was established at Quilichao, Colombia, and grazed separately by cattle and sheep. In a short period of time, large differences were observed in legume proportion in the two pastures because of different selection patterns. After 140 days of grazing, *C. acutifolium* practically disappeared in the paddocks grazed by sheep, but persisted in the pasture grazed by cattle. Dietary samples taken with esophageal-fistulated steers and sheep in the *Centrocoma*-grass pastures have shown that, while sheep selected 36% of legume, cattle selected only 8% (C. E. Lascano, unpublished results).
In general, it appears that, in pastures based on *Centrosea*, animals preferentially graze the legume in the dry periods of the year when the quality of the companion grass is low, particularly in terms of protein. This is similar to what has been observed in other grass-tropical legume pastures, involving legumes such as siratro, tropical kudzu, *S. humilis*, *S. hamata*, and *S. capitata*. It is also apparent that different animal species exhibit different selection habits toward *Centrosea* forage, with sheep having a higher preference for the legume than cattle.

**Animal Production from *Centrosea* Pastures**

**Cattle liveweight gains (LWG) from pastures based on centro (C. pubescens)**

Common *C. pubescens* is cultivated not only as a plantation cover crop, but also as a forage plant for ruminant animals in the wet tropical areas of the world where soils such as Inceptisols, are of medium natural fertility. Successful centro-based pastures have been reported with a number of grasses in East Africa, Australia, tropical America, and Southeast Asia and the Pacific. Annual productivity values ranged from 260 to 607 kg of LWG/ha (Table 4). Other examples of results in this range have been obtained in the Solomon Islands, Uganda, Brazil, Australia, and the Philippines.

Among the highest and most widely quoted animal-production values recorded from a centro-based pasture was 904 kg of LWG/ha in Queensland, Australia (Mellor et al., 1973). This high production level was obtained from *P. maximum*-centro in the first year of an experiment established on a naturally fertile soil recently cleared of rain forest. By the third year of the experiment, production had declined to 558 kg/ha. Subsequent work is showing that the high first-year animal gains resulted from initial high soil-nitrogen reserves in the freshly cleared rain-forest land, rather than to nitrogen input from centro.

A realistic estimate of productivity of *P. maximum*-centro pastures is provided by a recent grazing-systems study carried out over a 12-year period on soils which had been cleared of rain forest 10-20 years before (J. K. Teitzel, unpublished data). In this study, Guinea grass-centro pastures consistently produced an annual LWG of 500 to 600 kg/ha during the first 7 years before the steady application of higher stocking rates resulted in heavy weed infestation. Subsequent destocking and
Table 4. Annual liveweight gains (LWG) of cattle grazing grass-legume mixtures based on *C. pubescens*. Some comparisons with nitrogen-fertilized grass alone are given.

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Legume</th>
<th>LWG (kg/ha)</th>
<th>N fertilization (kg/ha/yr)</th>
<th>LWG (kg/ha)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruzi</td>
<td>centro</td>
<td>511</td>
<td>165</td>
<td>650</td>
<td>Mellor et al., 1973</td>
</tr>
<tr>
<td>Guinea</td>
<td>centro</td>
<td>450</td>
<td>168</td>
<td>585</td>
<td>Grof and Harding, 1970</td>
</tr>
<tr>
<td>Pangola</td>
<td>centro</td>
<td>410</td>
<td>100</td>
<td>531</td>
<td>Aronovich et al., 1970</td>
</tr>
<tr>
<td>Para</td>
<td>centro</td>
<td>305</td>
<td>200</td>
<td>310</td>
<td>Magadan et al., 1974</td>
</tr>
<tr>
<td>Guinea + Rhodes + <em>Hyparrhenia rufa</em></td>
<td>centro + stylo</td>
<td>315</td>
<td>140</td>
<td>393</td>
<td>Stobbs, 1969c</td>
</tr>
<tr>
<td>Guinea</td>
<td>centro + stylo + puero</td>
<td>410</td>
<td>150</td>
<td>665</td>
<td>Eng et al., 1978</td>
</tr>
<tr>
<td>Splendida setaria</td>
<td>centro</td>
<td>561</td>
<td>—</td>
<td>—</td>
<td>Bauer, 1984</td>
</tr>
<tr>
<td>Kazungula setaria</td>
<td>centro</td>
<td>480</td>
<td>—</td>
<td>—</td>
<td>Bauer, 1984</td>
</tr>
<tr>
<td>Napier</td>
<td>centro</td>
<td>475</td>
<td>—</td>
<td>—</td>
<td>Montemayor, 1974</td>
</tr>
<tr>
<td>Kazungula setaria</td>
<td>centro + stylo + puero</td>
<td>360</td>
<td>—</td>
<td>—</td>
<td>Clayton, 1983</td>
</tr>
<tr>
<td>Transvala digit</td>
<td>centro + stylo + <em>Desmodium ovalifolium</em></td>
<td>353</td>
<td>—</td>
<td>—</td>
<td>Eng, 1981</td>
</tr>
<tr>
<td>Molasses grass</td>
<td>centro</td>
<td>268</td>
<td>—</td>
<td>—</td>
<td>Sartini et al., 1979</td>
</tr>
<tr>
<td>African star grass</td>
<td>centro</td>
<td>260</td>
<td>—</td>
<td>—</td>
<td>Oyenuga and Olubajo, 1966</td>
</tr>
<tr>
<td>African star grass</td>
<td>centro</td>
<td>370</td>
<td>—</td>
<td>—</td>
<td>Okorie et al., 1965</td>
</tr>
<tr>
<td>Para</td>
<td>centro + siratro + Endeavour stylo</td>
<td>607</td>
<td>—</td>
<td>—</td>
<td>Watson and Whiteman, 1981a</td>
</tr>
</tbody>
</table>

(Continued)
Table 4. (Continued)

<table>
<thead>
<tr>
<th>Grassa</th>
<th>Legumeb</th>
<th>LWG (kg/ha)</th>
<th>Grass alone</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal</td>
<td>centro + siratro + Endeavour stylo</td>
<td>442</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Watson and Whiteman, 1981a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hamil Guinea</td>
<td>Centro + siratro + Endeavour stylo</td>
<td>362</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Watson and Whiteman, 1981a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Scientific names of the grasses are ruzi = *Brachiaria ruziensis*; Guinea = *Panicum maximum*; pangola = *Digitaria decumbens*; Para = *B. mutica*; Rhodes = *Chloris gayana*; setaria = *Setaria anceps*; napier = *Pennisetum purpureum*; transvala digit = *Digitaria decumbens*; molasses grass = *Melinis minutiflora*, African star grass = *Cynodon plectostachyus*; signal = *B. decumbens*.

b. Scientific names of the legumes are centro = *Centrosema pubescens*; stylo = *Stylosanthes guianensis*; puerro = *Pueraria phaseoloides*; siratro = *Macroptilium atropurpureum*.

Slashing of weeds, followed by gradual restocking (to 2.5 animals/ha on common Guinea grass-centro and 3.5 animals/ha on Makueni Guinea grass-Belalto centro) resulted in weed suppression by Guinea grass-centro and a return to earlier levels of animal gains. This demonstration of pasture “resilience” is considered to be of commercial significance.

Other studies which have also shown high and sustainable production levels of an annual 500 to 600 kg of LWG/ha from pasture mixtures containing centro have been reported by Eng et al. (1978), Rika et al. (1981), Smith and Whiteman (1985b), and Watson and Whiteman (1981b). These studies were preceded by reliable assessments of soil-fertility status, and mineral deficiencies were corrected where necessary. It is therefore possible that the lower production levels reported in other studies are related to mineral deficiencies or imbalances.

The literature usually suggests that animal production from a particular grass can be increased by the inclusion of centro alone or in mixture with other legumes. However, still further increases are often obtained by applying nitrogen fertilizer (Table 4). For example, Grof and Harding (1970) in Australia measured annual LWG/ha increases of 37% from Guinea grass-centro and 108% from Guinea grass with 168 kg of N/ha over unfertilized Guinea grass alone.

Other experiments have shown significant increases in LWG by introducing centro to improved grass pastures (pangola) (Garza Treviño...
et al., 1978) or to native grasslands (Imperata cylindrica) (Siota et al., 1977). Vilela et al. (1983) found that growth rates of animals receiving an urea-and-mineral supplement while grazing a grass pasture were similar to those in unsupplemented animals grazing a grass-centro-glycine (Neonotonia wightii) mixture. Both groups of animals had growth rates which were almost twice those of an unsupplemented group grazing B. decumbens alone.

Thus, in the humid tropics, on soils of medium-natural fertility such as Inceptisols, centro-based pastures can produce 500-600 kg of LWG/ha annually and daily gains of 400-600 g/animal, depending on the stocking rate. However, further increases in LWG are obtained with the application of nitrogen fertilizer.

Milk production from pastures based on centro (C. pubescens)

Very few data are available on milk production from centro-based pastures. Two relevant studies were conducted in Brazil. At Campo Grande, Serpa et al. (1973) measured a daily milk production of 6.9 kg per cow grazing unfertilized pangola grass, 8.7 kg with pangola grass and 140 kg of N/ha, and 7.9 kg with pangola grass mixed with centro. In a second study at Nova Odessa, Velloso and de Freitas (1973) measured a daily milk production of 9.7 kg per cow grazing Pennisetum purpureum alone, 9.5 kg with P. purpureum mixed with legumes (centro included), 6.8 kg with Brachiaria mutica alone, and 7.9 kg with B. mutica mixed with legumes, including centro.

Another relevant experiment was conducted in a humid forest region of Peru (Tarapoto) on an acid soil of low natural fertility (Alfisol). During one year, milk production was measured from pastures containing Andropogon gayanus-Centrosema hybrid CIAT 438, and Brachiaria decumbens and 184 kg of N/ha. Daily milk production per cow was greater from the grass-legume mixture (10.3 kg) than from the nitrogen-fertilized grass (8.4 kg) during the rainy season, but was similar during the dry season (6.7 and 7.3 kg, respectively) (R. Pérez and W. López, personal communication).

Results on milk production from Centrosema-based pastures are in general agreement with the Australian field studies of Cowan et al. (1974). He found that, when grazing tropical pastures, Friesian cows produce a daily average of 10 to 12 kg of milk per head, Jersey cows 7 to 9 kg per head, and crossbred cows 6 to 10 kg per head.
Cattle liveweight gains from pastures based on other
_Centrosema_ species

Highly productive _Centrosema_ species adapted to acid, low-fertility soils such as Oxisols and Ultisols, have been identified in the selection process carried out by CIAT's Tropical Pastures Program. Several grazing trials have been established in Colombia in the Oxisols of the Llanos (Carimagua) and Ultisols of the Cauca Valley (Quilichao) with _C. acutifolium_, _C. macrocarpum_, and _C. brasiliannum_ in association with _A. gayanus_ and _Brachiaria_ spp.

In one trial at Carimagua, animal productivity was measured from pastures with legume mixtures of _C. macrocarpum_ CIAT 5065-S. _capitata_ CIAT 1019 and _C. brasiliannum_ CIAT 5234-S. _capitata_ CIAT 1315, each mixture in association with _A. gayanus_ cv. Carimagua 1. Grazing-management treatments included continuous and rotational grazing (7 days grazing with 21 days rest) with set stocking (2 animals/ha). For 2 consecutive years, considerable liveweight gains were recorded (Table 5). They were higher from these mixtures (150 kg/animal each year) than from grass alone (100 kg/animal each year—data not given in Table 5), with the main benefit of the mixture being during the 4-to-5-months dry season. During this period, animals lost weight, by as much as 100 g/day, on the grass alone, but gained weight, by as much as 67 g/animal each day, on the mixtures, particularly on the _C. brasiliannum-S. capitata_ mixture (Table 5). This is presumably because _C. brasiliannum_ is particularly drought tolerant. Of the two _Centrosema_ species planted, only _C. brasiliannum_ CIAT 5234 persisted (17%-19% in the sward) by the end of the third year of grazing, in spite of heavy _Rhizoctonia_ attack during the wet season. One important attribute of _C. brasiliannum_ in these pastures was high seed production which undoubtedly contributed, by soil-seed reserves, to legume persistence.

A recently established experiment at Carimagua uses _A. gayanus_ in association with _C. acutifolium_ CIAT 5277 and CIAT 5568 under continuous grazing with three stocking rates (0.75, 1.0, and 1.5 animals/ha) and under rotational grazing at the high stocking rate (1.5 animals/ha). Results after 2 years of grazing (Table 5) are very encouraging, in terms of animal gains and legume proportion in the pasture and under the different management treatments imposed. After 2 years of grazing, annual liveweight gains varied between 132 kg/animal at the high stocking rate under continuous grazing and 165 kg/animal at the low stocking rate. As with pastures based on _C.
Table 5. Cattle performance on pastures based on “new” *Centroloba* species in Colombia.

<table>
<thead>
<tr>
<th>Location</th>
<th>Legume in association with <em>A. gayanus</em></th>
<th>Daily liveweight changes (g/animal)</th>
<th>Observations and sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Dry season</td>
<td>Wet season</td>
</tr>
<tr>
<td><strong>Llanos Orientales</strong></td>
<td><em>C. macrocarpum</em> CIAT 5065 + <em>S. capitata</em> CIAT 1019</td>
<td>-40 to 39</td>
<td>569 to 708</td>
</tr>
<tr>
<td>(Carimagua)</td>
<td><em>C. brasilianum</em> CIAT 5234 + <em>S. capitata</em> CIAT 1315</td>
<td>34 to 67</td>
<td>661 to 667</td>
</tr>
<tr>
<td><strong>Llanos Orientales</strong></td>
<td><em>C. acutifolium</em> CIAT 5277 + CIAT 5568</td>
<td>-9 to 115</td>
<td>530 to 671</td>
</tr>
<tr>
<td>(Carimagua)</td>
<td></td>
<td></td>
<td>Continuous grazing with 3 stocking rates (0.75, 1.0, and 1.5 beasts/ha) and rotational grazing (1.5 beasts/ha) over 2 years (CIAT, 1987)</td>
</tr>
<tr>
<td><strong>Cauca Valley</strong></td>
<td><em>C. acutifolium</em> CIAT 5277 + CIAT 5568</td>
<td>262 to 304</td>
<td>532 to 603</td>
</tr>
<tr>
<td>(Quilichao)</td>
<td><em>C. macrocarpum</em> CIAT 5713</td>
<td>445 to 471</td>
<td>579 to 711</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexible grazing management with two grazing pressures over 1 year (CIAT, 1987)</td>
</tr>
</tbody>
</table>

a. Seven days grazing with 21 days rest.
brasilianum, the animals gained weight in the dry season by as much as 115 g/animal each day, because of the excellent performance of the legume during this critical part of the year. Legume proportion in the pasture has ranged from 20% to 40%, suggesting an ability to persist under different management options.

A third, and more recently established, grazing trial with “new” Centroema species is currently being conducted at Quilichao, a site characterized by an acid soil of low fertility but high organic matter (Ultisol) and by a bimodal rainfall distribution. In this experiment, associations of *C. acutifolium* accessions CIAT 5277 and CIAT 5568 and *C. macrocarpum* CIAT 5713 with *A. gayanus* cv. Carimagua 1 are being grazed at two ranges of grazing pressures (3-5 and 6-8 kg of green dry matter/day for every 100 kg of LW), using the flexible management strategy proposed by Spain et al. (1985). Results show that *C. macrocarpum* CIAT 5713 is better adapted to this environment than *C. acutifolium* CIAT 5277 and CIAT 5568. This is reflected in the higher legume contents in the pasture and greater animal gains, particularly during periods of low rainfall. The annual animal production potential from these pastures is 170-200 kg/animal and 400-600 kg/ha (Table 5). This potential is much greater than would be expected in the Llanos (200-300 kg/ha), but similar to what has been reported from humid areas with soils of medium, natural fertility, using Guinea grass-centro pastures, and from humid forest regions with acid soils of low fertility, using *A. gayanus-Centroema* hybrid CIAT 438 (Reátegui et al., 1985).

Some information is available on animal production from pastures containing *C. pascuorum* or *C. brasilianum* in Australia (Clements, this volume). The pastures have been used for dry-season grazing. Cattle have gained or maintained weight on these pastures at a time when substantial losses in liveweight are recorded on native pastures.

**Grazing Management of Centroema-Based Pastures**

Cattle liveweight gains in *Centroema*-based pastures are influenced by stocking rate. In wet tropical areas, sustainable stocking rates for *C. pubescens*-based pastures vary between 1 and 3 steer equivalents/ha. However, this range narrows to 2 to 3 steers/ha when soil mineral deficiencies are corrected. In areas with a defined dry season and with acid, infertile soils such as the Colombian Llanos, pastures based on
“new” *Centrocomma* spp. have carried as many as 2 steers/ha with relatively high levels of animal performance (150 kg/animal annually).

The effect of the grazing system on animal gains on *Centrocomma*-based pastures is not consistent. In Australia, for example, Grof and Harding (1970) found that with the same stocking rate, an alternate grazing system produced 15% more LWG than continuous grazing from a Guinea grass-centro pasture. However, Stobbs (1969a), in Uganda, found no significant difference in LWG between a 17.5- and 35-days grazing cycle in a pasture with legumes, including *C. pubescens*, when grazed at the same stocking rate. Similarly in the Colombian Llanos, liveweight gains from an *A. gayanus-C. brasilianum-S. capitata* pasture were not different under continuous and rotational grazing, using the same stocking rate. However, in this study, the grazing system had a significant effect on the botanical composition of the pasture. Some pastures under continuous grazing were legume dominant (57%) and heavily invaded by native species, whereas pastures rotationally grazed were more balanced in terms of grass-legume components (17% legume) (CIAT, 1987). An effect of the grazing system on the botanical composition of legume-based pastures has also been observed with *P. maximum*-siratro in Uganda (Stobbs, 1969b). It appears that the grazing system can affect the botanical composition of *Centrocomma* pastures which, in the long run, will also influence animal production.

**Integration of *Centrocomma* Pastures in Production Systems**

**Integration with native pastures**

One of the problems of raising cattle in the tropics is the fluctuating liveweight of animals through the year as a consequence of poor performance during the dry season, particularly when grazing native pastures (Paladines and Leal, 1979). Integration of pastures based on *Centrocomma* spp. with native grasses can help overcome dry-season constraints. Separate land areas of native grasses and *Centrocomma*-improved grass pastures can be used strategically at different periods of the year according to the category of animal such as lactating cows with high nutritional requirements or fattening steers (Lascano and Spain, 1986; Winks, 1975). Alternatively, *Centrocomma* pastures can be used as standover or deferred feed (Horrell, 1958). In this system, cattle graze native pastures during the growing season and in the dry season graze a
Centrocesta-based pasture that has been deferred to take advantage of the high quality of the legume for this time of the year.

Another alternative use of Centrocesta spp. is in association with native grasses that are managed without fire. This strategy includes strip-planting the legume in the native pasture to enhance the use of native grasses by the grazing animal, resulting in an increased carrying capacity and greater LWG per animal as has been shown in the Colombian Llanos with S. capitata while it persisted in the pastures (CIAT, 1987).

Integration with improved pastures

Various grass-Centrocesta pastures are able to support fairly high levels of animal production, but with fluctuations resulting from seasonal effects such as cold or dry periods, on the growth of the pasture. Management problems associated with this uneven distribution of growth are discussed by Teitzel et al. (1974). They suggest integrating the economy of grass-centro pastures with the better seasonal growth and stress-buffering characteristics of nitrogen-fertilized prostrate-grass pastures. They also suggest that a useful combination is about 25% grass with N and 75% grass with centro, with the nitrogen-fertilized grass pasture located on the heavier and deeper soils which have superior soil-moisture-retaining characteristics during cool or dry seasons. However, on predominately poorly drained farms, the nitrogen-fertilized grass pastures should be used as wet-season buffers and planted on those areas that are well-drained (Teitzel and Middleton, 1979). In both instances, the purpose of these nitrogen-fertilized grass pastures is to minimize seasonal fluctuations in forage availability and to relieve stress on grass-centro pastures which are more sensitive to management.

The integrated systems mentioned above were compared over a 12-year period in a recently terminated grazing study (J. K. Teitzel, unpublished data). The integrated systems produced 20% to 27% more beef at 13% to 20% higher stocking rates than equivalent grass-centro systems. Subsequent computer simulation studies have indicated that the optimal allocation of types and areas of pasture on different land classes is dependent on beef prices and land class structure on the farm (Teitzel et al., 1986).
Integration with crops

In intensively cropped areas of Asia and other parts of the tropics, the need for more food crops greatly restricts land for forage crops, especially on small farms. This has resulted in the integration of short-term forages with food crops as intercrops, relay, alley, or even companion crops. Usually, noncreeping legumes such as *Stylosanthes humilis*, *S. guianensis*, *S. hamata*, and *Lablab purpureus*, are preferred to *C. pubescens* when undersowing with crops such as sorghum, maize, or rice, for dry-season forage supply. Centro establishes too slowly and has a creeping habit (Moog, 1986; Shelton and Humphreys, 1975; Topark-Ngarm and Gutteridge, 1986). However, great potential exists for the intensive use of *Centrosema*-based pastures on commonly grazed upland areas, paddy banks, and backyards during the wet season or the paddy-growing season. In the Philippines, centro is grazed by cattle throughout the year in the upland cropping areas together with crop residues and agricultural byproducts (Montemayor, 1974).

In East Africa, the Caribbean, and Central and South America, short-term ley farming with pastures in rotation with crops is practiced. For this purpose, several *Centrosema* spp. would be useful as was *C. pascuorum* in the semiarid tropics of northwest Australia (Peake et al., 1983). In general, improvements in soil structure, soil-water retention, and residual soil nitrogen are some of the potential benefits that are derived from ley farming, using *Centrosema* spp. alone or in mixture with a grass.

Integration with trees

Centro was one of the first legumes cultivated as a ground cover in rubber, coconut, and oil-palm plantations in Southeast Asia, India, the Pacific region, and, to a limited extent, Africa (Whyte et al., 1953). Full details of this practice, and of animal production from such ground covers, are provided by Chee and Wong (this volume).

Thomas (1978) considered that the greatest potential for integration of legumes with trees existed with mature coconut plantations where tall unimproved strains of coconut provide better light regimes at ground level than the dense canopies of mature oil-palm and rubber plantations. This is strongly supported by Rika et al. (1981) who measured annual liveweight increases of 550 kg/ha from a signal grass (*Brachiaria decumbens*)-centro pasture under coconuts in Indonesia. Reynolds (1977) achieved lower levels of animal production under
coconuts in Western Samoa, but production from a Guinea grass-centro pasture was 159% higher than from the native pasture. The situation was not so clear in the Solomon Islands where Watson and Whiteman (1981a) did not observe any significant differences in the productivity of sown and naturalized pastures, both of which contained centro. A subsequent attempt by Smith and Whiteman (1985a) to improve the relative performance of the sown pasture by implementing rotational grazing, also failed to produce significant treatment differences.

The performance of goats on pastures under coconuts was studied by Posas (1981) in the Philippines, and no production differences between the pastures studied (Brachiaria mutica-centro and B. mutica-siratro) were observed. However, a grazing system outproduced a cut-and-carry system in terms of annual LWG/ha. Another cut-and-carry system studied in Ghana by Asiedu and Karikari (1985) involved stall-feeding lambs with ground covers from mango plantations. It was found that grass-legume (including centro) swards gave higher returns than pure legume covers.

Information on animal productivity from centro in other plantation crops is provided by Chee and Wong (this volume). Chen and Omar (1984) screened a range of pasture plants in a clipping experiment for their suitability under oil palm in Malaysia. It was found that under the oil-palm canopy, Desmodium ovalifolium outyielded C. pubescens and Calopogonium caeruleum which, in turn, outyielded D. heterophyllum and Stylosanthes guianensis cvs. Cook and Endeavour.

**Future Research**

In wet tropical areas with soils of medium natural fertility, there are still limitations to the intensive use of centro-grass pastures for beef and/or milk production. These limitations are related to mineral deficiencies and/or inadequate management which affect pasture productivity and persistence. Therefore, more information is required on the persistence of centro-grass pastures as affected by grazing system and pressure under conditions where soil-mineral deficiencies or imbalances have been corrected.

Priority must also be given to exploiting the high forage potential of the Centrosema genus as only a few species have been well evaluated. "New" species such as C. pascuorum for semiarid conditions, C. virginianum for subtropical conditions, and C. macrocarpum, C.
brasilianum, and C. acutifolium for areas with acid, low natural fertility soils and prolonged dry season, should be exploited to provide improved pasture alternatives for large tropical areas. With these species, research should emphasize efficient fertilizer use for establishment and maintenance, low-cost pasture establishment methods, efficient rhizobium selection for high nitrogen fixation, and development of pasture management strategies for long-term persistence of planted species and sustained animal production.

References


Centrosema: biology, agronomy, and utilization


Nutritive value of Centrosema and animal production


Nutritive value of Centrosema and animal production


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Nutritive value of Centrosema and animal production


Chapter 12

CENTROSEMA IN PLANTATION AGRICULTURE

Chee Yan Kuan and Wong Choi Chee*

Abstract

In coconut, oil-palm, or rubber plantations, a mixture of legume species is planted as a soil cover in the interrows. In evaluating Centrosema species for this role, C. pubescens was superior in growth, dry-matter production, nodulation, and resistance to pests and diseases. Centrosema macrocarpum was high yielding but less persistent. The economic and biological importance of C. pubescens as a legume cover crop in plantations is discussed. The establishment of legumes, their beneficial effects (such as nitrogen fixation, nutrient return, soil erosion control, and nutritive value), and their use for animal production, are described. Centrosema pubescens is more shade tolerant than Calopogonium mucunoides and Pueraria phaseoloides. The main constraints to the use of legume covers are poor seed quality, high cost of establishment, maintenance problems, weed competition, and attacks by pests and diseases. Research priorities are suggested.

Introduction

Plantation agriculture in Malaysia, Indonesia, Philippines, and Thailand consists mainly of coconut, oil-palm, and rubber crops. The total area under these major plantation crops is 15.41 million hectares,

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Centrosea: biology, agronomy, and utilization

comprising 6.66, 6.02, and 2.73 million hectares of coconut, rubber, and oil palm, respectively (Table 1). The establishment of legumes as a ground cover in the interrows of rubber and oil palm is an important agronomic practice. Centrosea pubescens is one of the species planted. The importance of C. pubescens is shown by the example of the relatively large quantity of seeds imported into Malaysia compared with other legume seeds in 1981 and 1982 (Table 2). The total imported was 1.7, 2.4, and 1.3 million kg for C. pubescens, Pueraria phaseoloides, and Calopogonium mucunoides, respectively. The agronomic contribution of C. pubescens (centro) is difficult to quantify because it is grown in mixtures with other legume species such as C. caeruleum, C. mucunoides (calopo), Mucuna cochinchinensis, and P. phaseoloides (puero). This paper presents an agronomic assessment of Centrosea species, their establishment, shade tolerance, beneficial effects, and constraints to their use in plantation crops.

Table 1. Area (thousands of ha) under plantation crops (coconut, oil palm, and rubber) in Malaysia, Indonesia, Philippines, and Thailand, 1984.

<table>
<thead>
<tr>
<th>Country</th>
<th>Coconut</th>
<th>Oil palm</th>
<th>Rubber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaysia</td>
<td>15</td>
<td>1440</td>
<td>1971</td>
</tr>
<tr>
<td>Indonesia</td>
<td>3011</td>
<td>1253</td>
<td>2609</td>
</tr>
<tr>
<td>Philippines</td>
<td>3217</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Thailand</td>
<td>420</td>
<td>35</td>
<td>1371</td>
</tr>
<tr>
<td>Total</td>
<td>6663</td>
<td>2728</td>
<td>6015</td>
</tr>
</tbody>
</table>


Table 2. Amount of legume cover-crop seeds (thousands of kg) imported into Peninsular Malaysia in 1981 and 1982.

<table>
<thead>
<tr>
<th>Species</th>
<th>1981</th>
<th>1982</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calopogonium caeruleum</td>
<td>130</td>
<td>254</td>
<td>384</td>
</tr>
<tr>
<td>Calopogonium mucunoides</td>
<td>537</td>
<td>732</td>
<td>1269</td>
</tr>
<tr>
<td>Centrosea pubescens</td>
<td>731</td>
<td>978</td>
<td>1709</td>
</tr>
<tr>
<td>Desmodium ovalifolium</td>
<td>16</td>
<td>37</td>
<td>53</td>
</tr>
<tr>
<td>Pueraria phaseoloides</td>
<td>813</td>
<td>1563</td>
<td>2376</td>
</tr>
</tbody>
</table>

Introduction and Evaluation of *Centrosema* Species

Experience with *Centrosema* cultivation in plantations dates back to the early 19th Century when *C. plumieri*, a climber from tropical America with large flowers, was introduced as a ground cover in coconut, oil-palm, and rubber plantations. It was later replaced by *C. pubescens* which grew well in fertile soils without fertilizer (Burkill, 1935). The commercially cultivated *C. pubescens* is commonly known as centro. It is a very leafy, vigorous, trailing, twining, climbing, perennial herb. The leaves are trifoliolate and leaflets are dark green, elliptical, or ovate-elliptical. Flowers are bright or pale lilac. The pods are linear with prominent margins, 7.5 to 15 cm long, flat, thick, and straight or slightly curved. The pods are dark brown when ripe and contain as many as 20 seeds per pod. The seeds are slightly oblong to squarish with rounded corners and are about 4 by 3 mm in size. Seed color is brownish with dark grey patterns, and the texture of the seed coat is smooth and shiny. One thousand seeds weigh about 25 g. A recent survey of the germination characteristics of commercial seed samples (1979-81) showed 28% normal seedlings, 2% abnormal seedlings, 41% hard seeds, and 29% dead seeds (Chee and Tan, 1982). The high percentage of dead seeds resulted from poor harvesting and processing techniques and poor storage facilities.

In Malaysia, Wong et al. (1982) and C. C. Wong (unpublished data) found that, of the 32 accessions of *Centrosema* species introduced from Australia and CIAT (Centro Internacional de Agricultura Tropical), Cali, Colombia, *C. pubescens* was superior in growth, dry-matter production, noduleation, and pest-and-disease resistance, although *C. macrocarpum* had appeared promising at first. Other species, including *C. pascuorum* and *C. brasiliannum*, did not survive and were highly susceptible to *Epilachna indica* (ladybird beetle) damage and *Rhizoctonia solani* infestation during the wet season. *Centrosema schiedeanum* cv. Belalto was similar to the common centro in growth habit, but its dry-matter production was higher. Both cultivars grow well and seed readily. Such characters may allow them to persist by seedling regeneration. *Centrosema brasiliannum* showed poor regrowth and poor persistence because of severe damage attributed to *E. indica* and *R. solani*. *Centrosema macrocarpum* had very good initial growth but vigor and persistence declined over the years. Only *C. macrocarpum* CIAT 5645, 5730, and 5733 were satisfactory, with high dry-matter production in subsequent years. Flowering of *C. macrocarpum* was
seasonal and seed set was poor. *Centrosera plumieri* was nonpersistent under cutting and grazing. Similarly, *C. virginianum* was stunted under local conditions.

**Establishment and Maintenance of Leguminous Cover Crops**

In legume-cover establishment, *C. pubescens* is planted with other legume species such as *Calopogonium caeruleum*, *C. mucunoides*, and *P. phaseoloides*. The aim is to cover the bare ground as fast as possible. A mixture is recommended because of differences in the growth habit of each species and in order to counter the pest and disease problems inherent in pure legume stands. Such a practice provides for ecological succession of the individual legume species when the canopy of the perennial crops closes, causing a reduction in light penetration. In the mixture planted, *C. mucunoides* grows rapidly during the first few months after sowing, but it does not persist as a strong component for more than 12 months. *Pueraria phaseoloides* dominates during the second and third year after planting, while *C. caeruleum* and *C. pubescens* persist longer than the other two legume species under the developing rubber canopy. The recommended legume mixture is 3.5, 2.0, and 0.5 kg/ha of *P. phaseoloides*, *C. pubescens*, and *C. caeruleum* (Teoh et al., 1979).

In order to ensure a quick legume coverage of the exposed soil during replanting, it is important to adopt a good planting system and use preemergence and postemergence herbicides. Chemical weed control reduces labor costs and manpower for weeding, especially during the immature rubber phase. The Rubber Research Institute of Malaysia has recommended, for flat land, a planting system with an interrow more than 6 m wide, an economical planting system called the "double compressed band" (Chee et al., 1983).

Initially, old rubber trees are felled and the stumps uprooted, stacked, and burned. The area is surveyed and the rubber planting rows are marked. A 1-meter strip on both sides of the rubber row is rotovated for planting legumes. The remaining interrow areas are not plowed.

The cover-crop seeds are first tested and good quality seeds are selected for use. Before planting, the seeds are inoculated with *Rhizobium* compost and mixed with an equal weight of Christmas Island rock phosphate. The seeds are sown onto a 60-cm band of the rotovated area on both sides of the rubber row (Figure 1).

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Figure 1. Double-compressed-band planting system for legume cover in the interrow of rubber. (○ = Rubber planting point; [ ] = compressed-planting band.)

Immediately after planting the seeds, preemergence herbicides should be sprayed. Preemergence herbicides that are effective against a wide range of weed species but considered safe to most of the legumes are alachlor, metolachlor, and oxyfluorfen; the last-named chemical, however, is detrimental to C. pubescens. The rate used is 500 liters of solution, containing the chemical at an appropriate concentration, per hectare. Band application of these preemergence herbicides on the planting band is recommended.

After sowing the legume seed, management of the legume cover is very important. The weeds close to the vigorously growing cover crops are controlled by spraying postemergence herbicides. The herbicides recommended depend on weed species present, and the rate used is 500 liters of spray solution per hectare. The herbicides are paraquat, para- col (paraquat and diuron), glyphosate, 2,4-D, and Dasatox 325 (mixture of DSMA, 2,4-D, and diuron). To boost growth of the legume covers, 4 weeks after legume seed germination, 56 kg of N-P-K-Mg compound fertilizer (15:15:6:4) and 630 kg of Christmas Island rock phosphate are applied per ha. A complete ground cover is achieved after 150 to 180 days.
Beneficial Effects of Legume Covers

Economic benefits

Mainstone (1961 and 1963) found that rubber trees grown in association with legume covers became tappable 12 months earlier and yielded 20% more over 10 years of tapping than those with natural covers. Pushparajah and Chellapah (1969) demonstrated the residual effect of legume covers in two trials. They showed that to give a rubber yield similar to that obtained by using legume covers, additional fertilizers had to be applied to trees in nonlegume areas. In the first trial, even with an additional 200 kg of N/ha, rubber yields in grass or *Mikania micrantha* (a broad-leaved creeper) plots were less than that under legume covers with only a minimal application of nitrogen at 17 kg/ha.

In the second trial, where yields were recorded over 13 years, trees in grass plots needed an extra application over this period of at least 737 kg of N/ha, while those under natural cover required even more. Ti et al. (1971), by an economic analysis, showed that legume covers were profitable. This was confirmed by Lim and Chai (1976) who found that the additional cost incurred by the use of leguminous covers would be offset by a 6% to 8% yield increase over the first 6 years of tapping. The most significant economic advantage of leguminous covers when compared with natural cover arises from a 1-year reduction in the immature period of rubber. This finding is applicable at all rubber price levels. Based on the evidence available on residual effects and extra fertilizer needed for nonlegume areas, Pushparajah and Tan (1977) calculated that, for replanting about 56,330 ha of rubber annually in Malaysia, the total nitrogen fertilizer saved per year by implementing a legume policy would be about 64,665 t of nitrogen.

With oil palm, Gray and Hew (1968) found the highest yield over 4.75 years was obtained from plots planted with *C. pubescens* and *P. phaseoloides*. Where *Mikania micrantha* was dominant, a yield depression of 20% was recorded. This effect could be reduced to 11% by fertilizer application. In grass plots, 8% less yield was obtained, while *Nephtrolepis biserrata* (a fern) plots showed a marked response to N-P-K-Mg compound fertilizer applications. Yield differences between *Flemingia macrophylla* and two other legumes (*C. pubescens* and *P. phaseoloides*) were negligible (Table 3). During the first 4.75 years of harvesting, the fertilized plots containing *C. pubescens* and *P. phaseoloides* gave an additional yield of 0.75 t of fresh fruit bunches/ha when compared with the fertilized grass plots.
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Table 3. Oil-palm yield (tons of fresh fruit bunches/ha) with different types of interrow vegetation.

<table>
<thead>
<tr>
<th>Fertilization *</th>
<th>Grass</th>
<th><em>Mikania micrantha</em></th>
<th><em>Nephrolepis biserrata</em></th>
<th>Centro and <em>Pueraria phaseoloides</em></th>
<th><em>Flemingia macrophylla</em></th>
<th>Centro and <em>Flemingia macrophylla</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Without</td>
<td>9.18</td>
<td>7.79</td>
<td>8.54</td>
<td>9.74</td>
<td>9.18</td>
<td>9.31</td>
</tr>
<tr>
<td>Mean</td>
<td>9.17</td>
<td>8.30</td>
<td>9.10</td>
<td>9.83</td>
<td>9.36</td>
<td>9.47</td>
</tr>
</tbody>
</table>

\* Each oil palm received 1.36 kg N-P-K 1 fertilizer (that is, 10% N, 10% P\textsubscript{2}O\textsubscript{5}, 11% K\textsubscript{2}O, and 2% MgO) and 9.53 kg N-P-K 2 fertilizer (that is, 8% N, 8% P\textsubscript{2}O\textsubscript{5}, 17% K\textsubscript{2}O, and 2% MgO) over the experimental period of 4.75 years.


With coconuts, Rika (1985) found that an improved pasture (*Macroptilium atropurpureum* cv. Siratro, *C. pubescens*, *Panicum maximum*, and *Brachiaria decumbens*) increased the monthly coconut yield to 507-776 kg/ha at different stocking rates of cattle, compared with the native pasture where the monthly yield was only 483 kg/ha.

**Nitrogen fixation**

Nitrogen fixation by legumes is of extreme importance in reducing the nitrogen fertilizer requirements of rubber and oil-palm crops. Many estimates of the total amount of nitrogen fixed by nodulated legumes have been reported. Results vary with the host legume, the efficiency of *Rhizobium* strains involved, and the environmental and soil conditions governing the fixation process. In a pot experiment, Watson (1957) reported nitrogen fixation by *C. pubescens* to be 235 kg of N/ha. Subsequently, Watson et al. (1963) estimated fixation at an annual 170 kg of N/ha from a legume mixture (*C. mucunoides*, *C. pubescens*, and *P. phaseoloides*) under rubber. Broughton (1977) found an annual average of 150 kg of N/ha over a 5-year period from a cover crop under rubber, containing *P. phaseoloides*, *C. pubescens*, and *C. mucunoides*. Under oil palm, a legume cover fixed an average of 150 kg of N/ha (Agamuthu and Broughton, 1985).

**Nutrient return**

Watson et al. (1964a and 1964b) demonstrated the benefits of leguminous cover crops to the soil nutrient status compared with those
obtained from natural cover. Results in Table 4 show that legume covers returned 6038 kg of litter/ha compared with 5383 kg/ha from natural cover 24 months after planting. Table 5 shows that the leaf litter from legume covers returned 226 to 353 kg of N/ha compared with 13 to 117 kg/ha from natural cover 5 years after legume establishment. Also, higher amounts overall of phosphorus, potassium, and magnesium were returned by legumes to the soil compared with natural cover. In addition, these large amounts of legume-leaf litter have

<table>
<thead>
<tr>
<th>Cover vegetation</th>
<th>Dry weight of litter (kg/ha)</th>
<th>Nutrient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>Leguminous creepers</td>
<td>6038</td>
<td>140</td>
</tr>
<tr>
<td>Grasses</td>
<td>6140</td>
<td>63</td>
</tr>
<tr>
<td><em>Mikania micrantha</em></td>
<td>4096</td>
<td>68</td>
</tr>
<tr>
<td>Natural cover</td>
<td>5383</td>
<td>64</td>
</tr>
</tbody>
</table>

a. Mixed *P. phaseoloides, C. pubescens,* and *C. mucunoides.*
b. Mixed *Axonopus compressus* and *Paspalum conjugatum.*
c. Mixed indigenous bushes.

SOURCE: Watson et al., 1964a.

Table 5. Total amount of various nutrients (kg/ha) returned to the soil over a 5-year period under different cover vegetation under rubber.

<table>
<thead>
<tr>
<th>Cover vegetation</th>
<th>Nutrient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Leguminous creepers</td>
<td>226-353</td>
</tr>
<tr>
<td>Grasses</td>
<td>24-65</td>
</tr>
<tr>
<td><em>Mikania micrantha</em></td>
<td>74-119</td>
</tr>
<tr>
<td>Natural cover</td>
<td>13-117</td>
</tr>
</tbody>
</table>

a. See footnotes of Table 4 for details of species.

SOURCE: Watson et al., 1964b.
Centrosema in plantation agriculture

beneficial effects on the soil's physical properties. Soong and Yap (1975) found that legume covers had beneficial residual effects on soil structure by increasing the aggregation of fine soil particles, average size of the soil aggregates, total and air-filled porosity, and permeability of the soil to the downward movement of water.

Loss of applied nitrogen in rubber plantations can be severe. Watson et al. (1962) found that as much as 24% of applied nitrogen can be lost through volatilization. The nitrogen fixed by legume covers and the manner in which it is slowly released to the soil is, therefore, of great importance.

Soil erosion control

Most rubber crops are grown on undulating to steep land which is prone to soil erosion. Peninsular Malaysia has an annual rainfall between 1800 and 3000 mm (Ooi and Chia, 1974). Erosion is a serious problem during the replanting of old rubber trees, when they are felled and the land is cleared. The soil surface remains bare for about 6 months before the legume covers form a protective layer over the soil.

The creeping legume plants maintained in the interrows of rubber help to prevent soil erosion and reduce the effects of extreme climatic conditions. They protect the soil surface against falling rain drops, offer resistance to moving water, and slow down the rate of runoff. Also, the plant roots hold the soil in place, and the roots and crop residues help to improve soil structure.

Haines (1932) showed that in an immature stand of rubber, the amount of soil deposited in a period of 20 months on the terraces from the 8-m interrows on sandy soils such as the Serdang series, varied with the kind and type of existing cover. The reduction in erosion by covers, as measured by deposition on the terraces, ranged from 3.3 to 13.4 cm. Of the covers examined, creeping legumes led to the least deposition on the terraces. Bushy legumes such as Crotalaria and Tephrosia, led to more deposition on the terraces. These results demonstrated the beneficial effects of maintaining good covers on soils prone to erosion.

Nutritive value of legume covers

Devendra (1979) studied the nutritive values of cover legumes (Table 6) and found them to be higher than those of cultivated grasses such as Panicum maximum, Pennisetum purpureum, and Brachiaria
Table 6. Nutritive value of the leaves and stems of legume cover crops grown under rubber in Malaysia.

<table>
<thead>
<tr>
<th>Species</th>
<th>Dry matter in fresh plants (%)</th>
<th>Crude protein (%)</th>
<th>Crude fibre (%)</th>
<th>Ether extract (%)</th>
<th>Ash (%)</th>
<th>N-free extract (%)</th>
<th>Gross energy (M cal/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Calopogonium mucunoides</em></td>
<td>25.6</td>
<td>15.6</td>
<td>31.5</td>
<td>2.3</td>
<td>6.2</td>
<td>44.4</td>
<td>2.60</td>
</tr>
<tr>
<td><em>Centrosema pubescens</em></td>
<td>24.3</td>
<td>22.2</td>
<td>30.9</td>
<td>2.5</td>
<td>9.5</td>
<td>34.9</td>
<td>3.62</td>
</tr>
<tr>
<td><em>Desmodium ovalifolium</em></td>
<td>24.0</td>
<td>9.2</td>
<td>40.0</td>
<td>2.1</td>
<td>9.2</td>
<td>39.5</td>
<td>3.10</td>
</tr>
<tr>
<td><em>Mucuna cochinchinensis</em></td>
<td>16.6</td>
<td>35.0</td>
<td>14.5</td>
<td>3.0</td>
<td>9.0</td>
<td>38.6</td>
<td>-</td>
</tr>
<tr>
<td><em>Pueraria phaseoloides</em></td>
<td>19.1</td>
<td>19.1</td>
<td>28.8</td>
<td>2.1</td>
<td>7.9</td>
<td>48.8</td>
<td>3.71</td>
</tr>
</tbody>
</table>


*mutica.* Herbage of *C. pubescens* contained 22.2% crude protein, which was higher than that of *C. mucunoides* and *P. phaseoloides.* The crude fibre content of *C. pubescens* was 30.9%, which was similar to that of *C. mucunoides* and *P. phaseoloides.*

Use of Legumes in Plantation Agriculture

Animal production

Centro has been widely cultivated as ground cover in rubber, coconut, and oil-palm plantations in Southeast Asia, India, the Pacific region, and, to a limited extent, in Africa. A lot of published research suggests there is potential for livestock production in plantation agriculture and that farmers can derive additional income without adverse effects on the main crop (Table 7).

In mature coconut plantations, indigenous grasses normally support more than one cattle beast/ha in Indonesia. However, by undersowing with improved pastures such as signal grass (*Brachiaria decumbens*), green panic (*Panicum maximum var. trichoglume*), siratro, and centro, 330
### Table 7. Cattle performance under plantation crops.

<table>
<thead>
<tr>
<th>Pasture</th>
<th>Stocking rate (beasts/ha)</th>
<th>Age of tree crop (years)</th>
<th>Annual liveweight gain (kg/ha)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COCONUT PLANTATIONS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guinea + centro</td>
<td>2.2-2.5</td>
<td>22-25</td>
<td>381</td>
<td>Reynolds, 1977</td>
</tr>
<tr>
<td>Complex pasture mixture</td>
<td>2.7</td>
<td>60</td>
<td>385</td>
<td>Nitis and Rika, 1978</td>
</tr>
<tr>
<td>Signal + Guinea</td>
<td>3.6</td>
<td>60</td>
<td>497</td>
<td>Nitis and Rika, 1978</td>
</tr>
<tr>
<td><em>Paspalum</em> spp.</td>
<td>4.8</td>
<td>60</td>
<td>647</td>
<td>Nitis and Rika, 1978</td>
</tr>
<tr>
<td>Centro and others</td>
<td>6.3</td>
<td>60</td>
<td>732</td>
<td>Nitis and Rika, 1978</td>
</tr>
<tr>
<td>Centro + siratro + green panic + signal</td>
<td>5.0</td>
<td>60</td>
<td>550</td>
<td>Rika et al., 1981</td>
</tr>
<tr>
<td>Signal + centro</td>
<td>1.5</td>
<td>—</td>
<td>117</td>
<td>Manidool, 1984</td>
</tr>
<tr>
<td>Complex mixture of signal, <em>Para, B. humidicola</em>, centro, puerco, stylo</td>
<td>1.5-3.5</td>
<td>—</td>
<td>437</td>
<td>Watson and Whiteman, 1981</td>
</tr>
<tr>
<td>Native grasses + centro</td>
<td>2.5</td>
<td>—</td>
<td>363</td>
<td>Smith and Whiteman, 1985</td>
</tr>
<tr>
<td>Native pasture + centro</td>
<td>—</td>
<td>—</td>
<td>283</td>
<td>Sani and Basery, 1982</td>
</tr>
<tr>
<td>Native pasture + centro + copra-cake supplement</td>
<td>—</td>
<td>—</td>
<td>331</td>
<td>Sani and Basery, 1982</td>
</tr>
<tr>
<td><strong>OIL-PALM PLANTATIONS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guinea + stylo + native grasses + legumes</td>
<td>1</td>
<td>5-7</td>
<td>117</td>
<td>Chen et al., 1978</td>
</tr>
<tr>
<td>Native pastures + stylo + centro + puerco + <em>D. ovalifolium</em> + calopo</td>
<td>1</td>
<td>1-3</td>
<td>138</td>
<td>Chen and Othman, 1983</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1-3</td>
<td>234</td>
<td>Chen and Othman, 1983</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1-3</td>
<td>384</td>
<td>Chen and Othman, 1983</td>
</tr>
</tbody>
</table>

---

* Guinea = *Panicum maximum*; signal = *Brachiaria decumbens*; green panic = *P. maximum* var. *trichoglume*; *Para* = *B. mutica*; puerco = *Pueraria phaseoloides*; calopo = *Calopogonium mucunoides*; stylo = *Stylosanthes guianensis*. 

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the stocking rate can be increased to 3-4 cattle/ha (Rika et al., 1981). At an optimal stocking rate of 800 kg cattle/ha, an annual liveweight gain of 550 kg/ha has been recorded. During the wet season, stocking rate has no adverse effect on the grass-to-legume ratio, crude-protein content, and digestibility, but decreased nutritive value of pasture was noted in the dry season (Nitish and Lana, 1978). In Thailand, planting a centro- \textit{B. decumbens} pasture under coconut also increased animal productivity more than two-fold (Manidool, 1984). In Malaysia, cattle grazing on native pasture, including centro under coconuts, gained a daily 769 g/head compared to a daily 900 g/head when supplemented with copra (Sani and Basery, 1982).

In the Solomon Islands, cattle grazing a naturalized \textit{Axonopus compressus-Mimosa pudica}-centro mixture under coconuts, with a density of 125 palms/ha and 60% light transmission, gained a daily 0.34 kg/head or an annual 292 kg/ha as averaged over 3 stocking rates (Watson and Whiteman, 1981). Unfortunately, improved grasses did not persist but centro and pueru remained productive. Continuous grazing at 3.5 head/ha was better than a rotational grazing system (Smith and Whiteman, 1985).

In Western Samoa, liveweight gain of cattle increased from 180 kg/ha on native grasses with centro to 350 kg/ha on an improved-pasture mixture containing \textit{Brachiaria miliformis} (syn. for \textit{B. subquadripata}), \textit{B. mutica}, \textit{Ischaemum aristatum}, centro, and pueru (Reynolds, 1977). However, selective grazing by cattle often resulted in the invasion and increasing dominance of unpalatable weeds.

In Malaysia, centro, calopo, \textit{C. caeruleum}, and pueru, in rubber, coconut, and oil-palm plantations, provide high-quality fodders to livestock for about 7 years or more when the plantation canopy closes significantly to reduce productivity and persistence of the legumes. Chee and Devendra (1979) found that, in rubber plantations, three systems of herbage cover were feasible under trees younger than 3 years old (Table 8). One system (natural cover) is found mostly in smallholdings (about 2 ha), while the other two systems are found in estates (more than 45 ha of rubber trees).

The vegetation under the rubber trees can support goats or sheep (Devendra, 1978; Wan Embong, 1977). On the basis of a 3% intake of dry matter per 20 kg of body weight for indigenous sheep, the daily intake is 0.60 kg (Devendra, 1976). Thus, from Table 8, the carrying capacity is 2, 6, and 12 animals per hectare for systems 1, 2, and 3, respectively. That is, three and six times more animals can be carried 332
Table 8. The plant species, dry-matter production, and stocking capacities of three ground cover systems under rubber in Malaysia.

<table>
<thead>
<tr>
<th>System</th>
<th>Vegetation</th>
<th>Plant species</th>
<th>Dry matter (kg/ha)</th>
<th>Goats or sheep (no./ha)</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Natural cover</td>
<td><em>Axonopus compressus</em> + <em>Paspalum conjugatum</em> + <em>Ottochloa nodosa</em> + <em>Mikania micrantha</em> + <em>Nephrolepis biserrata</em></td>
<td>500</td>
<td>2</td>
<td>Devendra, 1976</td>
</tr>
<tr>
<td>2</td>
<td>Natural cover and legumes</td>
<td>as above, but with <em>C. pubescens</em> + <em>C. mucunoides</em> + <em>P. phaseoloides</em></td>
<td>1400</td>
<td>6</td>
<td>Tan Keh Huat, pers. comm.</td>
</tr>
<tr>
<td>3</td>
<td>Pure legumes</td>
<td><em>Cajanus cajan</em> + <em>C. pubescens</em></td>
<td>2600</td>
<td>12</td>
<td>Devendra and Chee, 1979</td>
</tr>
</tbody>
</table>

because of the increased availability of feed under natural cover plus legumes, and pure legumes, respectively.

In oil-palm plantations, liveweight gains of cattle declined from a daily 379 g/head to a daily 123 g/head under continuous grazing, depending on the stocking rates and age of the palms. About 2 years after field-transplanting oil palms, three head of cattle (Kedah-Kelantan breed) per hectare can be grazed. This has to be reduced to two beasts/ha in year 4-5 and then to one beast/ha in year 6-7 and onward (Chen et al., 1978; Chen and Othman, 1983). Centro productivity decreases with the onset of grazing and with the gradual closure of the palms’ canopy which reduces sunlight.

**Cattle damage to plantation crops**

Because of their grazing habit, cattle cause some damage to oil palms. However, the damage is minimized if a proper management
system is adopted to cater for both animals and oil palms. At the optimal stocking rate, when sufficient green forage is available, very little damage to oil-palm fronds occurs. In general, the number of oil-palm fronds nibbled by the grazing cattle increases as greater grazing pressure is imposed. Field data show that 21%, 40%, and 57% of fronds were grazed at stocking rates of 1, 2, and 3 head of cattle per hectare, respectively. The severity of individual frond damage increased with higher grazing pressure. However, most of the damaged fronds were in the lower canopy and already senescent. If free grazing were carried out too early, when palms were 1 year old, a decrease of about 30% in the weight of fresh fruit bunches would occur as a result of cattle damage to the young growing fronds (Haji-Idris et al., 1982).

Grazing effect on plantation crops

In Indonesia, the number and yield of coconuts increased linearly with stocking rate from 2.7 to 6.3 beasts/ha (Rika et al., 1981). In Malaysia, despite damage to fronds by grazing cattle, the production of oil-palm fresh fruit bunches (FFB) per hectare was not severely affected. In fact, all treatments with cattle grazing gave FFB yields higher than or similar to that of ungrazed plots (Table 9). An adverse effect of heavy grazing on FFB was not observed until the fourth year of oil-palm production (1985), when there was a shortage of forage and FFB yield at the highest stocking rate was 17% lower than that at the medium stocking rate (20.79 t/ha and 25.13 t/ha, respectively). Contrary to our

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Oil-palm FFB yield by year (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 beast²/ha</td>
<td>1.29</td>
</tr>
<tr>
<td>2 beasts/ha</td>
<td>1.58</td>
</tr>
<tr>
<td>3 beasts/ha</td>
<td>1.52</td>
</tr>
<tr>
<td>Control 1 (ungrazed)</td>
<td>1.70</td>
</tr>
<tr>
<td>Control 2 (ungrazed)²</td>
<td>1.06</td>
</tr>
</tbody>
</table>

a. Kedah-Kelantan cattle.
b. With clean weeding (started late 1984).

SOURCES: Chen et al., 1978; Chen and Othman, 1983.

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expectations, the higher the stocking rate, the higher the FFB produced in the early years. This beneficial effect is believed to come from the reduction of weeds as a result of grazing. When feed supply was again adequate in the fifth year, the FFB yield recovered rapidly. Another interesting result of this experiment was that a clean-weeded control treatment, obtained by the use of herbicide commencing in late 1984, took more than 1.5 years to catch up with the yield of other treatments. Surprisingly, clean weeding turned out later to be the best treatment for oil-palm yield. Hence, grazing has a similar effect to chemical weeding on oil-palm production, but the grazing option avoids the extra expenses of herbicides and the later ecological imbalances as well.

Shade Tolerance

Growth and persistence of legume species are closely related to the amount of light available to them under rubber and oil-palm canopies. Shading is associated with low assimilation rates in these plants. The response of net assimilation rate to shading differs from species to species and determines their tolerance to shade. *Centrosea pubescens* is more shade tolerant than *P. phaseoloides* and *C. mucunoides* because of its much lower net assimilation rate. Yoon (1971) found that, under different densities of rubber, 2.5 years after planting, *P. phaseoloides* predominated at the lower tree densities where light transmission was high (Table 10). However, with increasing tree density and decreasing light availability, ground coverage by *P. phaseoloides* decreased

Table 10. Growth of pueru, calopo, and centro under canopies of rubber planted at different densities, Malaysia.

<table>
<thead>
<tr>
<th>No. of trees/ha</th>
<th>Light transmitted after 2.5 years (%)</th>
<th>Ground cover after 2.5 years</th>
<th>Light transmitted after 4 years (%)</th>
<th>Ground cover after 4 years (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pueru</td>
<td>calopo</td>
<td>centro</td>
<td>pueru</td>
</tr>
<tr>
<td>210</td>
<td>83.1</td>
<td>31.3</td>
<td>5.0</td>
<td>6.0</td>
</tr>
<tr>
<td>297</td>
<td>75.8</td>
<td>22.5</td>
<td>8.0</td>
<td>4.0</td>
</tr>
<tr>
<td>398</td>
<td>61.9</td>
<td>13.8</td>
<td>5.5</td>
<td>9.3</td>
</tr>
<tr>
<td>556</td>
<td>46.7</td>
<td>9.3</td>
<td>5.5</td>
<td>6.8</td>
</tr>
<tr>
<td>741</td>
<td>36.6</td>
<td>5.5</td>
<td>5.5</td>
<td>8.5</td>
</tr>
<tr>
<td>1063</td>
<td>17.0</td>
<td>1.8</td>
<td>3.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

gradually from 31% to 2%. There were only small amounts of centro and calopo, irrespective of tree density. After 4 years, *P. phaseoloides* and *C. mucunoides* had disappeared completely, while *C. pubescens* had a percentage coverage of 1%-26%, depending on the amount of light transmitted through the canopy of the rubber trees.

**Constraints to the Use of Legume Covers**

**Economics**

The main disadvantage in using legume covers is the cost of establishment and maintenance. Teoh et al. (1979) found that the total cost during the first year of establishment in Malaysia was US$158.00 to US$185.00 per hectare, depending on soil type, terrain, and location. This is a financial problem even for big plantation companies.

**Pests and diseases**

*Epilachna indica* is the most destructive pest of *C. pubescens* in Malaysia. The adults and larvae destroy the foliage by eating away the tissue between the veins, skeletonizing the leaves. New growth flushes are attacked, and the cover is sometimes reduced to bare stem. Another insect, *Melanagromyza centrosematis* (a small fly), occasionally causes severe loss of germinating seedlings.

*Centrosemia pubescens* is susceptible to attack by *Rhizoctonia solani*. This disease spreads rapidly under the damp conditions prevailing under plantation crops. Dry weather halts the infection and allows the cover to regenerate, but the disease returns at the onset of the next rain. *Centrosemia pubescens* is also susceptible to mosaic virus.

**Seed quality**

Poor seed quality is another important factor limiting successful legume planting. Most *C. pubescens* seeds are imported to Malaysia from Indonesia, Sri Lanka, India, Philippines, and Thailand because the seeds are cheaper than those produced locally.

**Weeds**

Weeds pose another big problem in plantation crops in the tropics, especially where poor germination results in uneven cover-crop stand.
Centrosema in plantation agriculture

Until recently, weeds were removed manually, but the great increase in labor cost has made this impractical (Teoh and Chong, 1977).

Conclusions

In rubber and oil-palm plantations, legume establishment is a standard agronomic practice, both in new plantings and when replanting. In coconut plantations, the use of legumes for forage has great potential. Unfortunately, this has not been fully exploited. A mixture of legume species is recommended and *C. pubescens* is an important component. Because of the huge area under plantation crops, the potential use of *C. pubescens* in combination with other legume species is great, not only as a ground cover, but also as a forage.

The following areas are identified for further research:

Further collection of *C. pubescens* and related species, and evaluation for high nitrogen fixation, vigorous growth, production of large quantities of herbage, and resistance to *E. indica* and *R. solani*.

Seed production and quality, and propagation of promising *Centrosema* species.

Factors affecting the growth and persistence of *C. pubescens* in mixtures with other legume species and in grass-legume mixtures under different levels of shading.

The effects of plant competition on sustainable stocking rate, growth, nitrogen economy, and nutritive value.

Comparative nutrient requirements of *C. pubescens* and other promising pasture legumes.

Economic analyses of the use of *C. pubescens* as a legume cover and as a forage under different plantation crops.

Acknowledgments

The authors wish to thank the Board of the Rubber Research Institute, Dr. Haji Abdul Aziz S. A. Kadir (Director, Rubber Research Institute), and Dr. Haji Mohd. Yusof bin Hashim (Director General of the Malaysian Agricultural Research and Development Institute) for
permission to present this paper. Thanks are also due to Dr. E. Pushparajah (Assistant Director, Biology Department, Rubber Research Institute) and Dr. Chan Heun Yin (Head, Soils and Crop Management Division, Rubber Research Institute) for their help and encouragement.

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Centrosema: biology, agronomy, and utilization


Chapter 13

REGIONAL EXPERIENCE WITH 
CENTROSEMA: CARIBBEAN

R. T. Paterson*

Abstract

In the Caribbean region, the maritime influence is strong, and there is little diurnal or annual temperature fluctuation except in parts of Cuba and Hispaniola. Rainfall varies greatly, from 1000 to 8000 mm per year, with a dry season that can be as long as 7 months. Drought years are relatively common in the drier areas, while violent storms can result in a loss of effective rainfall when the water runs off. Soils vary widely in texture, pH, and fertility.

Centrosema is indigenous to the whole region, the most common species being C. pubescens, C. virginianum, and C. plumieri. Evaluation has been carried out on all major soil types, mostly with C. pubescens. In general, this species has not been very successful: it is slow to establish, susceptible to several plant diseases, attacked by insects, and tends to disappear under grazing. However, it is recommended for use in the Dominican Republic and is an important legume in parts of Cuba. In Trinidad, C. plumieri has given good results in one experiment, while in Antigua, C. schottii (from Cuba) and Centrosema hybrid CIAT 438 have been recommended for onfarm use even though no attempt has been made to produce seed in commercial quantities.

Future work with Centrosema should concentrate on lesser known species which appear to have greater agronomic potential. Better strains

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Introduction

The Caribbean region encompasses the chain of islands running east from Cuba and Jamaica to the British Virgin Islands and Antigua and south to Trinidad. It therefore forms an arc which spans the distance from the Yucatán Peninsula in Mexico to the Orinoco Delta in Venezuela. While the Bahama islands (including Turks & Caicos Islands) are usually considered to lie outside the region, they are briefly considered here for the sake of completeness because they share similar climatic and edaphic conditions with several truly Caribbean islands. The region, including the Bahama islands, lies between latitudes 10° and 27° N and longitudes 59° and 85° W.

The largest island in the area is Cuba (114,524 km²; 10 million inhabitants), although Hispaniola, which is divided between Haiti and the Dominican Republic, supports a larger population on a smaller land area (76,484 km²; 10.4 million inhabitants). The climate of the region is influenced mainly by proximity to the sea, although altitude also plays a part, particularly in Hispaniola and parts of Cuba where the highest peaks are more than 3000 m above sea level.

Climate and Soils

Archibald (1982) described the climate of the region as moderate tropical. The maritime influence minimizes diurnal and annual temperature fluctuations so that, except where influenced by altitude, ambient temperatures seldom severely restrict the growth of tropical pastures. Rainfall, however, varies widely from area to area, even within small islands, in both total precipitation and distribution. There is a general tendency of increasing rainfall toward the southern end of the Caribbean chain even though this is influenced by topography and location. There is normally a severe dry season throughout the region, lasting 3 to 7 months and varying considerably from year to year. Droughts are relatively common, during which the annual rainfall is only about half the long-term average. Tropical storms bring heavy downpours, particularly during the hurricane season. In the wetter areas, annual rainfall may exceed 8000 mm with almost no dry season,
Regional experience with Centrosema: Caribbean

while the drier areas may receive less than 1000 mm, most of which falls in 3 to 4 months. Several authors such as Brown and Bally (1970), Hill (1966), and Lang (1967), have noted the following climatic tendencies throughout the English-speaking Caribbean countries:

less than 1000 mm—semiarid, rainfall deficit every month, strong dry season;

1000-1500 mm—subhumid, rainfall deficit for half the year, strong dry season;

1500-2000 mm—subhumid, rainfall deficit for as long as 6 months, marked dry season;

2000-3000 mm—humid, rainfall deficit for as long as 2 months, weak dry season; and

over 3000 mm—perhumid, no rainfall deficit, soils always moist.

Table 1 presents some representative rainfall figures.

<table>
<thead>
<tr>
<th>Month</th>
<th>Antigua</th>
<th>Dominica</th>
<th>Central Trinidad</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>58</td>
<td>133</td>
<td>69</td>
</tr>
<tr>
<td>February</td>
<td>37</td>
<td>81</td>
<td>41</td>
</tr>
<tr>
<td>March</td>
<td>47</td>
<td>75</td>
<td>30</td>
</tr>
<tr>
<td>April</td>
<td>65</td>
<td>70</td>
<td>51</td>
</tr>
<tr>
<td>May</td>
<td>91</td>
<td>98</td>
<td>117</td>
</tr>
<tr>
<td>June</td>
<td>49</td>
<td>196</td>
<td>264</td>
</tr>
<tr>
<td>July</td>
<td>89</td>
<td>279</td>
<td>224</td>
</tr>
<tr>
<td>August</td>
<td>95</td>
<td>257</td>
<td>236</td>
</tr>
<tr>
<td>September</td>
<td>122</td>
<td>220</td>
<td>191</td>
</tr>
<tr>
<td>October</td>
<td>136</td>
<td>201</td>
<td>157</td>
</tr>
<tr>
<td>November</td>
<td>140</td>
<td>203</td>
<td>191</td>
</tr>
<tr>
<td>December</td>
<td>91</td>
<td>153</td>
<td>145</td>
</tr>
<tr>
<td>Annual total</td>
<td>1018</td>
<td>1966</td>
<td>1716</td>
</tr>
<tr>
<td>Wettest station a</td>
<td>1869</td>
<td>8459</td>
<td>3050</td>
</tr>
<tr>
<td>Driest station a</td>
<td>648</td>
<td>1225</td>
<td>1265</td>
</tr>
</tbody>
</table>

a. Annual averages obtained from stations located in the wettest and driest areas, respectively, in each island.

SOURCES: Antigua, V. C. Bird International Airport, unpublished data. Dominica, Botanic Gardens, Roseau, unpublished data. Trinidad, University of the West Indies, St. Augustine, unpublished data.
The soils of most English-speaking Caribbean countries have been described by the UWI (1958 onward). They can be conveniently grouped according to their acidity:

**High-pH soils.** Many of the soils of the drier islands such as Antigua, Bahama islands, and Barbados, have developed over coral or maritime-clay parent material. They are often finely textured, frequently with free limestone in the profile, with a pH of 6.5 or more, and relatively fertile in terms of a high cation-exchange capacity, high levels of base saturation, and high exchangeable phosphorus. However, the high pH can affect the availability of micronutrients. The more saline soils in this group are sticky when wet and crack badly during the dry season.

**Medium-pH soils.** Many of the soils derived from volcanic parent material in islands such as St. Lucia and St. Vincent, have a pH ranging from 5.2 to 6.0. The higher rainfall induced by topography has resulted in a degree of leaching that frequently renders the soils as medium fertile in their virgin state.

**Low-pH soils.** Highly acid, infertile soils, sometimes with a high aluminum content, are found in islands such as Trinidad and Jamaica. In the virgin state, these soils have a pH of 5.0 or below, but in some areas, heavy applications of limestone, together with organic or chemical fertilizers have been used to improve soil fertility. These soils range from heavy and poorly drained types to light and highly leached sands. They are often used for animal production since they are poorly suited to crops.

Data from soil analyses typical of these three categories are presented in Table 2.

**Native Centrosema Species in the Region**

In an early report on the flora of the Virgin Islands, Eggers (1879) noted that *Centrosema virginianum* was common in ditches and on fences in all islands. Millspaugh (1902) stated that it was frequently found in dry locations and that the species takes on many forms of leaf, both in shape and size, especially in St. Croix. Stehle (1956) listed both *C. virginianum* and *C. pubescens* among the legumes found in St. Croix. Liogier and Martorell (1982) referred to the presence of *C. plumieri* in Puerto Rico, St. Thomas, the Greater Antilles, and from St. Kitts to Trinidad; *C. pubescens* on banks, sandhills, and in thickets at lower to
Table 2. Typical data from soil analyses in the Caribbean.

<table>
<thead>
<tr>
<th>Soil acidity, soil type, and country</th>
<th>Depth of sample (cm)</th>
<th>pH (water)</th>
<th>Electrical conductivity (micromhos/cm)</th>
<th>Exchangeable bases (meq/100 g)</th>
<th>Base saturation (%)</th>
<th>P₂O₅ (Truong) (ppm)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>High pH Ottos Clay, Antigua</td>
<td>0-3</td>
<td>7.0</td>
<td>164</td>
<td>29.4</td>
<td>98</td>
<td>33</td>
<td>Hill, 1966</td>
</tr>
<tr>
<td></td>
<td>25-36</td>
<td>8.1</td>
<td>286</td>
<td>24.2</td>
<td>97</td>
<td>11</td>
<td>Hill, 1966</td>
</tr>
<tr>
<td>Medium pH Woodfords Hill Clay, Dominica</td>
<td>0-15</td>
<td>5.5</td>
<td>n.d.</td>
<td>7.3</td>
<td>53</td>
<td>9</td>
<td>Lang, 1967</td>
</tr>
<tr>
<td></td>
<td>23-115</td>
<td>5.2</td>
<td>n.d.</td>
<td>7.5</td>
<td>36</td>
<td>9</td>
<td>Lang, 1967</td>
</tr>
<tr>
<td>Low pH Piarco Fine Sand, Trinidad</td>
<td>0-13</td>
<td>4.3</td>
<td>50</td>
<td>0.0</td>
<td>20</td>
<td>Trace</td>
<td>Brown and Bally, 1970</td>
</tr>
<tr>
<td></td>
<td>38-96</td>
<td>4.3</td>
<td>26</td>
<td>0.0</td>
<td>16</td>
<td>Trace</td>
<td>Brown and Bally, 1970</td>
</tr>
<tr>
<td></td>
<td>137-167</td>
<td>4.6</td>
<td>17</td>
<td>0.0</td>
<td>7</td>
<td>Trace</td>
<td>Brown and Bally, 1970</td>
</tr>
</tbody>
</table>

a. Data not determined.
middle elevations in Puerto Rico, the Greater Antilles, and from Antigua to Trinidad; and C. virginianum on banks, hillsides, and in thickets at lower elevations in Puerto Rico, the Virgin Islands, and throughout the West Indies. Other species occur in the region (Schultze-Kraft et al., this volume), notably C. schottii in Cuba.

In view of the wide distribution of the genus in the region, there are ecotypes that are adapted to a very wide range of climatic and edaphic conditions. Nevertheless, their contribution to livestock production appears to be limited. Machado and Menéndez (1979) noted the abundance of native C. pubescens in the central and eastern districts of Cuba, but referred to poor results under grazing or cutting regimes, both when grown as pure stands or associated with pasture grasses. In St. Croix, C. virginianum is commonly found in ungrazed areas (Eggers, 1879; M. Michaud, personal communication), but of 28 pastures surveyed by a modified step-point technique, Michaud and Michaud (1986) found little Centrosera. These results confirm unpublished observations in Antigua over the past 12 years (P. Philip, personal communication).

**Agronomic Investigations in the Region**

Most of the work carried out on Centrosera in the region has concentrated on C. pubescens and on C. schiedeanum cv. Belalto. The work on soils of high, medium, and low pH will be discussed separately.

**High-pH soils**

Detailed evaluations of Centrosera species have been carried out in calcareous soils in both Antigua and Barbados, and supplementary data have been collected from other islands.

**Antigua.** In an evaluation program which started in 1974, more than 100 grass and 300 legume accessions (including several accessions of Centrosera) were tested in five different sites. Care was taken to achieve good establishment in the first year by careful weeding and lenient cutting regimes. Subsequently, the introductions were left to compete with any invading herbaceous species. About 2 years after sowing, the plots were subjected to rotational grazing. After a period of good grazing management, occasional overgrazing was imposed. Measurements, made throughout the whole of the testing period,
included dry-matter yields, plant vigor, spread, insect and disease attack, use by small ruminants, persistence under grazing, and contribution to sward composition. Promising species were selected from the program to be used in onfarm demonstrations of forage systems, which were further monitored to provide additional information. This work was documented by Devers (1979) and Keoghan (1980) and has been summarized by CARDI (1982), while the evaluation techniques have themselves been evaluated and fully discussed by Keoghan (1985). The results of this work are briefly summarized as follows:

On a shallow calcareous clay soil (Fitches clay), 10 *C. virginianum* accessions, *Centrosema* hybrid CIAT 438, two *C. pubescens* accessions, and *C. schiedeanum* cv. Belalto were tested. All showed low to medium edaphic adaptability and medium tolerance of climatic conditions, but none was considered to show agronomic promise (CARDI, 1982; Keoghan, 1980).

On a deep calcareous clay of the same Fitches series, one *C. brasillianum* (CPI 55698), three *C. pascuorum*, two *C. pubescens* (CPI 46543 and CPI 63895), and four *C. virginianum* accessions were considered to show low agronomic adaptability, largely because of a lack of tolerance to the soil conditions. Seven *C. schottii* and one *C. plumieri* (from Barbados) were initially classified as well adapted to both the soil and the climate and to show agronomic promise, although only one *C. schottii* from Cuba (Cu 12) was subsequently recommended for use in short-term pastures or for protein-energy banks (CARDI, 1982).

On a heavy cracking clay (Ottos Clay), the tested accessions included one *C. brasillianum*, eight *C. pubescens*, one *C. schottii*, nine *C. virginianum*, and *Centrosema* hybrid CIAT 438. CIAT 438 was considered productive and persistent under grazing and was recommended for long-term pastures, while the Cuban *C. schottii* was recommended for short-term sowings because of its initial vigor. All other accessions lacked either productivity or persistence (CARDI, 1982).

The above summarized results from the shallow Fitches Clay and the Ottos Clay were subjected to pattern analysis to classify the accessions and to help to decide on new germplasm for further testing. For each soil type, the material fell into 10 categories ranging from 1 (most productive and persistent) to 10 (least productive and not persistent). No *Centrosema* accessions fell into categories 1 or 2; *C. schiedeanum*
cv. Belalto, C. pubescens CPI 46599, C. schottii Cu 12, and Centrosema hybrid CIAT 438 fell into category 3 on the Ottos Clay; while two C. pubescens accessions, three C. virginianum accessions, and Centrosema hybrid CIAT 438 fell into category 4 on the Fitches Clay (Keoghan, 1980).

Several reports in the literature such as that of Bowen (1956), indicate that Centrosema spp. are not highly specific with regard to the strains of Rhizobium that will result in nodulation. However, the nodules so formed are often ineffective for fixing nitrogen. Detailed study of a C. virginianum accession from Antigua revealed the presence of nodule-forming Rhizobium strains in soils from several areas in the Caribbean. Strains from Antigua produced the best growth, but it was concluded that since effective bacteria are widespread in the region, inoculation was unlikely to yield large benefits with this species. When four lines of C. pubescens were grown on clay soils in Antigua, half or more of the plants examined had failed to form nodules, and the majority of the nodules appeared to be ineffective (Ahmed, 1978). It may be that this contributed to the poor performance of C. pubescens accessions in the work outlined above.

Although both C. schottii and Centrosema hybrid CIAT 438 were recommended for use in dry, calcareous soils, only 0.5 kg of seed of the latter was produced in the 21 months to June 1982 and none has been harvested since. Commercial use of Centrosema in Antigua has therefore been limited to its inclusion in legume mixtures sown in small areas on a few farms (CARDI, 1982). In contrast, recent annual usage of seed of Teramnus labialis and Neonotonia wightii was about 40 kg each species, together with about 80 kg of Macroptilium atropurpureum. These species all occurred frequently in the first three groups of the pattern analyses on both major soil types, and are considered as both productive and persistent under either grazing or cutting regimes.

**Barbados.** Critical evaluation of Centrosema in Barbados was started in 1972 with the establishment of two experiments to compare C. pubescens with a range of other Australian commercial legumes. A series of observation plots of pure stands of 13 different legumes, including C. pubescens and C. plumieri, was also sown to provide material for either grazing or feeding trials (Quintyne, 1972 to 1976).

In the first experiment, four legume species (Clitoria ternatea, Macroptilium atropurpureum cv. Siratro, Macrotyloma axillare cv. Archer, and C. pubescens) were fertilized with two levels of nitrogen.
(0 and 110 kg/ha) and three levels of potassium (0, 55, and 110 kg/ha). Samples were cut each time the plants matured sufficiently to carry dry seed pods. This practice resulted in cutting about every 8 weeks for *C. ternatea*, and about every 16 weeks for the other species. The fertilizer treatments failed to give significant responses, but *C. ternatea* and siratro significantly outyielded Archer and *C. pubescens* (yields of 17.77, 18.99, 13.30, and 13.13 t of DM/ha, respectively). *Clitoria ternatea* was affected by root rot, leaf spot, and insect attack; Archer suffered from root rot; *C. pubescens* from leaf spot; and siratro from insect damage.

In the second experiment, six legume species were studied with two levels of nitrogen (0 and 110 kg/ha) and three clipping intervals (8, 12, and 16 weeks). Significant differences were found only between species of which *C. pubescens* was the lowest yielding (Table 3).

A series of intake and digestibility studies was conducted on several different legumes, using sheep as the test animal (Table 4). The material was either dried or frozen for storage between the time of cutting at 16-week regrowth and its use in the experiments. Although the crude protein content of *C. pubescens* was similar to that of other species (Table 3), the neutral detergent fiber content was higher (Table 3) and

### Table 3. Herbage yields and chemical composition of legumes grown in Barbados, 1972-1974.

<table>
<thead>
<tr>
<th>Species</th>
<th>Total DM yield (t/ha)</th>
<th>Chemical composition (%)&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>48 weeks</td>
<td>80 weeks</td>
</tr>
<tr>
<td><strong>C. pubescens</strong></td>
<td>11.8</td>
<td>16.1</td>
</tr>
<tr>
<td>M. atropurpureum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cv. Siratro</td>
<td>18.1</td>
<td>27.8</td>
</tr>
<tr>
<td><strong>Clitoria ternatea</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. axillare</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cv. Archer</td>
<td>20.0</td>
<td>25.4</td>
</tr>
<tr>
<td><strong>N. wightii</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cv. Cooper</td>
<td>25.4</td>
<td>41.7</td>
</tr>
<tr>
<td><strong>N. wightii</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cv. Tinaroo</td>
<td>24.6</td>
<td>42.2</td>
</tr>
</tbody>
</table>

<sup>a</sup> CP = crude protein; NDF = neutral detergent fiber; Cell. = cellulose.

Table 4. Voluntary intake, dry-matter digestibility, and approximate nutritive-value index of dried and frozen forage legumes tested with sheep, Barbados, 1973-1976.

<table>
<thead>
<tr>
<th>Species</th>
<th>Year</th>
<th>Voluntary intake (VI) (g/w 0.75)</th>
<th>Digestible dry matter (DDM) (%)</th>
<th>Nutritive value index(a) (NVI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DRIED FORAGE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. pubescens</em></td>
<td>1973</td>
<td>51.0</td>
<td>36.4</td>
<td>23.2</td>
</tr>
<tr>
<td></td>
<td>1974</td>
<td>34.7</td>
<td>39.8</td>
<td>17.3</td>
</tr>
<tr>
<td><em>M. atropurpureum</em></td>
<td>1973</td>
<td>58.9</td>
<td>50.9</td>
<td>37.5</td>
</tr>
<tr>
<td>cv. Siratro</td>
<td>1974</td>
<td>87.4</td>
<td>50.2</td>
<td>54.8</td>
</tr>
<tr>
<td><em>N. wightii</em></td>
<td>1974</td>
<td>66.7</td>
<td>50.3</td>
<td>42.1</td>
</tr>
<tr>
<td>cv. Tinaroo</td>
<td>1976</td>
<td>76.7</td>
<td>60.5</td>
<td>58.0</td>
</tr>
<tr>
<td><em>Clitoria ternatea</em></td>
<td>1976</td>
<td>64.7</td>
<td>54.5</td>
<td>44.1</td>
</tr>
<tr>
<td><strong>FROZEN FORAGE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. pubescens</em></td>
<td>1974</td>
<td>59.3</td>
<td>51.1</td>
<td>37.9</td>
</tr>
<tr>
<td><em>M. atropurpureum</em></td>
<td>1973</td>
<td>94.9</td>
<td>59.3</td>
<td>70.3</td>
</tr>
<tr>
<td>cv. Siratro</td>
<td>1974</td>
<td>89.6</td>
<td>56.8</td>
<td>63.6</td>
</tr>
<tr>
<td><em>N. wightii</em></td>
<td>1974</td>
<td>86.2</td>
<td>57.6</td>
<td>61.7</td>
</tr>
<tr>
<td>cv. Cooper</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. NVI = VI x DDM x 100/80.


The digestibility lower (Table 4). Voluntary intake by sheep was also relatively low (Table 4), and interest in the species waned. On several occasions from 1974 onward, introductions of *C. pubescens*, *C. schottii*, and *Centrosera* spp. were made, but none attracted attention.

Although *C. pubescens* is not included in the list of legume species recommended for general use in Barbados, Proverbs and Quintyne (1986) noted that while the species did not persist in heavy clays in the 1500 mm rainfall area, it grew well in the soils of Scotland District. The use of common centro and *C. schiedeanum* cv. Belalto is likely to be limited by their susceptibility to the spray drift of 2,4-D which is frequently used to control weeds in sugarcane.

**Other islands.** Although Oakes (1970) lists *C. plumieri*, *C. pubescens*, and *C. virginianum* among the prominent herbaceous legumes in the U.S. Virgin Islands, none of these is mentioned among the most
important indigenous, naturalized, or introduced legumes from the viewpoint of animal production.

Six *C. pubescens* accessions were tested in St. Croix from 1952 to 1965 on a heavy, high-pH clay overlying loose marl (Fredensborg Clay). Of these, the best was P.I. 219833, but all were chlorotic, becoming necrotic as a result of nutrient deficiencies (unspecified) induced after only one or two close clippings. Other accessions studied included P.I. 212980, P.I. 224967, and P.I. 311505 (Virgin Islands . . . , 1952 to 1966). Of the 16 legumes for which yield data are available (Oakes, 1970), *Macroptilium atropurpureum* P.I. 270312 was the most productive (52.49 t of fresh weight/ha; 22.05 t of dry matter/ha), while the lowest was from *C. pubescens* (7.39 t of fresh weight/ha; dry matter not recorded). It is clear that the *C. pubescens* accessions tested were not well adapted to the environment. Interest in the genus was subsequently lost and no testing of other *Centrosema* species has been recorded.

In calcareous soils in Cuba, where *C. pubescens* is usually not well adapted, *C. plumieri* behaved as a wet-season annual (Menéndez and Martínez, 1980). This agrees with results obtained in Antigua, where an accession from Barbados behaved in the same way, although it tended to become a short-term perennial under more favorable conditions (Keogh, 1980).

In the Bahama islands, on Andros Island, an experiment was performed in which *Panicum maximum* var. *trichoglume* (green panic) was either fertilized with nitrogen or grown in association with one of the legumes *M. atropurpureum*, *Stylosanthes humilis*, or *C. pubescens* (Guyton, 1977). When irrigated, the grass-*C. pubescens* combination performed well, although its yield was inferior to that of the grass-*M. atropurpureum* association. The lowest yields of all were recorded when the grass and *C. pubescens* were grown together without irrigation.

**Medium-pH soils**

Most of the work carried out on *Centrosema* in medium-acid soils in the Caribbean region has been reported from Jamaica and Cuba. Work has also been done in the Dominican Republic, but it has proved difficult to obtain details. A summary of the agronomic characteristics and nutritional value of *C. pubescens*, together with recommendations for cultural practices has been recently published (Iturbide Collino, 1980).
Jamaica. During the period 1976-1978, a cutting experiment was carried out on Bodies Clay Loam to compare four legumes (Table 5). Plots were fertilized twice a year with phosphorus and potassium at a 4-to-3 ratio to provide annual applications of 376 kg/ha of K₂O. The legumes were cut back about 4 months after planting and thereafter sampled at intervals of 12 weeks. *Leucaena leucocephala* was cut at a height of 13 cm, while the others were cut at 8 cm. Under this management, *L. leucocephala* and *N. wightii* produced the highest yields over the 3-year period, while the yields of *C. pubescens* and *Pueraria phaseoloides* fell sharply in the second and third years.

Table 5. Green-matter (GM) yields (t/ha) and crude protein (CP) contents (%) of legumes grown in Jamaica, 1976-1978.

<table>
<thead>
<tr>
<th>Species</th>
<th>1976</th>
<th></th>
<th>1977</th>
<th></th>
<th>1978</th>
<th></th>
<th>Mean</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GM</td>
<td>CP</td>
<td>GM</td>
<td>CP</td>
<td>GM</td>
<td>CP</td>
<td>GM</td>
<td>CP</td>
</tr>
<tr>
<td><em>Leucaena leucocephala</em></td>
<td>60.86</td>
<td>19.3</td>
<td>79.52</td>
<td>22.7</td>
<td>75.53</td>
<td>26.3</td>
<td>71.30</td>
<td>22.8</td>
</tr>
<tr>
<td><em>Neonotonia wightii</em></td>
<td>102.07</td>
<td>14.8</td>
<td>81.47</td>
<td>16.2</td>
<td>69.77</td>
<td>17.9</td>
<td>84.44</td>
<td>16.3</td>
</tr>
<tr>
<td><em>Centrosema pubescens</em></td>
<td>76.23</td>
<td>17.6</td>
<td>30.74</td>
<td>17.6</td>
<td>19.34</td>
<td>20.5</td>
<td>42.10</td>
<td>18.6</td>
</tr>
<tr>
<td><em>Pueraria phaseoloides</em></td>
<td>67.33</td>
<td>14.8</td>
<td>23.78</td>
<td>15.7</td>
<td>7.81</td>
<td>16.3</td>
<td>32.97</td>
<td>15.6</td>
</tr>
</tbody>
</table>

SOURCE: J. Logan, personal communication.

In a further experiment (Logan and McLeod, 1982), which ran from September 1978 to October 1979, Jamaica Red Poll x Jamaica Hope yearling steers were grazed on either *Digitaria decumbens* (pangola grass) alone or plots of which 75% were sown to pangola and the remainder to *C. pubescens*. The animals were rotationally grazed on six similar areas (36 days of rotation) at a stocking rate of 5.9 animals/ha. All plots were fertilized with single superphosphate at 524 kg/ha and muriate potash at 375 kg/ha, applied in two applications, while all the areas sown to pangola grass received sulfate of ammonia at 1500 kg/ha, split into six equal dressings. Irrigation was applied as necessary during the dry season. The animals on the grass alone gained 0.31 kg/day (620 kg/ha) while those with access to the legume gained 0.38 kg/day (776 kg/ha). Although the legume increased the growth rates of the steers, it was almost totally eliminated after 7 months of grazing; the stocking rate was apparently too heavy.

Although work on legumes in association with grasses has been carried out in Jamaica by the Ministry of Agriculture since 1949, no fully satisfactory grass-legume mixtures have yet been identified. The results from the grazing experiment described above are rated as fair,
while leucaena and siratro appear promising (JLA, 1983). Commercial acceptance of legumes is limited, and high levels of both organic and chemical fertilizers are still being applied to pure grass pastures, particularly for milk production. The role of *Centrocoma* at present appears confined to being part of the native vegetation found in unimproved pastures and so contributing to the nutrition of animals grazing natural pastures.

**Cuba.** In view of the wide natural distribution of the genus *Centrocoma* in Cuba (Appendix II, this volume), it is hardly surprising that it has been included in many studies of pasture legumes. What is not so easily explained is why almost all published studies have been confined to *C. pubescens*, in view of the limited success achieved with this species. In a study to compare 10 legumes on a ferralitic, quartzitic soil, *C. pubescens* failed to establish (Menéndez et al., 1984). In other work where it was successfully established, it was outperformed both in yield and persistence by glycine (Valdés and Pérez, 1971) or siratro (Monzoti and Alvarez, 1978). Nevertheless, in the eastern part of the Provincias Orientales, Menéndez et al. (1979) consider it to be of interest because it grows vigorously and is commonly found in grazed areas. In contrast, in the western part of the same region, on Latosols at 1000 m altitude, only *Teramnnus* spp. persisted well with sod-forming grasses when subjected to grazing (Menéndez and Machado, 1978).

On a relatively infertile sand with a pH of 5.4 on the Isla de la Juventud, 23 legumes, including four *Centrocoma* accessions, were evaluated in a RIEPT (Red Internacional de Evaluación de Pastos Tropicales; International Tropical Pastures Evaluation Network) Regional Trial B (Gutiérrez and Delgado, 1985). The two *C. pubescens* accessions, CIAT 5053 and CIAT 5126, failed to survive into the second year of evaluation. *Centrocoma brasilianum* CIAT 5055 was of moderate productivity, while after a slow start, *C. macrocarpum* CIAT 5065 was considered to be among the best of the legumes tested. Other species that did well were *Stylosanthes guianensis* var. *pauciflora* CIAT 1283 and *Desmodium ovalifolium* CIAT 350. In this experiment, despite a low incidence of diseases and insect pests, all *Centrocoma* accessions were attacked by insects.

Of 44 native and introduced *Centrocoma* accessions tested, J. Menéndez (personal communication) noted that 26 were susceptible to bean golden mosaic virus. Many of the susceptible ecotypes were *C. pubescens*, although CIAT 5172 was classified as highly resistant and productive in both forage and seed production. The widespread
occurrence of the virus in Cuba may explain, in part, the apparent lack of success with *Centrosema* spp.

Machado et al. (1979) considered that the future of *C. pubescens* depended on the development of new varieties that can produce at least 10 t of DM/ha per year with 20% CP and which could support 2 cows/ha. Other priorities included disease resistance and abundant seed production.

**Low-pH soils**

Reports of work on *Centrosema* on highly acid soils are available only from Trinidad and the Dominican Republic.

**Trinidad.** Guyadeen (1951) considered that *C. pubescens* showed promise, particularly in the light of high levels of crude protein and phosphorus, coupled with low levels of crude fiber in its foliage. Despite this, the legume has not yet been commercially accepted by farmers.

The Trinidad and Tobago Ministry of Agriculture, Lands and Fisheries has included *C. pubescens* in several sowings made on acid soils in the past 20 years (MALF, 1965 to 1978). In 1965, an unnamed accession was introduced from Singapore, together with four other commercially available legumes: *Pueraria javanica* (synonym for *P. phaseoloides*); *Calopogonium mucunoides*; *Stylosanthes gracilis* (synonym for *S. guianensis*); and *Desmodium ovalifolium*. In the first year, it was rated the worst of the five, because of slow growth and susceptibility to insect attack. In subsequent years, its performance showed no great improvement, so it was dropped from the evaluation program by 1972. Although it showed high nutritive quality and was well accepted by ruminants, its persistence was poor because it recovered slowly from defoliation and was susceptible to attack by leaf-eating insects and an unidentified leaf virus.

In later years, *C. pubescens* again entered into the list of species under test. In a further experiment (MALF, 1975) with 11 commercial legumes, it was rated amongst the highest in quality but the yields were again low.

In a more recent experiment (Harricharan et al., 1982), a total of 44 legumes, representing the major genera and having diverse origins and growth habits, was evaluated over a period of 18 months at the University Field Station. Each was given a production rating based on persistence and adaptability to the environment, growth vigor and yield.
Regional experience with Centrosema: Caribbean

of dry matter, and resistance to drought, pests, and diseases. The performance of the Centrosema spp. is shown in Table 6. Although the reference provides no details of soil analyses, the light basal fertilizer dressings used (50 kg of triple superphosphate/ha and 50 kg of muriate of potash/ha) suggest that the soil may not have been highly infertile or acid, even though many of the soils in the area are. Of the legumes evaluated in this experiment, only four, including C. pubescens, had more than 20% crude protein content. Apart from C. plumieri, eight others achieved ratings of "highly productive." Despite the promise shown by this species, no further work has been done with C. plumieri.

<table>
<thead>
<tr>
<th>Species</th>
<th>Crude protein content (%)</th>
<th>Production rating&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. plumieri (from Barbados)</td>
<td>14.7</td>
<td>1</td>
</tr>
<tr>
<td>C. pubescens Florida 12461</td>
<td>21.0</td>
<td>2</td>
</tr>
<tr>
<td>C. schottii CF 589</td>
<td>14.7</td>
<td>2</td>
</tr>
<tr>
<td>C. pascuorum CPI 55697</td>
<td>19.6</td>
<td>3</td>
</tr>
<tr>
<td>C. virginianum CPI 55695</td>
<td>14.0</td>
<td>3</td>
</tr>
</tbody>
</table>

<sup>a</sup> Ratings: 1 = highly productive; 2 = moderately productive; 3 = least productive.


In 1980, a RIEPT Regional Trial B was sown at the Ministry of Agriculture Field Station at Centeno. The species sown comprised 12 legumes, including two Centrosema entries, and five grasses. The results were published by Persad (1983) and also appear in the unpublished Centeno annual reports, 1980 onward. Both common C. pubescens and Centrosema hybrid CIAT 438 established poorly and seedlings were small compared with those of the other legumes. Ground cover was low and insect damage, mainly by chrysomelid leaf beetles, was high. (Insects of this group are also serious pests of pasture legumes in Cuba, according to Menéndez and Martínez, 1980). Herbage yields initially were much smaller than those of the more vigorous legumes such as Stylosanthes guianensis CIAT 184 and CIAT 136 and Zornia latifolia CIAT 728. By 1982, Centrosema hybrid CIAT 438 had the fifth highest yields, behind the three accessions named above and Desmodium ovalifolium CIAT 350, but the dry-season yield was only 65% of that of the highest producer (S. guianensis CIAT 184), while the wet-season
yields were 64% of the best species (Z. latifolia) and 84% of S. guianensis. Common C. pubescens gave the poorest yields of all species included in the experiment. Both Centrosema lines continued to be heavily attacked by insects, the lowest rating for damage after the initial establishment period being 3.7 on a scale from 1 (no attack) to 4 (severe damage). This compared very poorly with species such as S. guianensis, S. capitata, and Z. latifolia, which were frequently rated at 1.0 (no damage).

When C. virginianum from Antigua was grown on acid, infertile Piaroco Fine Sand in a detailed pot study, inoculation with an effective Rhizobium strain, also from Antigua, resulted in extra plant growth and nitrogenase activity only in the presence of a nutrient solution that included Ca, P, and S (Ahmed, 1978; Ahmed and Quilt, 1981). Uninoculated plants were nodulated and also showed a response to added nutrients, but the greatest response occurred with both inoculation and nutrient application. Similar results were obtained with C. pubescens on the same soil. Pelleting seed with lime, either alone or with Mo, did not increase plant growth, although lime applied at 125 kg/ha produced a positive response (Ahmed, 1978). The results showed that seed pelleting with lime did not satisfy plant requirements for Ca on this infertile soil.

Dominican Republic. On three different infertile clay soils, RIEPT Regional Trials B were sown in 1983 (Germán, 1986a, 1986b, and 1986c). At all three sites, C. macrocarpum CIAT 5062 and CIAT 5065 were planted, together with C. brasilianum CIAT 5234. At one site, these were accompanied by C. acutifolium CIAT 5112 and C. pubescens CIAT 5189, while at the other two, C. acutifolium CIAT 5278 was used. In general, similar results were obtained at all three sites.

Germination was good and although some accessions were slow in the early stages, all had achieved acceptable cover within 3 months. Diseases were usually not a severe problem, but all Centrosema accessions were attacked by a range of insects, the attacks being more pronounced in the second year. In both dry and wet periods, the yields obtained from C. pubescens were poor, while DM production from the C. macrocarpum and C. brasilianum accessions could be described as fair to good, with the best results being obtained from C. macrocarpum CIAT 5065. In all cases, the Centrosema accessions were outyielded by other legumes, notably by a range of Stylosanthes and Zornia accessions, of which the most productive appeared to be S. guianensis CIAT 1280 and Z. brasiliensis CIAT 7485.
The Potential of *Centrosema* in the Region

While naturally occurring *Centrosema* spp. are important in some areas of Cuba, only in the Dominican Republic is any attempt being made to actively promote their use. In the Lesser Antilles, *C. plumieri* in Trinidad and *C. schottii* and *Centrosema* hybrid CIAT 438 in Antigua have shown to be promising in experiments. CIAT 438 has been recommended for commercial use in Antigua, but no serious attempt has been made to provide seed to farmers because alternative legumes such as *Neonotonia wightii*, *Macroptilium atropurpureum*, and *Teramnus labialis*, are already accepted and small-scale seed production is available (Paterson, 1986). Because the seed-production scheme is relatively new, to extend the range of species offered would not be desirable until the regional demand for the existing legumes is fully satisfied, or until problems with these species require alternatives.

*Centrosema* is not sufficiently trouble-free in the region to make it an unequivocal choice for future use. In many of the reports cited above, it is considered to be slow to establish, even when later results are satisfactory (for example, Persad, 1983). Occasional disease problems have been reported such as leaf rust (*Uromyces appendiculatus*) on *C. schottii* in Antigua (CARDI, 1982); possible *Rhizoctonia*, *Pythium*, or *Botrytis* infection on *C. virginianum* in Antigua (Ahmed, 1978); bean golden mosaic virus on a range of *Centrosema* spp. in Cuba (J. Menéndez, personal communication); and an unidentified leaf virus on *C. pubescens* in Trinidad (MALF, 1971). Insect damage, often attributed to chrysomelid beetles, has been reported from as far apart as Cuba (Menéndez and Martínez, 1980) and Trinidad (MALF, 1980), although the recommended species in Antigua was relatively free of insect damage. These problems, and lack of persistence under grazing (Logan and McLeod, 1982), inhibit the use of *C. pubescens* and *C. virginianum* in the Caribbean. A case can be made for wider use of the lesser known species such as *C. plumieri* and *C. schottii*.

Future *Centrosema* Research

Selection of improved strains of *Rhizobium* may result in more vigorous growth of *Centrosema* spp., particularly in the early stages (Ahmed, 1978). This could help to solve the problems of poor or slow establishment. More attention should be paid to species other than *C. pubescens* because this has been, on the whole, disappointing in the Caribbean
region. Clearly, in any selection or breeding work, close attention should be paid to resistance to pests and diseases, persistence under grazing, and productivity under a regime of minimal fertilizer inputs.

Acknowledgments

Many colleagues helped to provide the information which is presented in this review. Special thanks are due to Joy and Michael Michaud (St. Croix), Robbie Quintyne (Barbados), and Maritza Hee Houn (Trinidad) who freely gave their time in providing access to unpublished material.

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Chapter 14

REGIONAL EXPERIENCE WITH CENTROSEMA: CENTRAL AMERICA AND MEXICO

P. J. Argel, A. Peralta M., and E. A. Pizarro*

Abstract

Central America and Mexico together, where 10 species of Centrosema have been collected, are considered to be one of the centers of diversification of this genus. Centrosema pubescens is the most widely distributed species and the most heavily researched during the 1960s and seventies. Since 1980, evaluation in adaptation and forage production trials has extended to 12 additional species, of which C. acutifolium, C. brasilianum, and C. macrocarpum have shown the best adaptation to the soil and climatic conditions of the region. Insect pests and diseases most commonly reported are leaf eaters and rhizoctonia foliar blight, respectively.

Regional Centrosema evaluations under grazing are scarce, and limited to C. pubescens and C. macrocarpum. The only results on animal production available for Centrosema are for commercial C. pubescens in Mexico; they indicate daily liveweight gains of 524 g/animal from C. pubescens-Digitaria decumbens pastures versus 385 g/animal from D. decumbens alone.

The genus Centrosema has a high potential for the region. Future research should concentrate on germplasm collection and introduction; agronomic and weed-control studies, especially in humid tropical

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regions; grazing trials to determine persistence and animal production; and integration of crops with *Centrocoma* pastures in the agriculture-livestock-forestry production systems that prevail in Central America and tropical Mexico.

**Natural Occurrence of** *Centrocoma* **in the Region**

*Centrocoma* is a New World genus with about 35 species distributed from the United States to Argentina, including the Caribbean (Schultze-Kraft et al., this volume). At least 11 species have been identified as native to Central America and Mexico (Abaunza Amador, 1978; D'Arcy, 1980; Meyrat, 1975; Standley and Steyermark, 1946; Taylor, 1976). Regarding germplasm, it appears that tropical Mexico and Panama are the best sampled countries in terms of native ecotypes that are now available in the form of seed (Duque et al., 1985; Peralta M. et al., 1987; Reid, 1983).

Available information suggests that *C. pubescens* is the most frequent and widely distributed species in the region. It is found mainly on moderately to highly fertile soils and in regions with humid to subhumid and hot to somewhat cooler climates. This wide distribution has resulted in a large intraspecific variation represented by morphological types that express the climatic and soil conditions where they grow. For example, in semidry climates, it is common to find early, low-growing, vegetative types with limited flowering and small basal pods. In humid climates and high-fertility soils, vigorously climbing types with abundant and prolonged flowering and large pods are found. On the acid Ultisols, which are typical of the forest and derived savanna ecosystems, prostrate, stoloniferous types with good rooting capacity at the nodes are common.

Other species that are frequently found and that have a wide distribution are *C. macrocarpum* and *C. plumieri*. *Centrocoma schiedeana*um, a species that is very closely related to *C. pubescens* taxonomically, appears to have two distribution centers (Mexico, and Costa Rica with Panama) where it is usually found at higher altitudes. *Centrocoma sagittatum* and *C. pascuorum* are species with a wide distribution in Central America but are not common; *C. pascuorum* occurs exclusively in low-altitude regions with less than 1000 mm annual rainfall. *Centrocoma virginianum* is particularly frequent in Mexico but a few collection sites of botanical material are known in

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Regional experience with Centrosemia: Central America and Mexico

Guatemala, Honduras, and Costa Rica. The distribution of *C. schottii* is limited to regions with calcareous soils in Mexico, particularly in the Yucatán Peninsula. *Centrosemia angustifolium* has been reported only in Panama and Costa Rica. Other *Centrosemia* species that are reported to be native to Panama are *C. brasiliannum* and *C. vexillatum*.

Adaptation and Seasonal Dry-Matter Production

Evaluation of tropical forage legumes adapted to the local conditions of Mexico and other Central American countries began during the 1960s (FAO, 1972; Sánchez, 1968). Efforts were concentrated on the productivity of mainly Australian commercial forage cultivars (Claverán Alonso, 1978). *Centrosemia* was identified as one of the genera most promising and best adapted to the hot and humid regions of Mexico (Ramos, 1985; Sánchez, 1968), Panama (FAO, 1972), and Belize (Lazier, 1980a and 1980b). Observations were made in small plots under cutting or under controlled periodic grazing.

In Belize, for example, four lines of three *Centrosemia* species (*C. pubescens*, using a native ecotype and common centro, *C. plumieri*, and *C. schiedeanum* cv. Belalto) were tested in 1975 among 25 legumes comprising 13 genera and 19 species (J. R. Lazier, personal communication). *Centrosemia plumieri* showed no outstanding performance in any of the trials, while *C. schiedeanum* cv. Belalto usually grew well at the same sites. *Centrosemia pubescens* showed improved performance at a higher level of applied P (40 versus 10 kg of P/ha). Another trial with 30 legumes (19 genera, comprising 27 species) that included *C. plumieri* CF 16-1 and *C. pubescens* CF 177, was conducted in a Planosol in a region with 2200 mm annual rainfall. Both species persisted after 10 cutting cycles every 6 weeks, but they produced only a third of the yield obtained from *Macroptilium atropurpureum* cv. Siratro, considered to be the best legume in the trial (J. R. Lazier, personal communication).

These initial evaluation efforts in the region did not lead to recommendations for large-scale commercial use of *Centrosemia*.

Since 1980, the scope of evaluation of the genus *Centrosemia* has been expanded considerably. In an intensive program of forage grass and legume collection, introduction, and evaluation in Belize, for example, 19 *C. pubescens* accessions, 10 *C. plumieri* accessions, six *C. macrocarpum* accessions, four *C. schottii* accessions, and one hybrid,
were evaluated during the period 1981-1984 (Parham, 1984). In these preliminary evaluations, the best performance was, once again, that of *C. pubescens*.

Studies conducted in the other countries in the region have been part of a set of regional trials organized within the International Tropical Pastures Evaluation Network (RIEPT, i.e., Red Internacional de Evaluación de Pastos Tropicales), with germplasm provided mainly by the Centro Internacional de Agricultura Tropical (CIAT). Germplasm tested included 13 *Centrosoema* species (Table 1). Significant numbers of accessions have been evaluated in Mexico and Panama, particularly of *C. pubescens*, *C. macrocarpum*, *C. brasiliannum*, *C. acutifolium*, *C. schiedeanum*, and *C. pascuorum*. Evaluations have consisted of adaptation trials or Regional Trials type A (RTA) in which germplasm survival under minimal fertilizer inputs is observed for a 2-year period (Toledo and Schultze-Kraft, 1982). Simultaneously or parallel to these

<table>
<thead>
<tr>
<th>Species</th>
<th>Mexico</th>
<th>C. Rica</th>
<th>Honduras</th>
<th>Nicaragua</th>
<th>Panama</th>
<th>Belize</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. acutifolium</em></td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td><em>C. angustifolium</em></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. brachypodum</em></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. brasiliannum</em></td>
<td>10</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>4</td>
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<tr>
<td><em>C. macrocarpum</em></td>
<td>12</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td><em>C. pascuorum</em></td>
<td>1</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td><em>C. plumieri</em></td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td><em>C. pubescens</em></td>
<td>20</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>21</td>
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<tr>
<td><em>C. rotundifolium</em></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><em>C. sagittatum</em></td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><em>C. schiedeanum</em></td>
<td>5</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><em>C. schottii</em></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. hybrid CIAT 438</em></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>61</td>
<td>9</td>
<td>8</td>
<td>5</td>
<td>19</td>
<td>42</td>
</tr>
</tbody>
</table>

a. Spanish acronym, RIEPT = Red Internacional de Evaluación de Pastos Tropicales.
b. Germplasm evaluated outside the RIEPT.

**SOURCES:** RIEPT, unpublished data, and J. R. Lazier, personal communication.

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evaluations, dry-matter seasonal yields have been measured during the periods of maximum and minimum rainfall (Regional Trials type B, RTB). Other evaluations have been conducted under conventional conditions of agronomic experimentation, particularly in Tocumen and Gualaca in Panama.

The area being considered extends from latitudes 7° to 30° N and from longitudes 77° to 107° W. The predominant ecosystem is that of the tropical rain forest (TRF) (Table 2). In this ecosystem, annual rainfall ranges from 2099 mm in Hojancha, Costa Rica, to 4000 mm in Gualaca, Panama, with dry periods that can last 3-6 months. *Centrosera* evaluations in the tropical dry forest (TDF) have been conducted in El Ejido and Rio Hato in Panama, while in this same country, forest-derived savanna ecosystems (TRF-DS) are found at Calabacito and Chepo, respectively. The tropical semievergreen seasonal forest (TSSF) is found at La Esperanza, Honduras, and Huimanguillo, Jericó, and Niltpepec in Mexico. In Mexico, *Centrosera* germplasm has also been evaluated in the savanna ecosystem. Soils are mostly acid (pH 4.5–5.5) with a variable P content, which is usually low to moderate, and Al saturation that ranges from low to highly toxic.

**Centrosera pubescens**

*Centrosera* evaluations in Central America and Mexico were initiated almost exclusively with one or two *C. pubescens* accessions, one of which is now known to be *C. schiedeanum* (Clements et al., 1983), represented by the variety Belalto. Another variety that has been widely evaluated is common centro.

Kretschmer (1970), for example, reported that, in onfarm trials in Costa Rica, *C. pubescens* (centro) showed good agronomic performance and high seed production compared with other legumes such as *Stylosanthes humilis* and *Neonotonia wightii* cv. Tinaroo.

More recent evaluations, during RIEPT regional trials A and B, have been conducted in forest and savanna ecosystems of the region (Table 3). Accessions CIAT 438 (*Centrosera* hybrid), 5189, and 5126 have, in general, shown good to excellent adaptation to the forest ecosystem, reflecting the effect of climatic, biotic, and edaphic conditions on plant growth and development. Accession CIAT 5126, for example, exhibited excellent adaptation in Turrialba, Costa Rica, but performed poorly in Puerto Cabezas, Nicaragua. Accessions CIAT 438 and 5189 showed
Table 2. Predominant ecosystems, rainfall, and soil characteristics of *Centrosera* germplasm evaluation sites in Central American countries and Mexico since 1980.

<table>
<thead>
<tr>
<th>Country</th>
<th>Site</th>
<th>Predominant ecosystem&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Rainfall mm/year</th>
<th>No. of dry months&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Soil pH (1:1)</th>
<th>Al sat. (%)</th>
<th>P (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nicaragua</td>
<td>Nueva Guinea</td>
<td>TRF</td>
<td>2536</td>
<td>3-4</td>
<td>4.4</td>
<td>21.0</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Pto. Cabezas</td>
<td>TRF</td>
<td>2693</td>
<td>3</td>
<td>—</td>
<td>52.0</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>El Recreo</td>
<td>TRF</td>
<td>3159</td>
<td>3-4</td>
<td>4.3</td>
<td>34.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Costa Rica</td>
<td>San Isidro</td>
<td>TRF</td>
<td>2954</td>
<td>4</td>
<td>5.2</td>
<td>49.2</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>San Carlos</td>
<td>TRF</td>
<td>3425</td>
<td>3-4</td>
<td>5.9</td>
<td>1.5</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>Turrialba</td>
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</table>

<sup>a</sup> TRF = Tropical rain forest; TSSF = tropical semievergreen seasonal forest; TDF = tropical dry forest; TRF-DS = tropical rain forest-derived savanna.

<sup>b</sup> Less than 100 mm rainfall/month.

<sup>c</sup> pH was measured in a 1:2 suspension.

SOURCE: RIEPT, unpublished data.
<table>
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<tr>
<th>Country</th>
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<th>Dry-matter yields (kg DM/ha every 12 weeks)</th>
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</table>

b. G = good; M = moderate; P = poor; E = excellent.
poor adaptation in Soná, Panama, because of severe attacks by rhizoctonia foliar blight.

Wide variation was also observed for seasonal dry-matter yields and within countries during 12-week growth periods in both the forest and savanna ecosystems. The trend of all accessions, including CIAT 438, in the savanna ecosystem was toward increased yields during the maximum rainfall season; this contrasts with the trend observed in the forest ecosystem of San Isidro, Costa Rica. Perhaps in the forest ecosystem, during the rainy season, growth is reduced by foliar diseases and leaf-sucking and leaf-eating insects.

Araya (1968) studied *C. pubescens* in Tocumen, Panama, in an alluvial soil (pH 6.7) with high P (42.6 ppm), K (114 ppm), Ca, and Mg levels. Increasing P levels from 0 to 33 kg/ha tended to reduce *Centrosema* yields but, while large differences were observed between treatments, they were not statistically significant because dry-matter yields were highly variable. Protein content remained at about 20%, irrespective of the level of applied P.

In a greenhouse trial, using savanna soil in Mexico, Meléndez N. et al. (1976) also observed a low response of *C. pubescens* to applied P. Nevertheless, Urrutia R. (1972) observed that *C. pubescens* foliage and root yields were reduced when grown in an Oxisol from Guatemala limed with CaCO₃ at rates higher than 1200 ppm. This was counterbalanced with P applications of 50-75 ppm, thus indicating the low availability of this nutrient in the soil.

*Centrosema pubescens* (centro) was evaluated in several cutting trials in Gualaca, Panama. The annual average rainfall is about 4000 mm and distributed between April and November. Soils are acid Inceptisols (pH 4.7), low in P (1.3 ppm), and with 21% Al saturation. Yield variations were found for the different cutting frequencies and seasons of the year (FAO, 1972; Ortega and Samudio, 1980). Higher yields (2000 kg of DM/ha) were obtained during the rainy season, while only 10%-15% of the yield was obtained during the dry months. Total yields were reduced with age at cutting—a probable result of the combined effects of high humidity, temperature, diseases, and probably insects on the aging and decomposition rates of plant material. During the dry season, an 84-day cutting interval gave the highest yields, but based on the total annual production of the species, a 42-day cutting interval was considered adequate.

Centro retains foliage during the dry season but lacks vigor. During the dry season, the plants suffer less from leaf-eating insects and foliar
diseases. In Belize, at a site with an annual rainfall of 1500 mm and a fertile, alluvial soil (pH 6.3 and 41 ppm P), centro was more productive under cutting than was a native ecotype of *C. pubescens* (Lazier, 1980b). However, when both were subjected to mob-grazing every 6 weeks for about 2 hours a day, the native *C. pubescens* accession CF 6-1 showed higher dry-matter yields compared with centro and a denser coverage of the grazing area in association with *Brachiaria mutica* (Lazier, 1980a). In other words, the native accession that gave lower yields under cutting was more productive than common centro under grazing, probably because of its more stoloniferous growth habit.

In general, *C. pubescens* has given intermediate yields throughout the study area, particularly in the humid forest regions. In Mexico, Panama, and Costa Rica, cercospora leaf spot has reduced its yields. Native ecotypes grow spontaneously along roadsides in a considerable variety of ecological conditions, but their seasonal productivity is usually lower than that of introduced accessions. Yet, the poor persistence of common centro under grazing (C. Ortega, personal communication) suggests that this can be a limiting factor for the species. However, the high number and diversity of *C. pubescens* accessions in introduction nurseries of national institutions in the area suggests considerable scope for future evaluations.

**Centrosema macrocarpum**

This species, which is relatively new in evaluation schemes, is one of the most promising for the study area, particularly in forest ecosystems (Schultze-Kraft and Keller-Grein, 1985). Table 4 shows that in these ecosystems, its adaptation has been good in Panama, except in Soná where accession CIAT 5065 suffered attacks by little-leaf mycoplasma (Arosemena et al., 1986). In Jericó, Mexico, this accession has given dry-matter yields as high as 4426 kg/ha during the maximum rainfall season—a figure comparable with that obtained in Río Hato, Panama, during the minimum rainfall season. Considerable yield variations are observed within countries, as in the case of Ebano and Destierro in Mexico. Less yield variation can be observed in savanna ecosystems, mainly during the minimum rainfall period.

In a tropical dry forest ecosystem (Río Hato, Panama), accessions CIAT 5062, CIAT 5434, CIAT 5478, and CIAT 5065 have given yields that vary between 2825 and 4789 kg of DM/ha during the minimum rainfall season. However, CIAT 5065 has a less stoloniferous growth
Table 4. Results of adaptation (RIEPT\textsuperscript{a} regional trials A) and seasonal dry-matter yield (RIEPT regional trials B) evaluations of *Centrosemia macrocarpum* accessions in Mexico and Central America.

<table>
<thead>
<tr>
<th>Country</th>
<th>Location</th>
<th>CIAT accession no.</th>
<th>Adaptation\textsuperscript{b}</th>
<th>Dry-matter yields (kg DM/ha every 12 weeks)</th>
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\textsuperscript{a} Spanish acronym, RIEPT = Red Internacional de Evaluación de Pastos Tropicales (International Tropical Pastures Evaluation Network).

\textsuperscript{b} G = good; M = moderate; E = excellent.
habit, and retains less foliage during dry periods, than other accessions. Under acid-soil conditions (pH 4.5) and high Al saturation (78%) in Calabacito, Panama, this accession has shown moderate chlorosis symptoms during the first weeks of growth when seeds were uninoculated, but this disappeared as the plants developed. This condition does not occur in fertile soils or when seeds are inoculated with an appropriate Rhizobium strain. Insect attacks and diseases in this species have been moderate throughout the study area (Aranda and Pinilla, 1986; López Naranjo, 1986b).

Centrosema macrocarpum develops good associations with erect grasses such as Hyparrhenia rufa, Panicum maximum, and Andropogon gayanus. In Chiriquí, Panama, a fertilizer experiment was carried out on an acid Ultisol (pH 4.5, 78% Al saturation, and low exchangeable bases) with a C. macrocarpum CIAT 5062-A. gayanus association. The legume showed a significant response, during its establishment, to 60 and 100 kg of K and P/ha, respectively (Table 5). However, the response was greater with the application of 40 kg of S/ha which increased total yields to 4297 kg of DM/ha. This figure was similar to that obtained with the application of 40, 100, and 60 kg/ha of S, P, and K, respectively. In this experiment, sulfur was the most yield-limiting nutrient for both associated components.

<table>
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<th>Fertilizer (kg/ha)</th>
<th>DM yield (kg/ha)(^b)</th>
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<tr>
<td>40</td>
<td>100</td>
<td>60</td>
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</table>

\(^a\) Basal application (kg/ha) was Mg at 20, Zn at 2, B at 1, and Mo at 0.1. The legume was inoculated with Rhizobium.

\(^b\) Harvested 96 days after planting.

Source: B. Pinzón, personal communication.
Centrosema macrocarpum accessions have shown good performance and productivity in humid and dry tropical-forest ecosystems, as well as in derived savannas, throughout the study area. They grow vigorously and produce a considerable amount of foliage which is retained during most of the dry season, even in areas with a 5-month drought such as in the Azuero Peninsula in Panama. In this region, accessions CIAT 5062 and 5434 are more stoloniferous and productive than CIAT 5065, and also show lower pest and disease incidence.

The main limitation of C. macrocarpum appears to be its scarce flowering and seed setting under cutting or in association with grasses, thus restricting its regeneration and persistence in pastures. However, CIAT 5065 persisted after 1 year of grazing in association with H. rufa in Chiriqui, Panama (Pitty et al., 1986). The legume even dominated in the high stocking rate treatment (2.5 animal units/ha), showing a high number of stolons that originated at the base of mother-plant stems, once the plants were defoliated by animals and the apical crown was destroyed. Obviously, management is important for the persistence of the species. Accession CIAT 5062 tends to be more stoloniferous than CIAT 5065 under the conditions that prevail in Calabacito, Panama, and also shows good compatibility with A. gayanus and excellent animal acceptability (E. Arosemena, personal communication).

Therefore, the future success of the species in the region will depend on varieties with either a strongly stoloniferous growth habit which can produce new plants at rooted nodes or an ability to produce seed under grazing. Commercial seed production could be conducted in sites with adequate growth periods and well-defined dry seasons, which are present in all Central American countries and Mexico.

Centrosema brasiliánun

The adaptation range of this species varies from poor to excellent in the area (Table 6). Good adaptation to forest ecosystems is reported frequently, despite the fact that this species suffers severely from rhizoctonia foliar blight (RFB) during the rainy season. Accession CIAT 5234 has been the most widely evaluated in both savanna and forest ecosystems, particularly in adaptation trials. In savanna ecosystems, yields of this accession have been lower than in forest ecosystems, although in Niltpec, Mexico, yields were 3674 kg of DM/ha during the maximum rainfall season. In general, the highest yields for the species have been observed during the maximum rainfall season, regardless of the ecosystem, demonstrating the potential productivity of the species despite its susceptibility to RFB.
Table 6. Results of adaptation (RIEPTa regional trials A) and seasonal dry-matter yields (RIEPT regional trials B) evaluations of *Centrosema brasiilianum* accessions in Mexico and Central America.

<table>
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<tr>
<th>Country</th>
<th>Location</th>
<th>CIAT accession no.</th>
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<th>Dry-matter yields (kg DM/ha every 12 weeks)</th>
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<td>5234</td>
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<td>—</td>
<td>—</td>
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<td>5234</td>
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<td>—</td>
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<td>G</td>
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<td>Hojancha</td>
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SAVANNA ECOSYSTEMS

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<th>Country</th>
<th>Location</th>
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<td>—</td>
<td>—</td>
<td>2586, 2469</td>
</tr>
</tbody>
</table>

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b. E = excellent; G = good; M = moderate; P = poor.
Abundant flowering and seed production are traits that have been observed in this species throughout the study area. This contributes to plant persistence and compensates for yield reductions caused by RFB. In forest ecosystems, however, aggressive stoloniferous weeds invade the plots after cutting because of the reduced competitive ability of the species under conditions of RFB infection (Arosemena et al., 1986). This situation appears different in forest-derived savanna ecosystems where the weed complex is less aggressive.

The species persists and provides standing green forage during dry periods. It shows considerable regrowth and regeneration when the rainy season starts, a result of abundant seed production, thus reaching average populations of as many as 200 plantlets/m². Its main limitation occurs during the rainy season when it is attacked by RFB. Severe defoliation can occur after intense rainy periods followed by short dry intervals. Even under these conditions, however, *C. brasiliannum* continues flowering and setting seed if the disease occurs late in the rainy season. In Mexico, more damage to adult plants has been observed under grazing (25% or more) than under cutting.

The productivity and the persistence of the species remains to be defined under evaluation conditions with animals for a reasonable period of time and under different managements relevant to the production systems of the study area. However, there is no doubt of the compatibility of the species with tillering or erect grasses and of its adequate nodulation with native *Rhizobium* strains.

**Centrosera acutifolium**

This species has been evaluated only recently in the Central American and Mexican tropics. Its adaptation in the region has been reported as moderate, good, and excellent (Table 7). The most widely evaluated accession in the region is CIAT 5112 which has given variable yields between sites and countries. Yields have been higher in forest ecosystems. The results obtained so far show a good potential of the species in appropriate sites.

Accession CIAT 5112 has shown good persistence and competitive ability with weeds in the forest ecosystem in Mexico (Amaya Hernández, 1986). In a savanna ecosystem, derived from tropical rain forest, in Calabacito, Panama, accessions CIAT 5112 and CIAT 5278 have shown good adaptation and dry-matter production, with 378
Table 7. Results of adaptation (RIEPT\textsuperscript{a} regional trials A) and dry-matter seasonal yield (RIEPT regional trials B) evaluations of *Centrosema acutifolium* accessions in Central America and Mexico.

<table>
<thead>
<tr>
<th>Country</th>
<th>Location</th>
<th>CIAT accession no.</th>
<th>Adaptation\textsuperscript{b}</th>
<th>Dry-matter yields (kg DM/ha every 12 weeks)</th>
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<td></td>
<td>Jericó</td>
<td>5112</td>
<td>—</td>
<td>1026</td>
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</tr>
<tr>
<td></td>
<td>Huimanguillo</td>
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<td>—</td>
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<td>G</td>
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<td>—</td>
</tr>
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<td>Turrialba</td>
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<td>2343</td>
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<td>La Ceiba</td>
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<td>G, G</td>
<td>—</td>
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<td>Calabacito</td>
<td>5278, 5112</td>
<td>E, G</td>
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**SAVANNA ECOSYSTEMS**

<table>
<thead>
<tr>
<th>Country</th>
<th>Location</th>
<th>CIAT accession no.</th>
<th>Adaptation\textsuperscript{b}</th>
<th>Dry-matter yields (kg DM/ha every 12 weeks)</th>
<th>Source</th>
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<td></td>
<td>Minimum rainfall period</td>
<td>Maximum rainfall period</td>
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<td>—</td>
<td>1113</td>
<td>3397</td>
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</tr>
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<td>—</td>
<td>160</td>
<td>477</td>
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</table>

\textsuperscript{a} Spanish acronym, RIEPT = Red Internacional de Evaluación de Pastos Tropicales (International Tropical Pastures Evaluation Network).

\textsuperscript{b} E = excellent; G = good; M = moderate.
acceptable tolerance to drought, abundant flowering and seed setting, a marked stoloniferous growth habit, and less susceptibility to RFB than C. brasilianum. Accession CIAT 5278 has performed similarly in Los Santos, Panama, in a tropical dry forest ecosystem with a dry period of 5-6 months. This species should be included in future evaluations because of its wide adaptation and good performance.

Evaluation Under Grazing

Few evaluations of Centrosema's performance under grazing have been conducted in Central America and Mexico. This possibly reflects the poor persistence of common centro (C. pubescens) in preliminary animal production trials (C. Ortega, personal communication). Garza Treviño and Portugal G. (1978) measured beef production on irrigated Digitaria decumbens in association with tropical legumes, including Centrosema, in a subhumid tropical climate of Mexico. Liveweight gains per animal were superior from this association (0.524 kg/day) compared with those obtained from the pure grass (0.385 kg/day). Diet crude-protein levels averaged 8.9% and 13%, respectively. Garza Treviño (1979) reported that the inclusion of C. pubescens in a similar D. decumbens pasture led to a 36% increase in beef production (636 kg/ha) during 364 grazing days, compared with the grass alone (468 kg/ha). At the same site, this association produced a daily 9.4 kg of milk per cow during an 86-day observation period. This was 5.6% higher than the production obtained from D. decumbens alone and fertilized with N (Portugal G. et al., 1977). It is obvious that this legume offers a high-quality forage since it improves the productivity of grass pastures such as D. decumbens, which is known for its excellent forage quality. However, there is no report on the persistence of these pastures after the first grazing year.

The compatibility and potential production of C. plumieri in cutting trials (Lazier, 1981a) and under grazing in association with B. mutica in Belize (Lazier, 1981b) have also been reported, but these are observations made under very specific mob-grazing conditions and for periods not exceeding 18 months. While C. plumieri persisted and improved its coverage during the observation period, it was not as productive as other legumes such as Codariocalyx gyroides. More work is necessary before reliable conclusions on the value of C. plumieri under grazing can be made.
Nodulation

*Centrosema* is highly promiscuous with respect to nodulation with native *Rhizobium* strains in the area. This promiscuity is a favorable factor for good species adaptation. However, there is some specificity, particularly within *C. macrocarpum*. Accessions such as CIAT 5065, require inoculation for vigorous initial growth, especially if established in acid, low-fertility soils.

Excellent nodulation with native strains has been observed in *C. plumieri* and *C. pubescens* in Mexico (González, 1977). Velasco Z. et al. (1980) also found two effective strains among 21 tested under greenhouse conditions in Tabasco, Mexico. Strain CC-18 was significantly superior to the uninoculated, fertilized treatment and gave the highest nodule number.

Seed Production

At Iguala, Guerrero (Mexico), located at latitude 18° 20’ N, several species and accessions have shown their ability to produce seed (Table 8). High yields were observed in *C. brasiliannum* and *C. pubescens*, while yields were lower for *C. acutifolium* and *C. macrocarpum*. All seed was hand-harvested in several passes.

At Gualaca, Panama (latitude 9° N, 4000 mm annual rainfall, 25 °C average temperature), *C. macrocarpum* has flowered well on trellises,

<table>
<thead>
<tr>
<th>Species</th>
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<th>Annual yield (kg/ha)</th>
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<tbody>
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<td>505</td>
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<td><em>C. brasiliannum</em></td>
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<td>1390</td>
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<tr>
<td><em>C. pubescens</em></td>
<td>5189</td>
<td>1066</td>
</tr>
<tr>
<td><em>Centrosema</em> hybrid</td>
<td>438</td>
<td>1450</td>
</tr>
<tr>
<td><em>C. acutifolium</em></td>
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<td>275</td>
</tr>
<tr>
<td><em>C. acutifolium</em></td>
<td>5277</td>
<td>716</td>
</tr>
</tbody>
</table>

but yields have been lower than in Mexico, averaging only 50 kg of hand-harvested seed/ha. The species failed to flower during the establishment year in this location, possibly because there was no defined dry period during that particular year or because of other unknown plant physiological conditions. However, in El Bongo, Panama, in a tropical dry forest ecosystem with 900 mm rainfall and a well-defined dry season, *C. macrocarpum* flowered and set seed, even without trellises and after several standardization cuts (Duque and Vargas, 1985). The same occurs in Río Hato, Panama, in a similar ecosystem (G. González, personal communication).

In Panama, other species such as *C. brasilianum* and *C. acutifolium*, flower and set seed in forest ecosystems such as in Soná and Chepo. They also set seed in forest-derived savanna ecosystems such as in Calabacito.

**Potential and Limitations**

Evaluation of *Centrosema* in Central America and Mexico in the last decade has led to the identification of species with high production potential. *Centrosema brasilianum* grows well in acid infertile savanna soils and, as does *C. macrocarpum*, it retains standing foliage during prolonged dry periods. It also produces a large amount of seed that guarantees the regeneration of plants, even under forest conditions where the species suffers severe attacks by *Rhizoctonia*. For nodulation, it is more promiscuous with native *Rhizobium* strains than are other *Centrosema* species, particularly in savanna ecosystems. As are *C. macrocarpum*, *C. pubescens*, and *C. acutifolium*, it is compatible with erect grasses because of its climbing growth habit.

In forest ecosystems with higher rainfall, *C. macrocarpum* and *C. acutifolium* accessions have shown good performance and productivity, although *C. macrocarpum* has a more vigorous initial growth when inoculated with an appropriate *Rhizobium* strain. The main disadvantage of this species is its limited stolon-rooting ability, at least in the accessions that have been observed so far in Central America and Mexico. *Centrosema acutifolium* has a more creeping growth habit, producing vigorous and branched stolons, which positively influence the persistence and competitiveness of the plant.

The adaptation and agronomic potential observed for *Centrosema* in the region suggests that it is a very important tropical legume genus.
with the ability to substantially improve production and productivity of current livestock-production systems. However, because of limited evaluation with animals under different climatic and management conditions, it is not yet possible to classify the genus in terms of animal production.

**Future Research Priorities**

Much of the research on tropical forages conducted in Central America and Mexico in the past 25 years focused only on gaining knowledge of the performance and agronomic characteristics of the species and their role in pastures. Their potential use in animal production systems was never clearly defined. Furthermore, most of the *Centroselecta* species tested were selected in tropical sites other than Central America and Mexico, and little attention has been paid to local varieties or to varieties from similar regions in Latin America. This means that the following research priorities are fundamental for the local development of the genus:

To continue the systematic collection and introduction of new germplasm in order to expand the genetic base and variability of the genus. This will enable the screening of promising material for productivity, persistence, and tolerance to environmental and biological stresses of different ecosystems.

To carry out agronomic and weed-control studies, mainly in forest ecosystems, with the most promising materials, particularly with *C. macrocarpum*, *C. brasilianum*, and *C. acutifolium*. This will identify limitations and determine seasonal productivity and potential use.

To intensify grazing studies with the agronomically most promising materials in order to define persistence under grazing, animal production, and utilization strategies in the production systems of the region.

To evaluate management systems involving the integration of crops and improved pastures of *Centroselecta*-grass associations in the agriculture-livestock-forestry production systems of tropical Mexico and Central America.
References


Regional experience with Centrosema: Central America and Mexico


and Portugal G., A. 1978. Producción de carne en asociaciones de Zacate pangola (Digitaria decumbens) con tres leguminosas: Proceedings of the sixth meeting. Asociación Latinoamericana de Producción Animal (ALPA), Mexico City, Mexico.


———. 1980b. Productivity of four commercial forage legumes and two native lines under clipping in Belize, C.A. Trop. Agric. (Trinidad) 57(4):343-351.

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Regional experience with Centrosema: Central America and Mexico


Regional experience with Centrosema: Central America and Mexico


Chapter 15

REGIONAL EXPERIENCE WITH CENTROSEMA: NORTHERN SOUTH AMERICA

B. Grof, A. J. Flores, P. E. Mendoza, and E. A. Pizarro*

Abstract

New variation and pasture-plant potential have been found in a number of Centrosema species. From 1979 to 1985, 381 accessions representing 15 species of Centrosema were evaluated in small-plot experiments under cutting and/or grazing at Carimagua in the Colombian Eastern Plains (Llanos Orientales). Simultaneously, the International Tropical Pastures Evaluation Network (RIEPT) evaluated Centrosema germplasm in the tropical savanna and forest ecosystems of northern South America.

Stoloniferous forms of C. acutifolium have yielded well under cutting and grazing in the Colombian Llanos. They were more tolerant of acid-soil savanna conditions, resisted heavy grazing, tolerated pests and diseases, nodulated well, and persisted better than other species. In 12 regional trials conducted in the Colombian Llanos, accessions of C. acutifolium, C. macrocarpum, and C. brasilianum have shown good adaptation across sites. In the Venezuelan Llanos, ecotypes of C. brasilianum and C. macrocarpum have been found to be highly promising with respect to dry-matter production and drought tolerance. In the intermediate savannas of Moblissa, Guyana, accessions of C. brasilianum, C. macrocarpum, and C. pubescens have shown good

* CIAT/IICA/EMBRAPA Regional Program on Tropical Pastures in the Cerrados, Centro de Pesquisa Agropecuária dos Cerrados (CPAC), Planaltina, DF, Brazil; Fondo Nacional de Investigaciones Agropecuarias (FONAIAP), Estación Experimental Anzoátegui, El Tigre, Anzoátegui, Venezuela; Instituto Colombiano Agropecuario (ICA), El Dorado, Bogotá, Colombia; and Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia, respectively.
promise. In forest ecosystems, over 22 sites, the most promising Centrosema species were C. acutifolium, C. macrocarpum, C. pubescens, and a C. pubescens x C. acutifolium hybrid. Although it is well-adapted to low soil fertility, C. brasilianum was less productive in both savanna and forest ecosystems than C. acutifolium and C. macrocarpum. Under heavy grazing (3 an./ha), presentation dry-matter yields were significantly higher for C. acutifolium than for C. macrocarpum. Under lenient grazing (1.5 an./ha), yield differences were insignificant.

Introduction

Northern South America, geographically encompassing Colombia, Venezuela, and the Guianas, contains a great diversity of climatic and edaphic environments. Of most interest, however, for expanding pasture and cattle production are the low-fertility, acid-soil regions of the lowland tropics, including the well-drained and poorly drained isohyperthermic savannas, tropical rain forests, and semievergreen seasonal forests. Studies have, so far, focused on the well-drained isohyperthermic savannas (llanos ecosystem) and the tropical forest ecosystems of Colombia and Venezuela where several Centrosema spp. have shown potential as forage legumes (Figure 1).

The llanos ecosystem is characterized by a total wet-season potential evapotranspiration of 900-1060 mm and a wet season lasting 6-8 months (Cochrane et al., 1985). Annual rainfall averages 1600-2200 mm and occurs from April to November. A marked dry season occurs from mid-December to late March or early May, depending on the location. The soils are predominantly Oxisols (pH 4.3-4.5), of low base status, high aluminum saturation (80%), and deficient in N, P, K, Ca, Mg, S, and some micronutrients.

Regarding specifically the Venezuelan situation, according to classifications by Ewel et al. (1976) and MAC (1960), 80% of Venezuela falls into a region with mean minimum and maximum temperatures of 21 and 29 ºC, respectively, mean annual precipitation of 700-2000 mm with 3-6 months dry season, and altitudes from 0 to 1000 m. According to Comerma and Paredes (1978), 32% of Venezuela is covered with low-fertility soils and, because of edaphic and topographic limitations, 30% of the country has potential only for pasture production. This percentage corresponds with land of usually low fertility (Sánchez, 1986). Some climatic and edaphic characteristics of Venezuelan Centrosema evaluation sites are presented in Table 1.
Figure 1. Major evaluation sites of *Centrosema* in northern South America. (1 = Tropical semievergreen seasonal forest; 2 = well-drained isohyperthermic savanna [llanos ecosystem].)
Table 1. Climatic and soil data from *Centrosemia* evaluation sites in Venezuela.

<table>
<thead>
<tr>
<th>Locality and state (Source)</th>
<th>Alt. (m)</th>
<th>Climate</th>
<th>Soil (0-20 cm)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean precip. (mm/yr)</td>
<td>Mean temp. (°C)</td>
<td>Sand (%)</td>
<td>Loam (%)</td>
<td>Clay (%)</td>
<td>pH</td>
<td>OM (%)</td>
<td>P (ppm) (Olsen)</td>
<td>Ca meq/100 g soil</td>
<td>K</td>
</tr>
<tr>
<td>Barinas, Barinas (Corrales and González, 1972)</td>
<td>250</td>
<td>2300</td>
<td>27.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>1193</td>
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<td>48</td>
<td>30</td>
<td>22</td>
<td>4.5</td>
<td>-</td>
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<tr>
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<td>928</td>
<td>26.3</td>
<td>93</td>
<td>3</td>
<td>4</td>
<td>4.9</td>
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<td>1.7</td>
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<td>Maracay, Aragua (Gueni and Gil, 1986)</td>
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<td>998</td>
<td>24.7</td>
<td>66</td>
<td>16</td>
<td>17</td>
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</table>
The tropical rain forest and tropical semievergreen seasonal forest ecosystems are characterized by a total wet-season potential evapotranspiration of 1061-1300 mm and a wet season lasting 8-10 months (Cochrane et al., 1985). Annual average rainfall ranges from 1600 to over 4000 mm. Seasonal forests have a marked dry season of 3-4 months while tropical rain forests have a wet season longer than 9 months. Soils vary greatly throughout the ecosystems and include both Oxisols and Ultisols with low pH (<5.0) and nutrient deficiencies.

*Centrocea pubescens* is the only well-known *Centrocea* species that has been evaluated widely and is available commercially. However, in recent years, plant exploration has resulted in a major increase of *Centrocea* germplasm held by various institutions. At present, there are about 1800 accessions of *Centrocea* in the germplasm collection of the Centro Internacional de Agricultura Tropical (CIAT) (Schultze-Kraft et al., 1986) and more than 450 native Venezuelan accessions at the Fondo Nacional de Investigaciones Agropecuarias (FONAIAP) (Flores, 1986).

**Species Evaluation: An Overview**

In Colombia, *C. pubescens* and, to a lesser extent, *C. plumieri* were previously regarded as valuable, drought-tolerant, forage legumes for intermediate and high-fertility soils at 0 to 1600 m.a.s.l. (Bermúdez García, 1973; ICA, 1970). Progenies from a cross between Brazilian accessions of *C. pubescens* and *C. acutifolium* were screened by CIAT near Cali, Colombia (Grof, 1982). One derivative (*Centrocea* hybrid CIAT 438) showed good adaptation to cleared-forest ecosystems in Colombia. Daily cattle liveweight gains on pastures of this legume associated with *Andropogon gayanus* over a 3-year period ranged 389-553 g/animal (CIAT, 1978 to 1980; Ramírez P., 1983). CIAT 438, however, is not adapted to the acid, low-fertility soils that prevail in the Colombian Llanos. Neither did the commercial Australian cultivar of *C. pubescens* persist when first tested in the Colombian Llanos in 1976 (B. Grof, unpublished data).

Hutton (1985) obtained fertile crosses between *C. pubescens* and accessions of *C. macrocarpum* and *C. acutifolium*, and tested them in northern South America. Successful hybrids of *C. pubescens* x *C. macrocarpum* combine the high seed yield and stoloniferous habit of *C. pubescens* with acid-soil tolerance and disease resistance of *C. macrocarpum* (Miles et al., this volume).
The recognition that other *Centrosea* spp. were adapted to more marginal environments than the commercial cultivars of *C. pubescens* led to wide evaluation of the genus. Work was first concentrated in Colombia: Quilichao in Cauca, and Carimagua in Meta, where CIAT’s major screening site for the llanos ecosystem is located. From 1977 to 1986, 805 accessions, representing 25 species, and 381 accessions, representing 15 species, were respectively tested in Quilichao and Carimagua (Table 2). The evaluations were carried out in plant nurseries and in small-plot cutting and/or grazing experiments. This is a relatively high proportion of the total number of species recorded for the genus (Williams and Clements, this volume).

<table>
<thead>
<tr>
<th>Species</th>
<th>No. of accessions tested at station:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quilichao</td>
</tr>
<tr>
<td><em>C. acutifolium</em></td>
<td>25</td>
</tr>
<tr>
<td><em>C. angustifolium</em></td>
<td>6</td>
</tr>
<tr>
<td><em>C. arenarium</em></td>
<td>2</td>
</tr>
<tr>
<td><em>C. bifidum</em></td>
<td>2</td>
</tr>
<tr>
<td><em>C. brachypodum</em></td>
<td>9</td>
</tr>
<tr>
<td><em>C. brasiliamum</em></td>
<td>198</td>
</tr>
<tr>
<td><em>C. carajasense</em></td>
<td>2</td>
</tr>
<tr>
<td><em>C. coriaceum</em></td>
<td>3</td>
</tr>
<tr>
<td><em>C. fasciculatum</em></td>
<td>2</td>
</tr>
<tr>
<td><em>C. grazielae</em></td>
<td>19</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>250</td>
</tr>
<tr>
<td><em>C. pascuorum</em></td>
<td>10</td>
</tr>
<tr>
<td><em>C. platycarpum</em></td>
<td>1</td>
</tr>
<tr>
<td><em>C. plumieri</em></td>
<td>24</td>
</tr>
<tr>
<td><em>C. pubescens</em></td>
<td>150</td>
</tr>
<tr>
<td><em>C. rotundifolium</em></td>
<td>4</td>
</tr>
<tr>
<td><em>C. sagittatum</em></td>
<td>6</td>
</tr>
<tr>
<td><em>C. schiedeanum</em></td>
<td>7</td>
</tr>
<tr>
<td><em>C. schottii</em></td>
<td>25</td>
</tr>
<tr>
<td><em>C. new sp. No. 4</em></td>
<td>6</td>
</tr>
<tr>
<td><em>“tetragonolobum”</em></td>
<td>12</td>
</tr>
<tr>
<td><em>C. triquetrum</em></td>
<td>1</td>
</tr>
<tr>
<td><em>C. venosum</em></td>
<td>1</td>
</tr>
<tr>
<td><em>C. vexillatum</em></td>
<td>2</td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>38</td>
</tr>
<tr>
<td><em>C. hybrids</em></td>
<td>—</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>805</strong></td>
</tr>
</tbody>
</table>

Many of the tested species originate from northern South America. For Venezuela, Flores (1986) lists the following native species of which germplasm was collected during joint FONAIAP/CIAT collecting missions: *Centrosema acutifolium*, *C. angustifolium*, *C. brasilianum*, *C. grazielae*, *C. macrocarpum*, *C. pascuorum*, *C. plumieri*, *C. pubescens*, *C. sagittatum*, *C. schottii*, *C. "tetragonolobum," C. triquetrum*, *C. venosum*, *C. vexillatum*, and *C. virginianum*. Some of these species have been described by Pittier (1944) and Ramia (1974). With the exception of *C. pascuorum* and *C. triquetrum*, the same species have also been collected in Colombia, in addition to *C. capitatum*, *C. latidens*, and *C. schiedeanum* (R. Schultze-Kraft, personal communication).

Flores (1986) observed, during collection trips, that the species most represented in the Venezuelan flora are *C. pubescens* (35% of the *Centrosema* accessions collected), *C. macrocarpum* (30%), and *C. brasilianum* (15%), each with a wide geographic distribution within Venezuela. While *C. pubescens* is widespread, *C. macrocarpum* is more common at forest margins at altitudes of 0 to over 1000 m, and *C. brasilianum* usually occurs between 0 and 500 m, especially in zones with high temperatures and 5-7 months of dry season. These species show adaptation to a wide range of Venezuelan soils, particularly *C. macrocarpum* which has been collected from soils of good fertility and higher pH (States of Aragua, Trujillo, Táchira, Barinas, and Monagas) to very poor soils with a pH of 4.1 (Federal Territory of Amazonas, States of Bolívar and Anzoátegui) (Flores, 1986). Accessions of these species, as well as introduced germplasm, are under evaluation in various locations in Venezuela, particularly at the FONAIAP Research Station at El Tigre, Anzoátegui.

Further important *Centrosema* evaluation is being conducted through the International Tropical Pastures Evaluation Network (RIEPT, i.e., Red Internacional de Evaluación de Pastos Tropicales) which, between 1979 and 1985, expanded considerably to include the tropical forest ecosystems of northern South America. More than 25 regional trials A and B (small-plot adaptation and productivity trials) were evaluated in as many sites in the region; the accessions evaluated included elite lines of *C. acutifolium*, *C. brasilianum*, *C. macrocarpum*, *C. pubescens*, and hybrids.
Agronomic Evaluation under Cutting

Savanna ecosystem: Carimagua, Colombia

At Carimagua, a preliminary experiment was conducted from 1979 to 1982 to study the agronomic variability of nine Centrosera species represented by 40 accessions in pure legume plots. The 40 accessions were scored for a range of agronomic attributes such as dry-matter (DM) yield, leaf-to-stem ratio, seed yield, and resistance to pests and diseases. A cluster analysis (Ward, 1963) was then used to analyze the data and to establish groups of species with particular agronomic characters. The analysis generated five distinctive groups in which certain agronomic types were immediately obvious (Figure 2). For example, cluster 5, with high yield and disease resistance, contained a group of desirable perennials for the isohyperthermic savannas where annual rainfall exceeds 2000 mm. Seed yield in this group, however, was inadequate and insect damage was severe. This group included all tested C. macrocarpum and C. acutifolium accessions, as well as C. brasilianum (4 accessions) and C. pubescens (3 accessions), most of which had been collected in acid, low-fertility soil habitats in savanna and forest ecosystems (R. Schultze-Kraft, personal communication).

All five accessions of the annual C. pascuorum fell into the group that produced the lowest DM yields (cluster 4). The highest seed yield and the highest number of self-sown seedlings were also recorded for these lines. High leaf-to-stem ratio was measured in cluster 3, a group containing a promising accession of C. brasilianum (CIAT 5234). Cluster group 2 contained three C. virginianum accessions and one accession of C. graziolae, both low-yielding species with a high leaf-to-stem ratio. Accessions of miscellaneous species (C. pubescens, C. brasilianum, C. graziolae, and C. schiedeanum) in cluster group 1 were only moderately productive.

This preliminary evaluation (Thomas and Grof, 1986) led to more detailed studies of selected accessions of “key” species best adapted to the Colombian Llanos.

Variation patterns among Centrosera spp. in seasonal distribution of dry-matter yield were found to be good indicators of the suitability and adaptation of species to local conditions. Five accessions of C. macrocarpum exhibited significant differences in DM production and distribution of seasonal yield. Ranking of accessions for yield was similar in the wet and dry seasons (Table 3).
CIAT accession no.

1 0 0 0 0 0 0 0 0 1 2 3 0 2 9 2 7 1 0 1 0 1 1 1 2 2 0 2 2 0 1 0 1 1 1 0 2 1 1 2
1 5 5 4 6 5 6 5 2 5 8 5 2 1 3 4 2 3 0 6 3 7 7 9 1 5 2 7 6 2 6 1 8 8 6 7 8 8 7
3 7 2 1 2 6 9 7 2 5 2 7 1 8 7 0 4 5 6 0 7 0 4 4 4 6 5 2 1 0 2 8 9 4 6

Cluster group

1 = Moderate DM yield
2 = Low DM yield, highest leaf-to-stem ratio
3 = Moderate DM yield, high leaf-to-stem ratio
4 = Annuals, lowest DM yield, highest seed yield
5 = Highest DM yield, disease resistant, highly susceptible to insects

Figure 2. Dendogram classification of 40 accessions, representing nine Centrosema species, by cluster analysis of several agronomic attributes at Carimagua, Colombia. ( Adapted from Thomas and Grof, 1986.)

Table 3. Seasonal distribution of dry-matter (DM) yield of five Centrosema macrocarpum accessions at Carimagua, Colombia.

<table>
<thead>
<tr>
<th>CIAT accession no.</th>
<th>DM yield (kg/ha)\a</th>
<th>Wet season</th>
<th>Dry season</th>
</tr>
</thead>
<tbody>
<tr>
<td>5062</td>
<td>5361</td>
<td>1881</td>
<td></td>
</tr>
<tr>
<td>5064</td>
<td>4497</td>
<td>1710</td>
<td></td>
</tr>
<tr>
<td>5065</td>
<td>4693</td>
<td>1982</td>
<td></td>
</tr>
<tr>
<td>5274</td>
<td>4243</td>
<td>1517</td>
<td></td>
</tr>
<tr>
<td>5276</td>
<td>3644</td>
<td>1642</td>
<td></td>
</tr>
</tbody>
</table>

\a. Differences between accessions were significant in both seasons.

SOURCE: B. Grof, unpublished data.
Thirteen accessions of six *Centrosea* species were evaluated in small plots (Table 4). *Centrosea acutifolium* CIAT 5277 was the outstanding accession in this trial. It produced the highest DM yield, exceeding (P<.05) all other entries during the dry season, including a similar species form, accession CIAT 5118. *Centrosea acutifolium* CIAT 5277 is native to the Colombian Llanos (Schultze-Kraft et al., 1987), and is thus well adapted edaphically. It has a high level of drought resistance and excellent tolerance to pests and diseases. It flowers late in the season, and the seed crop is, therefore, often reduced by moisture stress. In this experiment, accessions of *C. pubescens* varied greatly in yield (Table 4), whereas the single *C. virginianum* accession had low yields in both seasons. As other evaluations in Carimaguá have shown, no *C. virginianum* accessions have so far been identified as adapted to acid-soil savanna conditions. *Centrosea rotundifolium* occupied an intermediate position in total dry-matter production. Yields were reduced by rhizoctonia foliar blight (RFB) during the wet season, but dry-season performance of this species was good.

Table 4. Seasonal distribution of dry-matter (DM) yield of 13 accessions of six *Centrosea* species at Carimaguá, Colombia.

<table>
<thead>
<tr>
<th>Species and CIAT accession no.</th>
<th>DM yield (kg/ha)</th>
<th>Wet season</th>
<th>Dry season</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. acutifolium</em> 5277</td>
<td></td>
<td>3397</td>
<td>4429</td>
</tr>
<tr>
<td><em>C. acutifolium</em> 5118</td>
<td></td>
<td>3253</td>
<td>2414</td>
</tr>
<tr>
<td><em>C. pubescens</em> 5188</td>
<td></td>
<td>3093</td>
<td>1984</td>
</tr>
<tr>
<td><em>C. rotundifolium</em> 5283</td>
<td></td>
<td>1309</td>
<td>1469</td>
</tr>
<tr>
<td><em>C. schiedeanum</em> 5161</td>
<td></td>
<td>2575</td>
<td>1414</td>
</tr>
<tr>
<td><em>C. pubescens</em> 5155</td>
<td></td>
<td>1969</td>
<td>1379</td>
</tr>
<tr>
<td><em>C. pubescens</em> 5151</td>
<td></td>
<td>1648</td>
<td>1235</td>
</tr>
<tr>
<td><em>C. pubescens</em> 5059</td>
<td></td>
<td>760</td>
<td>1043</td>
</tr>
<tr>
<td><em>C. virginianum</em> 5246</td>
<td></td>
<td>685</td>
<td>946</td>
</tr>
<tr>
<td><em>C. pubescens</em> 5172</td>
<td></td>
<td>1229</td>
<td>921</td>
</tr>
<tr>
<td><em>C. pubescens</em> 5144</td>
<td></td>
<td>1048</td>
<td>811</td>
</tr>
<tr>
<td><em>C. brasiliannum</em> 5185</td>
<td></td>
<td>1622</td>
<td>776</td>
</tr>
<tr>
<td><em>C. pubescens</em> 5169</td>
<td></td>
<td>1986</td>
<td>696</td>
</tr>
</tbody>
</table>

SOURCE: B. Grof, unpublished data.

Considerable variation has been recorded among accessions of *C. brasiliannum*. Dry and wet season yields of 14 accessions of *C. brasiliannum* and one accession each of *C. plumieri*, *C. pubescens*, and *C. pascuorum* were measured in plots and classified by cluster analysis (Table 5). In general, foliar diseases, particularly RFB, and sucking
Table 5. Classification of 14 accessions of *Centrosema brasilianum* and one accession each of *C. plumieri*, *C. pubescens*, and *C. pascuorum* by cluster analysis of wet and dry season yields at Carimagua, Colombia.

<table>
<thead>
<tr>
<th>Dendrogram</th>
<th>Cluster group</th>
<th>No. of accessions</th>
<th>Group mean of DM yields (kg/ha)</th>
<th>Species and accessions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wet season</td>
<td>Dry season</td>
</tr>
</tbody>
</table>
| 1          | 3             | 1537              | 984             | *C. brasilianum* accessions (2) and  
|            |               |                   |                 | *C. pascuorum* CIAT 5376 |
| 2          | 1             | 654               | 1113            | *C. brasilianum* CIAT 5368 |
| 3          | 4             | 1151              | 861             | *C. brasilianum* accessions (3) and  
|            |               |                   |                 | *C. pubescens* CIAT 5270 |
| 4          | 2             | 2275              | 797             | *C. brasilianum* CIAT 5369 and *C.  
|            |               |                   |                 | *plumieri* CIAT 5070 |
| 5          | 7             | 1999              | 1655            | All *C. brasilianum* accessions,  
|            |               |                   |                 | including CIAT 5178 and  
|            |               |                   |                 | CIAT 5234 |

SOURCE: B. Grof, unpublished data.
insects caused yield reductions of most accessions during the wet season. Cluster 5 contained seven accessions of *C. brasilianum* with the highest total dry-matter yields well distributed throughout the year, including two superior lines, CIAT 5234 and CIAT 5178, which were selected for advanced testing. Accessions in clusters 3 and 4 produced modest yields in the dry season. The only accession in cluster 2 produced low yields during the wet season when it was badly affected by RFB, but showed increased productivity during the dry season. As new accessions of *C. brasilianum* currently under evaluation are more productive than previously selected superior lines, further evaluation is warranted in this species.

In general, accessions of *C. pascuorum* are not promising at Carimagua because of their annual habit and short growing season (Table 5 and B. Grof, unpublished data). In contrast to other accessions of this species, *C. pascuorum* CIAT 5376 in cluster 1 (Table 5) and CIAT 5176 in a previous experiment exhibited a long growing season and extended leaf production into the dry season. Both are late flowering.

Early introductions of *C. macrocarpum* tested at Carimagua were mostly erect, climbing, nonstoloniferous forms, represented by CIAT 5062 and CIAT 5065. Although productive in cutting trials or under light grazing (1.5 animals/ha), they were intolerant of close, frequent defoliation by grazing animals (CIAT, 1986; Grof, 1986). Examination of 29 accessions of *C. macrocarpum* and one *C. acutifolium* as control revealed a wide range of variation in rooted stolon density among accessions of this species (Table 6). Five accessions of *C. macrocarpum* and *C. acutifolium* (Group 4) were the "best" overall accessions, combining the desirable characteristics of high, well-distributed DM production with a high density of rooted stolons per unit area. Strong stoloniferous root development was closely correlated with persistence and yield. This was confirmed in a small-scale grazing experiment, comprising both stoloniferous and nonstoloniferous forms of *Centroselecta* (Grof, 1986).

The llanos ecosystem is characterized by a well-defined dry season that lasts from December to March or, as in some parts of Venezuela, even longer. During this period rainfall is unreliable and ineffective (<30 mm/month). Consequently, drought tolerance and dry-matter production lasting well into the dry season are characteristics of paramount importance for species success in this ecosystem. In another small-plot cutting trial at Carimagua, the relative yields of dry matter
<table>
<thead>
<tr>
<th>Group no.</th>
<th>CIAT accession no.</th>
<th>DM yields (kg/ha)</th>
<th>Rooted stolon density (no./m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Wet season</td>
<td>Dry season</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>1</td>
<td>5065, 5563, 5573, 5887</td>
<td>2762-3881</td>
<td>3054</td>
</tr>
<tr>
<td>2</td>
<td>5713, 5733, 5735, 5743</td>
<td>2788-3726</td>
<td>3243</td>
</tr>
<tr>
<td>3</td>
<td>5730, 5740, 5864, 5798, 5904, 5888, 5739</td>
<td>3570-5445</td>
<td>4363</td>
</tr>
<tr>
<td>4</td>
<td>5275, 5418, 5450, 5645, 5736, 5278A</td>
<td>3138-4994</td>
<td>3943</td>
</tr>
<tr>
<td>5</td>
<td>5460, 5732</td>
<td>4396-4994</td>
<td>4695</td>
</tr>
<tr>
<td>6</td>
<td>5392, 5395, 5452, 5616, 5620, 5674, 5901</td>
<td>2256-3825</td>
<td>2972</td>
</tr>
</tbody>
</table>

a. *C. acutifolium* as control.

SOURCE: B. Grof, unpublished data.
produced during the dry season were in the following declining order: *C. macrocarpum*, *C. acutifolium*, *C. brasilianum* > *C. pubescens* > *C. grazielae*, *C. schiedeanum*, *C. virginianum* > *C. pascuorum* (Table 7).

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of accessions</th>
<th>DM yieldsa (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Wet season</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5</td>
<td>4501</td>
</tr>
<tr>
<td><em>C. acutifolium</em></td>
<td>2</td>
<td>3579</td>
</tr>
<tr>
<td><em>C. brasilianum</em></td>
<td>6</td>
<td>3263</td>
</tr>
<tr>
<td><em>C. pubescens</em></td>
<td>8</td>
<td>2874</td>
</tr>
<tr>
<td><em>C. pascuorum</em></td>
<td>5</td>
<td>1855</td>
</tr>
<tr>
<td><em>C. grazielae</em></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>2</td>
<td>1530b</td>
</tr>
<tr>
<td><em>C. schiedeanum</em></td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

a. Mean of three years.
b. Mean DM yield of the five accessions of *C. grazielae*, *C. virginianum*, and *C. schiedeanum*.

SOURCE: B. Grof, unpublished data.

**Savanna ecosystem: evaluation in the Colombian Llanos**

Since 1979, 12 trials have been conducted in the Colombian Llanos at various sites and have included accessions of *C. acutifolium*, *C. brasilianum*, *C. macrocarpum*, and *C. pubescens*. The results in terms of seasonal yields for 12-week growth periods are summarized in Appendix 1 of this chapter. To date, *C. acutifolium* CIAT 5112, CIAT 5277, and CIAT 5278, and *C. macrocarpum* CIAT 5065 and CIAT 5062 have shown adaptation across sites. Leaf-eating insects and several foliar diseases are regarded as potential limiting factors to these accessions (Calderón, 1983; Lenné, 1983; Lenné et al., 1985), and inoculation with *Rhizobium* is necessary in some sites (R. Sylvester-Bradley, personal communication).

**Savanna ecosystem: evaluation in the Venezuelan Llanos**

Venezuelan Regional Trial A work (adaptation trials) has only been conducted at El Tigre, Anzoátegui, where *C. brasilianum* and *C.
pubescens performed best in the first year (Sanabria and González, 1983). Regional Centrolemma evaluation at the B trial level (measurement of DM production) in the Venezuelan Llanos has been restricted to three sites, that is, Calabozo and Espino in Guárico, and El Tigre in Anzoátegui; the respective results are summarized in Table 8. Additional information from the Guárico trial showed that C. brasilianum CIAT 5234 was better adapted and more drought tolerant than C. macrocarpum CIAT 5062 and C. pubescens (Arias et al., 1986). In the Espino trial, in addition to the three C. brasilianum accessions mentioned in Table 8, C. acutifolium CIAT 5112, C. macrocarpum CIAT 5065, and C. pubescens CIAT 5050, CIAT 5053 and CIAT 5126 were also under observation. Centrolemma brasilianum performed best but was inferior to Stylosanthes guianensis and S. capitata (Flores, 1986).

In Table 9, DM production data for the individual accessions evaluated at El Tigre, and summarized in Table 8, are presented, together with information on flowering, seed production, and crude protein content. To date, two accessions of C. brasilianum and eight of C. macrocarpum have been found to be highly promising with respect to DM production and drought tolerance (Flores, 1986).

**Savanna ecosystem: regional evaluation in Guyana**

Regional evaluation of Centrolemma was conducted in an adaptation trial in the intermediate savannas of Moblissa. These savannas are located between latitudes 4° and 6° N and between longitudes 57° and 57°30’ W, at 25-30 m.a.s.l. The mean annual rainfall is 2000 mm and mean annual temperature is 26 °C. At this very sandy site, C. macrocarpum CIAT 5065 showed particular promise because of tolerance to RFB, followed by C. pubescens CIAT 5053 and CIAT 5126. Centrolemma brasilianum CIAT 5055 and CIAT 5184 were disease susceptible (Wickham and Osuji, 1986).

**Forest ecosystems: Quilichao, Colombia**

Since 1977, small-plot evaluation work with Centrolemma spp. germplasm has been conducted at the Quilichao research station, Colombia (lat. 39°06’ N, long. 76°31’ W; 990 m.a.s.l.; 23 °C mean temperature; 1800 mm rainfall/year; acid, highly Al-saturated Ultisol) (CIAT, 1979 to 1982, 1984a, 1984b to 1987). A substantial portion of the CIAT Centrolemma germplasm collection (Table 2) has been
<table>
<thead>
<tr>
<th>Localities and State or Territory</th>
<th>Species</th>
<th>DM Production (t/ha)</th>
<th>Observations</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SAVANNA ECOSYSTEM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calabozo, Guárico</td>
<td><em>C. brasilián</em> CIAT 5234</td>
<td>0.4; 1.8; 0.8; 1.3</td>
<td>Cut at 3, 6, 9, 12 weeks, respectively, in rainy season</td>
<td>Arias et al., 1986</td>
</tr>
<tr>
<td>Espino, Guárico</td>
<td><em>C. brasilián</em> CIAT 5055</td>
<td>0.1; 0.7; 0.2; 0.4</td>
<td>Cut at 3, 6, 9, 12 weeks, respectively, in rainy season</td>
<td>Barreto M., 1986</td>
</tr>
<tr>
<td></td>
<td><em>C. brasilián</em> CIAT 5234</td>
<td>0.1; 0.7; 0.2; 0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>C. brasilián</em> CIAT 5247</td>
<td>0.2; 0.3; 0.1; 0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>El Tigre, Anzoátegui</td>
<td><em>C. brasilián</em> 7 acc.</td>
<td>0.8</td>
<td>Means of 2 cuts at 8-week intervals in rainy season</td>
<td>Flores, 1986</td>
</tr>
<tr>
<td></td>
<td><em>C. macrocarpum</em> 15 acc.</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>hybrids</em> 6 acc.</td>
<td>0.8</td>
<td></td>
<td></td>
</tr>
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<td><strong>FOREST ECOSYSTEMS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orinoco Delta, Territory Federal</td>
<td><em>C. plumieri</em></td>
<td>5.6</td>
<td>Annual production; in association with <em>D. decumbens</em></td>
<td>Velásquez and Bryan, 1975</td>
</tr>
<tr>
<td>Delta Amacuro</td>
<td><em>C. pubescens</em></td>
<td>4.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guachi, Zulia</td>
<td><em>C. pubescens</em> common</td>
<td>R: 0.6; 0.8; 1.4; 1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>D: 0.6; 0.6; 0.6; 0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>C. hybrid</em> CIAT 438</td>
<td>R: 0.6; 1.0; 1.4; 1.4</td>
<td>Cut at 3, 6, 9, 12 weeks, respectively, in rainy (R) and dry (D) seasons, respectively</td>
<td>Urdaneta et al., 1982</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D: 0.6; 0.8; 0.8; 1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maracay, Aragua</td>
<td><em>Centroæma</em> sp. IIZ-11</td>
<td>R: 0.3; 0.6</td>
<td>Means of 2 cuts in rainy season and 3 cuts in dry season, respectively</td>
<td>Rodríguez et al., 1984</td>
</tr>
<tr>
<td></td>
<td><em>C. pubescens</em></td>
<td>D: 0.3; 0.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*a. *C. macrocarpum* x *C. pubescens* hybrids.*
Table 9. Evaluation of 29 accessions of *Centrosema* spp. in El Tigre, Venezuela.

<table>
<thead>
<tr>
<th>Species</th>
<th>CIAT no.</th>
<th>Flowering</th>
<th>Seed production</th>
<th>DM production b (t/ha)</th>
<th>Crude protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Initiation</td>
<td>Maximum flowering (No. of days after planting c)</td>
<td>(kg/ha)</td>
<td>Cut 1</td>
</tr>
<tr>
<td><em>C. acutifolium</em></td>
<td>5568</td>
<td>110</td>
<td>133</td>
<td>284</td>
<td>0.7</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5065</td>
<td>115</td>
<td>168</td>
<td>91</td>
<td>1.1</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5434</td>
<td>123</td>
<td>171</td>
<td>33</td>
<td>1.6</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5452</td>
<td>119</td>
<td>182</td>
<td>63</td>
<td>1.7</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5620</td>
<td>133</td>
<td>182</td>
<td>79</td>
<td>1.1</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5629</td>
<td>122</td>
<td>181</td>
<td>137</td>
<td>1.7</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5633</td>
<td>118</td>
<td>182</td>
<td>53</td>
<td>1.2</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5645</td>
<td>116</td>
<td>173</td>
<td>217</td>
<td>1.6</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5674</td>
<td>130</td>
<td>176</td>
<td>58</td>
<td>0.6</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5713</td>
<td>120</td>
<td>169</td>
<td>166</td>
<td>2.2</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5730</td>
<td>153</td>
<td>199</td>
<td>47</td>
<td>1.1</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5735</td>
<td>133</td>
<td>188</td>
<td>93</td>
<td>1.3</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5737</td>
<td>146</td>
<td>106</td>
<td>49</td>
<td>1.5</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5740</td>
<td>139</td>
<td>187</td>
<td>60</td>
<td>0.8</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5744</td>
<td>108</td>
<td>194</td>
<td>64</td>
<td>1.3</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>5887</td>
<td>93</td>
<td>166</td>
<td>286</td>
<td>1.2</td>
</tr>
<tr>
<td><em>C. hybrid</em></td>
<td>5930</td>
<td>88</td>
<td>118</td>
<td>500</td>
<td>0.7</td>
</tr>
<tr>
<td><em>C. hybrid</em></td>
<td>5931</td>
<td>90</td>
<td>125</td>
<td>357</td>
<td>1.4</td>
</tr>
<tr>
<td><em>C. hybrid</em></td>
<td>5932</td>
<td>91</td>
<td>124</td>
<td>126</td>
<td>0.6</td>
</tr>
<tr>
<td><em>C. hybrid</em></td>
<td>5933</td>
<td>82</td>
<td>117</td>
<td>414</td>
<td>1.0</td>
</tr>
<tr>
<td><em>C. hybrid</em></td>
<td>5934</td>
<td>88</td>
<td>121</td>
<td>314</td>
<td>0.8</td>
</tr>
<tr>
<td><em>C. hybrid</em></td>
<td>5935</td>
<td>91</td>
<td>120</td>
<td>120</td>
<td>0.5</td>
</tr>
<tr>
<td><em>C. brasilianum</em></td>
<td>5234</td>
<td>90</td>
<td>138</td>
<td>157</td>
<td>0.5</td>
</tr>
<tr>
<td><em>C. brasilianum</em></td>
<td>5430</td>
<td>83</td>
<td>111</td>
<td>200</td>
<td>1.1</td>
</tr>
<tr>
<td><em>C. brasilianum</em></td>
<td>5487</td>
<td>92</td>
<td>116</td>
<td>343</td>
<td>1.4</td>
</tr>
<tr>
<td><em>C. brasilianum</em></td>
<td>5657</td>
<td>72</td>
<td>125</td>
<td>286</td>
<td>1.5</td>
</tr>
<tr>
<td><em>C. brasilianum</em></td>
<td>5671</td>
<td>87</td>
<td>113</td>
<td>243</td>
<td>0.8</td>
</tr>
<tr>
<td><em>C. brasilianum</em></td>
<td>5712</td>
<td>67</td>
<td>104</td>
<td>300</td>
<td>0.8</td>
</tr>
<tr>
<td><em>C. brasilianum</em></td>
<td>5810</td>
<td>85</td>
<td>120</td>
<td>214</td>
<td>1.0</td>
</tr>
</tbody>
</table>

a. The hybrids were *C. macrocarpum* x *C. pubescens*.
b. Wet season 1985, regrowth at 8 weeks.
c. Planting was on 1 August 1984.

characterized and evaluated in terms of adaptation to prevailing edaphic limitations and biotic constraints, particularly diseases. As a result, the intraspecific variation of a series of adapted species such as *C. acutifolium*, *C. brasiliannum*, and *C. macrocarpum*, was described and promising germplasm, warranting wider testing in major screening sites and in regional trials, was identified (Belalcázar and Schultze-Kraft, 1986; Keller-Grein, 1984; Schultze-Kraft and Keller-Grein, 1985; Schultze-Kraft et al., 1985; Schultze-Kraft et al., 1987).

**Forest ecosystems: regional evaluation in Colombia**

Since 1979, 22 regional trials have been planted in 18 different sites with a wide range of variability in climatic and edaphic characteristics. Altitudes ranged from 50 to 1600 m; mean annual precipitation from 1042 to 4775 mm; and soils varied greatly in fertility, with Al saturation ranging from 0% to 90%. Within this diversity of environments, accessions of *C. acutifolium*, *C. brasiliannum*, *C. macrocarpum*, *C. pubescens*, *C. schiedeanum*, *C. pascuorum*, *C. rotundifolium*, *C. virginianum*, and *Centroserma* hybrids were evaluated. For the Regional Trials B, distribution of seasonal yield was measured for 12-week-growth periods during times of maximum and minimum precipitation (Appendix 2 of this chapter). Over all sites, the most promising accessions were *C. macrocarpum* CIAT 5062 and CIAT 5065, *C. pubescens* CIAT 5189, *Centroserma* hybrid CIAT 438, and *C. acutifolium* CIAT 5112. At specific sites, the excellent performances of *C. macrocarpum* CIAT 5452, CIAT 5434, and CIAT 5629 (Macagual) and *C. acutifolium* CIAT 5568 (Urabá) were also noted (data not presented). In general, *C. brasiliannum* was affected by RFB. *Centroserma* hybrid CIAT 438 and *C. pubescens* CIAT 5189 were the superior accessions at the more fertile sites in the cleared-forest ecosystem.

**Forest ecosystems: regional evaluation in Venezuela**

A few regional trials have been conducted in Venezuelan forest ecosystems (Table 8). An experiment similar to the RIEPT B trials was carried out by Urdaneta et al. (1982) in Guachi, Zulia, evaluating 13 legumes, including *C. pubescens* (common centro) and hybrid CIAT 438. The hybrid outyielded common centro, but *Stylosanthes guianensis*, *S. capitata*, *Desmodium ovalifolium*, and *Zornia latifolia* were superior to *Centroserma* spp. Leaf-eating insects also severely attacked *Centroserma* (Calderón, 1983).
Evaluation Under Grazing

Carimagua, Colombia

Agronomic studies in Carimagua compared, under grazing, 16 accessions of four *Centrocoma* spp. (Wege, 1984). In one of these trials, *C. plumieri* was compared with two *C. acutifolium* accessions. Under a variable stocking rate, the highest legume content was maintained in the *C. acutifolium* CIAT 5278-*Andropogon gayanus* cv. Carimagua 1 association. In another trial, Wege (1984) compared *C. macrocarpum* accessions with *C. acutifolium* CIAT 5278 and found that a relatively rapid decline of legume content occurred in the *C. macrocarpum-A. gayanus* associations; there was clear evidence of the better tolerance for heavy grazing by the stoloniferous *C. acutifolium* CIAT 5278. This observation was confirmed in two other small-scale grazing experiments (Groff, 1986). In one of these grazing trials, higher yields and legume contents were recorded in a *C. macrocarpum* CIAT 5065 and CIAT 5062-*A. gayanus* pasture grazed at 1.5 an./ha than in a high stocking rate treatment of 3 an./ha. In the high stocking rate treatment, overall presentation yields were significantly higher for the stoloniferous *C. acutifolium* CIAT 5568 than for *C. macrocarpum* accessions. All three accessions outyielded *C. brasiliunum*. In the low stocking rate treatment, there was no significant difference between *C. acutifolium* and the two *C. macrocarpum* accessions. However, all outyielded *C. brasiliunum*.

Quilichao, Colombia

From 1980 to 1983, an experiment was conducted to evaluate, under grazing, alternative management strategies for grass-legume associations and to select the most productive associations (Giraldo and Toledo, 1986). Associations included *Panicum maximum* CIAT 604 and *A. gayanus* cv. Carimagua 1, each with *S. capitata* CIAT 1315 and *Centrocoma* hybrid CIAT 438, as well as *Brachiaria decumbens* cv. Basilisk with *Desmodium ovalifolium* CIAT 350. Three grazing pressures were used. The *A. gayanus-Centrocoma*, and *B. decumbens-D. ovalifolium* associations were highly compatible, maintaining acceptable legume contents during the trial at all grazing pressures (Giraldo and Toledo, 1986).

Since 1983, several other *Centrocoma* species and accessions have been evaluated under grazing at Quilichao. In one small-plot grazing
trial, *C. acutifolium* CIAT 5277 and CIAT 5568, and *C. macrocarpum* CIAT 5065 and CIAT 5434 in association with *A. gayanus* were subjected to different grazing frequencies (2, 4, 6 weeks rest) and stocking rates (2.4 and 3.6 AU/ha, where AU = 400 kg liveweight). Results after 3 years indicate that the more stoloniferous *C. macrocarpum* accession CIAT 5434 has persisted under both high and low stocking rates with 2 or 4 weeks of rest. In contrast, the more erect *C. macrocarpum* CIAT 5065 has persisted only at the low stocking rate with 2 or 4 weeks of rest. *Centroselecta acutifolium* CIAT 5277 and CIAT 5568 also persisted only at the low stocking rate combined with 4 weeks of rest (C. E. Lascano, personal communication).

The excellent performance of stoloniferous *C. macrocarpum* has also been evident in another grazing trial currently in progress at Quilichao (CIAT, 1987). After 2 years of grazing, the legume content of a *C. macrocarpum* CIAT 5713-*A. gayanus* association under low grazing pressure (6.8 kg green DM per 100 kg liveweight) increased from the initial 30% to 50%. In the high grazing pressure treatment (3-5 kg green DM per 100 kg LW), however, legume content was drastically reduced from 30% to 10%. In the same experiment, *C. acutifolium* CIAT 5277 and CIAT 5568 contributed 10% legume DM to the sward, irrespective of grazing pressure (C. E. Lascano, personal communication).

**Venezuela**

Evaluation of *Centroselecta* under grazing in Venezuela was carried out at Maracay. Zerpa and Villalobos (1953) observed the excellent performance of *C. pubescens* with *Digitaria decumbens* and to a lesser extent, *B. decumbens*. Later, *C. pubescens* was compared with *Leucaena leucocephala*, *Pueraria phaseoloides*, and *Teramnus uncinatus* associated with *B. mutica*, *Panicum maximum*, *Hyparrhenia rufa*, *D. decumbens*, and *Pennisetum purpureum*. Only the associations *D. decumbens*-*C. pubescens* and *D. decumbens*-*P. phaseoloides* were satisfactory. At the same site, Valenti (1983) observed that *C. pubescens* performed better than *S. guianensis* in association with *D. decumbens* and *C. plumieri* in association with *D. decumbens*. In Barinas and the region south of Lake Maracaibo, *C. pubescens* forms spontaneous associations with naturalized and introduced grasses such as *Echinochloa polystachya*, *P. maximum*, *H. rufa*, and *B. mutica* (Corrales and González, 1972; MAC, 1975).

In the well-drained savannas of El Tigre, Parra and Flores (1977) and Parra et al. (1978) observed that *C. pubescens* and *C. plumieri*, as pure
stands or in association, performed well in the wet season. However, they defoliated in the dry season. Similar observations were made by Guenni and Gil (1986) and Rodríguez et al. (1984) in an experiment where *P. phaseoloides* and *C. pubescens* produced best in the wet season, but were outyielded by *M. atropurpureum* and *L. leucocephala* during the dry. So far, no other *Centrosema* species have been evaluated under grazing in Venezuela.

Details of animal production from *Centrosema* pastures in northern South America are provided by Lascano et al. (this volume).

### Potential and Limitations

Until recently, *C. pubescens*, or common centro, was the only species of the *Centrosema* genus that had been used commercially in the region. As a result of extensive studies conducted in the Colombian and Venezuelan Llanos and the humid tropics, newly introduced *Centrosema* species have been domesticated.

Edaphically and climatically, the isohyperthermic savanna (llanos) ecosystem is a high-stress situation. The forest ecosystems usually show less edaphic stress. Promising forage species selected for these environments exhibited good adaptation to a range of soil fertility conditions and usually performed well on slightly more fertile soils. In both ecosystems, however, the pest and disease pressure on leguminous species is extremely severe.

In general, species collected from similar climatic zones performed agronomically better under the same conditions. To date, stoloniferous forms of *C. acutifolium* have yielded well under cutting and grazing. In several experiments, the best performance was shown by CIAT 5277 and CIAT 5278; both are native to Vichada in the Colombian Llanos (Schultze-Kraft et al., 1987). These accessions were more tolerant of acid-soil savanna conditions, resisted heavy grazing, tolerated pests and diseases, nodulated, and persisted better than other species. The Instituto Colombiano Agropecuario (ICA) plans to release CIAT 5277 during 1987.¹

*Centrosema* species must flower and mature seed early enough to ensure a reliable seed set for self-regeneration. The majority of

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¹ Editors' note: CIAT 5277 was released as cultivar Vichada on 9 October 1987, by the Instituto Colombiano Agropecuario (ICA).
accessions of *C. macrocarpum* are late-flowering genotypes; seed yields of these are much reduced in a normal growing season when soil moisture is in short supply as flowering begins. The highly promising *C. acutifolium* CIAT 5277 is also a moderately poor seed-producer in some environments because of its late-flowering habit. In addition, the use of existing accessions of *C. brasilianum* is greatly limited in the high rainfall (> 2000 mm) savanna regions because of susceptibility to RFB and sucking insects. Although it has been shown that there is no correlation between tolerance to RFB and rainfall at original *C. brasilianum* collection sites (Schultze-Kraft and Belalcázar, 1988), it would be convenient to increase the germplasm base from wetter environments.

*Centrosuma* is a genus of major economic potential. The potential of the genus, however, is far from being exhausted. It is still relatively easy to domesticate “new” species (forms), and a lot of useful variation can still be found in established species such as *C. pubescens*. There is considerable scope for the development of new cultivars of *Centrosuma*, especially for those that will overcome the problems of disease, low seed production, low palatability, and persistence.

Another attractive option is the exploitation of the apparent interspecific compatibility among species of the *C. pubescens* “complex” (Miles et al.; Williams and Clements, this volume). This includes forms of *C. macrocarpum*, *C. acutifolium*, and *C. pubescens*, and possibly several other closely related species with wide ecological and agronomic adaptation. Successful hybridization among this complex of species could open up new vistas and provide new variability to select genotypes with the desirable agronomic traits not available in naturally occurring ecotypes of *Centrosuma*.

**Future Research**

To date, most work on *Centrosuma* spp. in northern South America has been done at Quilichao and Carimagua, Colombia. Further emphasis should be placed on animal performance trials at different sites in the llanos ecosystem and particularly in the forest ecosystems. Promising accessions from multilocalional trials have been identified, and these need to be tested in associations with grasses and under grazing.

Several potentially limiting disease and pest problems (Lenné et al., this volume) deserve further evaluation, particularly under grazing.
Although other species also deserve more attention, resources would be better spent in the short term by promoting highly promising accessions to commercial status.

References


Cochrane, T. T.; Sánchez, L. G.; de Azevedo, L. Guimarães; Porras, J. A.; and Garver, C. L. 1985. Land in tropical America: A guide to climate, landscapes, and soils for agronomists in Amazonia, the Andean piedmont, central Brazil, and Orinoco, 3 vols. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia; and Empresa Brasileira de Pesquisa Agropecuária, Centro de Pesquisa Agropecuária dos Cerrados (EMBRAPA-CPAC), Planaltina, Brazil. Vol. 1, map plate 1, [p. 59]. (Presented in a mixture of English, Spanish, and Portuguese.)


Regional experience with Centrosema: northern South America


Sánchez, A. 1986. Características ecológicas de las zonas del país, actuales y potenciales afectadas por el síndrome parapléjico de los bovinos. Centro Nacional de Investigaciones Agropecuarias (CENIAP), Maracay, Venezuela. 9 p. (Typescript.)


Regional experience with Centrosema: northern South America


Appendix 1. Seasonal dry-matter (DM) yields of *Centrocomma* spp. in the tropical savanna ecosystem (llanos), Colombia, during the RIEPTa trials.

<table>
<thead>
<tr>
<th>Species</th>
<th>CIAT accession no.</th>
<th>Site</th>
<th>DM yield (kg/ha for 12 weeks)</th>
<th>Wet season</th>
<th>Dry season</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. acutifolium</em></td>
<td>5112</td>
<td>El Viento</td>
<td>306</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>El Paraíso</td>
<td>1564</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5277</td>
<td>Guayabal</td>
<td>193</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Orocú</td>
<td>2544</td>
<td>310</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5277</td>
<td>Las Leónas</td>
<td>1433</td>
<td>316</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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a. RIEPT = Red Internacional de Evaluación de Pastos Tropicales (International Tropical Pastures Evaluation Network).

b. DM yields were higher in the dry season than in the wet because of unusual dry-season rainfall.

c. Nine-week yields.


418
Appendix 2. Seasonal yields of *Centroëma* spp. in tropical forest ecosystems, Colombia, during the RIEPT® trials.

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*a. RIEPT = Red Internacional de Evaluación de Pastos Tropicales (International Tropical Pastures Evaluation Network).  
b. Nine-week yields.  
c. Six-week yields.*

**Sources:** Pizarro, 1986a and 1986b.
Chapter 16

REGIONAL EXPERIENCE WITH CENTROSEMA: PERU, BOLIVIA, AND ECUADOR

C. A. Reyes, G. Keller-Grein, and R. C. Pérez*

Abstract

Studies on commercial Centrosema pubescens in Peru, Bolivia, and Ecuador were initiated about 20 years ago. In the last decade, other species have been evaluated, principally introductions from CIAT. Research is mainly conducted in the Amazon region which has acid, infertile soils. Two hundred accessions have been tested, 179 of which are recent introductions that were established in 1986, mainly in Pucallpa, Peru. The most promising material for the region belongs to the species C. acutifolium, C. macrocarpum, C. pubescens, and, to a lesser extent, C. brasiliannum. While one C. macrocarpum accession and two C. pubescens accessions have been evaluated under grazing in association with grasses, no species has yet been commercialized.

Various factors restrict the use of Centrosema, particularly biotic factors. These include susceptibility to leaf-eating insects in general and, especially in C. brasiliannum and C. pubescens, susceptibility to fungal diseases (Rhizoctonia sp. and Cercospora sp., respectively). The lack of a well-defined dry period can affect seed production. High soil-water saturation restricts dry-matter production.

Future research priorities are the evaluation of a wider Centrosema germplasm base, studies on the potential of promising germplasm for

* Instituto Veterinario de Investigaciones Tropicales y de Altura (IVITA), Pucallpa, Peru; INIPE/IVITA/CIAT Proyecto Cooperativo de Investigación en Pasturas Tropicales, Pucallpa, Peru; and Instituto Superior Tecnológico (IST), Tarapoto, Peru, respectively.
reclamation of degraded pastures, and research on the potential of *Centrosea* in livestock-forest production systems.

**Introduction**

The Amazon region of Peru, Bolivia, and Ecuador, covering about 60% of these countries, has considerable agricultural potential. However, livestock operations in the region are still at an early developmental stage. They are based mainly on native pastures and, in a few cases, introduced grasses such as *Hyparrhenia rufa*, *Brachiaria* spp., and *Panicum maximum*.

Of the legumes, the most widely known in the region is tropical kudzu (*Pueraria phaseoloides*) which has become naturalized. However, the need to offer alternative legumes that can be used alone or in association with grasses in different ecosystems typical of the region, is well recognized. Work with *C. pubescens* throughout the tropics has shown that *Centrosea* can play an important role, especially because of its high potential in improving pasture quality.

Several species of *Centrosea* are native to Peru, Bolivia, and Ecuador. These are *C. angustifolium*, *C. brasilianum*, *C. capitatum*, *C. fasciculatum*, *C. latidens*, *C. macrocarpum*, *C. pascuorum*, *C. plumieri*, *C. pubescens*, *C. sagittatum*, *C. schottii*, *C. tapirapoanense*, *C. triquetrum*, *C. vexillatum*, and *C. virginianum* (Schultze-Kraft et al., this volume). Some of these species have been observed growing spontaneously in natural pastures.

This paper summarizes information on the present status of knowledge and experience gained with *Centrosea* spp. in this region, particularly Peru. Most of the *Centrosea* studies correspond to evaluations conducted within the International Tropical Pastures Evaluation Network (RIEPT, i.e., Red Internacional de Evaluación de Pastos Tropicales). Figure 1 shows the main evaluation sites referred to in this paper.

**Environmental Characteristics**

*Centrosea* spp. evaluations in Peru, Bolivia, and Ecuador are being conducted under various climatic and soil conditions. Tables 1 and 2 show the respective data for most of the sites. In terms of ecosystem,
Figure 1. Centrosema evaluation sites in Peru, Bolivia, and Ecuador, together with inset map showing location of region in South America.
Table 1. Climatic characteristics of some representative *Centrosema* evaluation sites in Peru, Bolivia, and Ecuador.

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<td>Puerto Bermúdez</td>
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<tr>
<td>Latitude S</td>
<td>06°00'</td>
<td>08°22'</td>
<td>10°18'</td>
</tr>
<tr>
<td>Longitude W</td>
<td>77°02'</td>
<td>74°34'</td>
<td>74°54'</td>
</tr>
<tr>
<td>Altitude (m.a.s.l.)</td>
<td>900</td>
<td>250</td>
<td>300</td>
</tr>
<tr>
<td>Annual rainfall (mm)</td>
<td>1284</td>
<td>1770</td>
<td>3312</td>
</tr>
<tr>
<td>No. of dry months(^a)</td>
<td>6(2)</td>
<td>3(0)</td>
<td>0(0)</td>
</tr>
<tr>
<td>Annual average temperature (°C)</td>
<td>21.9</td>
<td>25.0</td>
<td>26.0</td>
</tr>
<tr>
<td>Ecosystem(^b)</td>
<td>TSSF</td>
<td>TSSF</td>
<td>TRF</td>
</tr>
</tbody>
</table>

\(^a\) Months with less than 100 mm; parentheses refer to no. of months with less than 60 mm.

\(^b\) TSSF = Tropical semievergreen seasonal forest; TRF = tropical rain forest.
Table 2. Soil characteristics of some representative *Centrosoema* evaluation sites in Peru, Bolivia, and Ecuador.

<table>
<thead>
<tr>
<th>Soil characteristic at 0-20 cm depth</th>
<th>Peru</th>
<th>Bolivia</th>
<th>Ecuador</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moyobamba</td>
<td>Pucallpa</td>
<td>Puerto Bermúdez</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>43</td>
<td>39</td>
<td>—</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>20</td>
<td>29</td>
<td>—</td>
</tr>
<tr>
<td>Lime (%)</td>
<td>36</td>
<td>32</td>
<td>—</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>—</td>
<td>1.6</td>
<td>—</td>
</tr>
<tr>
<td>P (ppm)</td>
<td>10.2</td>
<td>1.0&lt;sup&gt;d&lt;/sup&gt;</td>
<td>8.0&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>pH</td>
<td>4.7</td>
<td>4.1</td>
<td>4.2</td>
</tr>
<tr>
<td>Exchangeable cations (meq/100 g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td>6.3</td>
<td>6.6</td>
<td>—</td>
</tr>
<tr>
<td>Ca</td>
<td>2.3</td>
<td>3.2</td>
<td>4.0</td>
</tr>
<tr>
<td>Mg</td>
<td>0.8</td>
<td>0.6</td>
<td>1.1</td>
</tr>
<tr>
<td>K</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Al saturation (%)</td>
<td>66</td>
<td>62</td>
<td>77</td>
</tr>
<tr>
<td>Soil order</td>
<td>Inceptisol</td>
<td>Ultisol</td>
<td>Ultisol</td>
</tr>
</tbody>
</table>

<sup>a</sup> At 0-25 cm soil depth.
<sup>b</sup> At 0-15 cm soil depth.
<sup>c</sup> At 0-30 cm soil depth.
<sup>d</sup> Bray II.
<sup>e</sup> Olsen.
<sup>f</sup> Method not available.
<sup>g</sup> Al and H.
they correspond to the tropical semievergreen seasonal forest and the tropical rain forest (Cochrane, 1982)—the most relevant difference being the number of dry months (Table 1). *Centrocoma* has also been evaluated in Bolivia at high altitudes (higher than 1000 m) with less than 800 mm annual rainfall (British Mission in Tropical Agriculture, 1979). Soils of *Centrocoma* evaluation sites belong to several orders, with variable pH (4.2-6.1) and Al-saturation values (0%-80%). Considerable variation is also observed for soil organic matter, nutrient contents, and soil physical characteristics (Table 2). In general, however, most of the *Centrocoma* evaluation trials are conducted in acid, intermediate to low-fertility soils.

**Species Evaluation**

At present, nine *Centrocoma* species have been evaluated—mostly at 20 sites (Figure 1, Table 3). The sites have been concentrated in Peru where, in 1986, the IVITA (Instituto Veterinario de Investigaciones Tropicales y de Altura) experiment station in Pucallpa became a major forage evaluation center for the humid tropics. Species with the highest number of evaluation sites are *C. pubescens* and *C. macrocarpum*. Species with the highest number of accessions under evaluation are *C. macrocarpum*, *C. brasilianum*, and *C. acutifolium*. Almost all the work with *Centrocoma* has consisted of agronomic evaluations of the legumes in pure stands in introduction nurseries or small plots under cutting. Only two accessions of *C. pubescens* and one of *C. macrocarpum* have been evaluated under grazing in association with grasses.

**Centrocoma pubescens**

From a chronological point of view, *C. pubescens* is the pioneering species and the one that has been most studied and widely distributed in the region. The first evaluations were made about 20 years ago with commercial seed from Australia. This Australian introduction began to spread through the region, at research level, with the name “common or commercial *C. pubescens*.” This material, and accession CIAT 438 (a *C. pubescens* form selected from a *C. pubescens* × *C. acutifolium* hybrid), are introductions that have been evaluated in the largest number of sites in the region, followed by accessions CIAT 5126, CIAT 5172, and CIAT 5189. Studies with *C. pubescens* cover a wide range of evaluation stages from laboratory studies to grazing trials.
Table 3. *Centroema* germplasm evaluation at sites\(^a\) in Peru, Bolivia, and Ecuador at February 1987.

<table>
<thead>
<tr>
<th>Species</th>
<th>Peru</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Bolivia</th>
<th></th>
<th></th>
<th></th>
<th>Ecuador</th>
<th></th>
<th></th>
<th></th>
<th>Total of different accessions evaluated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AM</td>
<td>I</td>
<td>IS</td>
<td>M</td>
<td>P</td>
<td>PB</td>
<td>PM</td>
<td>S</td>
<td>T</td>
<td>TM</td>
<td>YU</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. acutifolium</em></td>
<td>1</td>
<td>21</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td></td>
<td>1</td>
<td></td>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. arenarium</em></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. brasilianum</em></td>
<td>1</td>
<td>1</td>
<td>28</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td>28</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>136</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>37</td>
<td>1</td>
<td>5</td>
<td></td>
<td></td>
<td>139</td>
</tr>
<tr>
<td><em>C. pascuorum</em></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td><em>C. plumieri</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><em>C. pubescens</em></td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td><em>C. schiedeanaum</em></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

| Total of accessions evaluated per site | 3 | 5 | 6 | 3 | 194 | 10 | 3 | 9 | 47 | 3 | 13 | 4 | 2 | 2 | 7 | 6 | 3 | 2 | 2 | 2 |

\(a\) Location of sites were

- Peru: AM = Alto Mayo; I = Iquitos; IS = Iscozain; M = Moyobamba; P = Pucallpa; PB = Puerto Bermúdez; PM = Puerto Maldonado; S = Satipo; T = Tarapoto; TM = Tingo María; YU = Yurimaguas.
- Bolivia: CH = Chipiriri; SC = Santa Cruz; VS = Valle del Sacta; YA = Yapacaní.
- Ecuador: C = Coca; EN = El Napo; EP = El Puyo; PI = Pichilingue; SD = Santo Domingo.

SOURCE: RIEPT (Red Internacional de Evaluación de Pastos Tropicales), unpublished data.
Fertilization and establishment. A laboratory test was conducted in Pucalpca to study the germination of common *C. pubescens*, *Desmodium intortum*, *Pueraria phaseoloides*, *Sorghum vulgare* cv. Trudan, and *Stylosanthes guianensis* under different Al concentrations (0, 5, 10, 15, and 20 meq/100 ml water). *Centroselecta pubescens* showed the highest tolerance: to as much as 15 meq of Al (Santhirasegaram et al., 1972). In another study, conducted in pots with forage plants adapted to the Pucalpca area, Santhirasegaram (1974) found that *C. pubescens* does not require large amounts of phosphorus for establishment and initial growth, and that it does not respond to liming. Nevertheless, while studying two low-P soils of the Santo Domingo region, Ecuador, Loor Triviño (1975) observed that under greenhouse conditions P and S were the nutrients that most influenced total dry-matter production of tops, nodules, and roots of *C. pubescens*.

*Centroselecta pubescens*, *Macrotinia atropurpureum* cv. Siratro, *S. guianensis* CIAT 136, and *Lablab purpureus* cv. Rongai were introduced into existing grass pastures in Santa Cruz, Bolivia, using minimal soil preparation and broadcast seeding. This method was unsuccessful in all cases (British Mission in Tropical Agriculture, 1979). Based on this experience, another trial was planned in San Javier, Bolivia, in an intermediate to low-fertility soil and using *C. pubescens*, *Macrotylloma axillare* cv. Archer, *Neonotonia wightii*, and *S. guianensis* CIAT 136. The trial consisted of preparing 25% of the area in 1.4-m strips, broadcast seeding, and one pass with the harrow. Although their establishment was good, *C. pubescens* and *N. wightii* showed poor vigor over time (British Mission in Tropical Agriculture, 1979).

Agronomic trials: pure legume. In a pot experiment conducted in Pucalpca to study the effect of cutting height and defoliation on *C. pubescens*, *P. phaseoloides*, and *S. guianensis* regrowth, the highest dry-matter production was recorded when plants were cut at 15 cm compared with 5 cm. Nondefoliation also favored yield which was always highest for *C. pubescens* (Reyes and Santhirasegaram, 1974). In a trial with 12 legume introductions under different cutting frequencies in Pichilingue, Ecuador, two *C. pubescens* accessions (commercial and hybrid CIAT 438) showed dry-matter yields similar to the rest of the legumes. However, their nutritional quality in terms of crude protein was superior in both rainy and dry seasons (Tuárez Cobeña, 1977).

In an adaptation test conducted in an acid, low-fertility Ultisol in Jenaro Herrera, Peru, common *C. pubescens* was one of the legumes that performed satisfactorily (Abreu and Díaz, 1975). Regarding regional evaluations, Table 4 shows the dry-matter production potential.
Table 4. *Centro*sem*a pubescens* dry-matter yields in agronomic evaluation experiments in Peru, Bolivia, and Ecuador, 1982-86.

<table>
<thead>
<tr>
<th>Location</th>
<th>CIAT accession no.</th>
<th>DM (kg/ha every 6 weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum rainfall period</td>
</tr>
<tr>
<td>PERU</td>
<td>Alto Mayo</td>
<td>common 240</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hybrid 438 221</td>
</tr>
<tr>
<td></td>
<td>Iscoezarín</td>
<td>hybrid 438 93&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5189 20&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Pucallpa</td>
<td>common 273&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hybrid 438 486</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5189 513</td>
</tr>
<tr>
<td></td>
<td>Pto. Bermúdez</td>
<td>hybrid 438 946</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5189 566</td>
</tr>
<tr>
<td></td>
<td>Pto. Maldonado</td>
<td>common 116</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hybrid 438 106</td>
</tr>
<tr>
<td></td>
<td>Satipo</td>
<td>hybrid 438 806</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5189 804</td>
</tr>
<tr>
<td></td>
<td>Tarapoto, Coperholta</td>
<td>common 150</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hybrid 438 256</td>
</tr>
<tr>
<td></td>
<td>Tarapoto, IST</td>
<td>hybrid 438 419</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5189 176</td>
</tr>
<tr>
<td></td>
<td>Tarapoto, ESEP 1981</td>
<td>common 390</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hybrid 438 570</td>
</tr>
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<td></td>
<td>Tarapoto, ESEP 1983</td>
<td>hybrid 438 303</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5189 420</td>
</tr>
<tr>
<td></td>
<td>Tarapoto, Porvenir</td>
<td>common 183</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hybrid 438 430</td>
</tr>
<tr>
<td></td>
<td>Tingo María, La Morada</td>
<td>common 1043</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hybrid 438 1246</td>
</tr>
<tr>
<td></td>
<td>Tingo María, Pumahuasi</td>
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<td></td>
<td></td>
<td>hybrid 438 1070</td>
</tr>
<tr>
<td></td>
<td>Yurimaguas</td>
<td>common 766</td>
</tr>
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<td></td>
<td></td>
<td>hybrid 438 926</td>
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<tr>
<td>BOLIVIA</td>
<td>Chipiriri</td>
<td>common 92</td>
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<td></td>
<td></td>
<td>hybrid 438 71</td>
</tr>
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<td></td>
<td>Valle del Sacta</td>
<td>common 361</td>
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<td>hybrid 438 537</td>
</tr>
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<td></td>
<td>Yapacaní</td>
<td>hybrid 438 —</td>
</tr>
<tr>
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<td></td>
<td>5189 —</td>
</tr>
<tr>
<td>ECUADOR</td>
<td>Coca</td>
<td>hybrid 438 986</td>
</tr>
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<td></td>
<td></td>
<td>5189 1367</td>
</tr>
<tr>
<td></td>
<td>El Napo</td>
<td>common 1029</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hybrid 438 843</td>
</tr>
<tr>
<td></td>
<td>El Puyo</td>
<td>common 589</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hybrid 438 553</td>
</tr>
</tbody>
</table>

a. Cut every 5 weeks.
b. Cut every 7 weeks.
c. Cut every 10 weeks.

SOURCE: RIEPT (Red Internacional de Evaluación de Pastos Tropicales), unpublished data.
of three *C. pubescens* accessions (common, CIAT 5189, and hybrid CIAT 438) at different evaluation sites. Except for the Peruvian sites of Pucallpa, Satipo, and Yurimaguas, the highest production was observed during the maximum rainfall period. Considerable yield variation occurred between evaluation sites and accessions. The highest production was obtained in Coca-Payamino, Ecuador, where hybrid CIAT 438 and accession CIAT 5189 produced 3061 and 3734 kg DM/ha every 6 weeks, respectively, during the maximum rainfall period.

In different sites of the Santa Cruz area in Bolivia, representative of a wide range of ecological characteristics (low to high-fertility soils with a pH ranging from less than 5.0 to neutral, and annual rainfall from 600 to more than 4000 mm), the adaptation of 82 legume introductions, including three *C. pubescens* accessions (common from Australia, common from Colombia, and hybrid CIAT 438), was studied. However, none of these accessions was included in the list of eventually recommended legumes because they were attacked by insects and anthracnose (British Mission in Tropical Agriculture, 1979).

*Centrosema* hybrid CIAT 438 showed good adaptation when grown under coconuts in Tarapoto (R. C. Pérez, unpublished data). However, in an oil-palm plantation in Pucallpa, this accession, and CIAT 5126, CIAT 5189, and common *C. pubescens*, did not show any special promise because of severe attacks from leaf-eating insects and susceptibility to *Cercospora* sp. (G. Keller-Grein, unpublished data).

**Agronomic trials: associations with grasses.** Three legumes were studied for their compatibility with *Brachiaria decumbens*, *Hyparrhenia rufa*, and *Paspalum plicatulum* in small plots in Pucallpa. The following order was determined for the legumes according to their competitive ability: *S. guianensis* < *C. pubescens* < *P. phaseoloides* (Reyes, 1974). This work was complemented by evaluating the performance of a *H. rufa–C. pubescens* mixture at under four cutting frequencies (3, 6, 9, and 12 weeks). It was found the legume had no competition problems with the grass; its content in the pasture over time was 27%, 24%, 26%, and 19%, respectively (Reyes and Toledo, 1979).

In an agronomic experiment conducted in Pichilingue, Ecuador, Hudgens (1973) studied the compatibility and dry-matter production of six grasses (*Cenchrus ciliaris*, *Cynodon plectostachyus*, *Digitaria decumbens*, *H. rufa*, *Panicum maximum*, and *Pennisetum purpureum*) in association with three legumes (*C. pubescens*, *D. intortum*, and *Macroptilium atropurpureum*). They were compared with the pure
grasses, with and without N fertilization (100 kg of N/ha per year), under two cutting frequencies (3 and 6 weeks), and in two seasons of the year. Results showed greater compatibility with all grasses, persistence, and nutritional quality for *C. pubescens* than for the other legumes. Dry-matter production in associations with *C. pubescens* were not significantly different from the N-fertilized treatments, regardless of the grass species, or cutting season or frequency. However, associations produced more crude protein.

In El Prado, 25 km north of Santa Cruz, Bolivia, *P. maximum* cv. Petrie associations with seven legumes, including common *C. pubescens* and hybrid CIAT 438, were evaluated on a sandy, low-fertility soil with a pH of 5.5. The content of *C. pubescens* in the mixtures did not reach 5% on average, probably because of adaptation problems (British Mission in Tropical Agriculture, 1979).

**Grazing trials.** The effect of two grazing frequencies and intensities on the associations *C. pubescens* and *P. phaseoloides* with *Paspalum conjugatum* were studied by Santhirasegaram et al. (1975) in Pucallpa, Peru. At low grazing frequencies and intensities, legume contents at 48 days of grazing were 51% and 42% for *P. phaseoloides* and *C. pubescens*, respectively, compared with 10% and 20% for the respective legumes at high grazing intensities. This suggests that *C. pubescens* was better adapted to high grazing pressures than *P. phaseoloides*. In Pichilingue, Ecuador, Chávez Sión (1974) studied the association *P. maximum-C. pubescens* under continuous grazing at variable stocking rates and compared it with the grass alone. Only a 6% legume content was achieved because of the difficulties of establishing the legume into the already existing grass sward. There was no effect on diet quality, but higher productivity levels were observed in the rainy than in the dry season. At the same research station, Santillán (1983) studied the response of the multiple association *P. maximum* and *P. purpureum* with *C. pubescens* and *Neonotonia wightii* under different grazing systems and P fertilizer levels. No conclusion can be drawn from the results as to the contribution made by *C. pubescens* in particular.

In another study, in Santo Domingo, Ecuador, Berrezuaeta A. (1975) evaluated *Brachiaria ruziziensis* and two *P. maximum* introductions alone and in association with *C. pubescens*, *D. intortum*, and *N. wightii* under grazing. He also evaluated legume compatibility, persistence, and contribution to pasture quality. Only one grazing pressure of about 15 kg of DM/day per animal of around 400 kg liveweight was used, with several resting periods (21, 35, 42, 49, and 63 days). There was no significant effect of any legume on the productivity of the associations.
However, crude protein content of all legume treatments was significantly higher than that of grasses alone. In the shortest resting period (21 days) and in association with all three grasses, *C. pubescens* had higher crude protein percentages than had the other legumes.

In Yurimaguas, Peru, a grazing trial was established more than 5 years ago to measure animal productivity in six grass-legume associations (Table 5). Because of grass establishment problems, *Centrosema* hybrid CIAT 438 always contributed more than 90% of the herbage in the association with *Andropogon gayanus*. Under these conditions and with alternating grazing, average liveweight gains were a

<table>
<thead>
<tr>
<th>Association</th>
<th>Number of evaluation years</th>
<th>Average stocking rate (an./ha)</th>
<th>Liveweight gains g/an./day</th>
<th>Liveweight gains kg/ha</th>
<th>Average content of legume (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>P. maximum</em> + <em>P. phaseoloides</em>&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3</td>
<td>4.4</td>
<td>296</td>
<td>455</td>
<td>77</td>
</tr>
<tr>
<td><em>A. gayanus</em> + <em>S. guianensis</em>&lt;sup&gt;a&lt;/sup&gt; CIAT 184</td>
<td>5</td>
<td>4.4</td>
<td>412</td>
<td>482</td>
<td>49</td>
</tr>
<tr>
<td><em>A. gayanus</em> + <em>Centrosema</em> hybrid CIAT 438</td>
<td>4</td>
<td>4.4</td>
<td>430</td>
<td>606</td>
<td>100</td>
</tr>
<tr>
<td><em>B. decumbens</em> + <em>D. ovalifolium</em> CIAT 350</td>
<td>5</td>
<td>4.4</td>
<td>356</td>
<td>606</td>
<td>26</td>
</tr>
<tr>
<td><em>B. humidicola</em> + <em>D. ovalifolium</em> CIAT 350</td>
<td>3</td>
<td>5.5</td>
<td>447</td>
<td>748</td>
<td>30</td>
</tr>
<tr>
<td><em>A. gayanus</em> + <em>C. macrocarpum</em> CIAT 5065</td>
<td>1</td>
<td>3.3</td>
<td>775</td>
<td>502</td>
<td>13</td>
</tr>
</tbody>
</table>

a. an. = animal of about 200 kg liveweight.


SOURCE: O. Paladines, personal communication.

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daily 430 g/animal and an annual 606 kg/ha at a stocking rate of 4.4 animals/ha, in spite of the fact that the grass completely disappeared with time.

On an Alfisol at Tarapoto, Peru, a study was conducted to measure milk production by 5/8 Brown Swiss cows on the association *A. gayanus-Centrosema* hybrid CIAT 438, compared with a *B. decumbens* pasture fertilized with an annual 100 kg N/ha. The stocking rates used in the grass alone and in the association were 2.0 and 2.6 animals/ha, respectively. The average daily milk production was 7.8 l/cow from *Brachiaria* alone and 8.4 l/cow from the association (R. C. Pérez, unpublished data).

**Seed production.** In Pucallpa, Peru, Reyes (1979) found that common *C. pubescens* seed yields were increased four-fold when plant physical supports were used (Table 6). Phosphorus fertilization with as much as 40 kg of *P₂O₅*/ha also favored seed production (P < .05). A subsequent study conducted over 3 years confirmed this response to *P* (Figure 2).

<table>
<thead>
<tr>
<th>Management</th>
<th>Annual seed yield (kg/ha) when fertilized with <em>P</em> (kg <em>P₂O₅</em>/ha per year)</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Without trellises</td>
<td>86.0</td>
<td>112.5</td>
</tr>
<tr>
<td>With trellises</td>
<td>341.7</td>
<td>426.4</td>
</tr>
</tbody>
</table>

SOURCE: Adapted from Reyes, 1979.

In a drier environment in Ecuador, Farfán (1979) found a similar trend with commercial *C. pubescens* seed production with trellises and the application of 50 kg of *P*/ha. In Tarapoto, Peru, Silva (1986) obtained more than 500 kg of seed/ha of common *C. pubescens*, using 50 kg of *P₂O₅*/ha, 40 kg of *K₂O*/ha, and trellises. This yield was slightly higher than that obtained with *Centrosema* hybrid CIAT 438. Commercial seed production of this latter accession has recently begun in Tarapoto (Pérez et al., 1987).

**Onfarm experiments.** Onfarm evaluations of *Centrosema* hybrid CIAT 438 have begun in Yurimaguas, Peru, to reclaim degraded pastures. In one case, CIAT 438 was planted in a 4-ha degraded pasture
after minimal soil tillage and the application of 25 kg of $P_2O_5$/ha (rock phosphate) and 50 kg of Ca/ha (dolomitic lime). In another case, the legume was established in 4-m alternate strips in a 5-ha slope pasture that was also planted with *B. humidicola* and *Erythrina poeppigiana* (M. Ayarza and R. Dextre, personal communication). In a farm near Tarapoto, *C. pubescens* is showing low competitive ability with weeds in an *A. gayanus* pasture (G. Silva, personal communication).

**Other species**

Besides *C. pubescens*, another eight species of *Centrosema* are being evaluated in the region (Table 3). These studies began less than 10 years ago, and *C. macrocarpum*, *C. acutifolium*, and *C. brasilianum* are showing great potential. Among these species, *C. macrocarpum* has been advanced to grazing trials.

*Centrosema macrocarpum*. CIAT 5062 and CIAT 5065 have been evaluated for the longest time and at the most sites in the region. They showed promise at many sites (Table 7) and thus appear to have a wide adaptation range. As a result, more advanced studies with this species have received priority in order to evaluate its relative acceptance by cattle and its performance under grazing.
### Table 7. *Centrosema macrocarpum* dry-matter yields in agronomic evaluation experiments in Peru, Bolivia, and Ecuador, 1982-1986.

<table>
<thead>
<tr>
<th>Location</th>
<th>CIAT accession no.</th>
<th>DM (kg/ha every 6 weeks)</th>
<th>Minimum rainfall period</th>
<th>Maximum rainfall period</th>
</tr>
</thead>
<tbody>
<tr>
<td>PERU</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alto Mayo</td>
<td>5065</td>
<td>135</td>
<td>356</td>
<td></td>
</tr>
<tr>
<td>Iscozazin</td>
<td>5062</td>
<td>488&lt;sup&gt;a&lt;/sup&gt;</td>
<td>299&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5065</td>
<td>538&lt;sup&gt;a&lt;/sup&gt;</td>
<td>399&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Pucallpa</td>
<td>5062</td>
<td>994</td>
<td>720</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5065</td>
<td>812</td>
<td>870</td>
<td></td>
</tr>
<tr>
<td>Puerto Bermúdez</td>
<td>5062</td>
<td>1030</td>
<td>478</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5065</td>
<td>653</td>
<td>183</td>
<td></td>
</tr>
<tr>
<td>Satipo</td>
<td>5062</td>
<td>1301</td>
<td>354</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5065</td>
<td>1132</td>
<td>253</td>
<td></td>
</tr>
<tr>
<td>Tarapoto, IST</td>
<td>5062</td>
<td>730</td>
<td>446</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5065</td>
<td>510</td>
<td>326</td>
<td></td>
</tr>
<tr>
<td>Tarapoto, ESEP 1983</td>
<td>5062</td>
<td>560</td>
<td>905</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5065</td>
<td>785</td>
<td>1016</td>
<td></td>
</tr>
<tr>
<td>Tingo María, La Morada</td>
<td>5065</td>
<td>1953</td>
<td>2443</td>
<td></td>
</tr>
<tr>
<td>Tingo María, Pumahuasí</td>
<td>5065</td>
<td>970</td>
<td>1645</td>
<td></td>
</tr>
<tr>
<td>BOLIVIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chipiriri</td>
<td>5065</td>
<td>1040</td>
<td>747</td>
<td></td>
</tr>
<tr>
<td>Yapacaní</td>
<td>5062</td>
<td>—</td>
<td>295&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>ECUADOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coca</td>
<td>5062</td>
<td>2329</td>
<td>3734</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5065</td>
<td>1124</td>
<td>3216</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Cut every 5 weeks.

SOURCE: RIEPT (Red Internacional de Evaluación de Pastos Tropicales), unpublished data.

In studies to evaluate the relative acceptance of 12 legume accessions in Pucallpa, Peru, *C. macrocarpum* CIAT 5065 was better accepted by cattle during the minimum rainfall season than the other *Centrosema* accessions, that is, *C. brasilianum* CIAT 5234, common *C. pubescens*, and hybrid CIAT 438. During the maximum rainfall season, however, its acceptance was very low (IVITA and CIID, 1985).

*Centrosema macrocarpum* CIAT 5065 is being evaluated in Yurimaguas, Peru, in a mixture with *A. gayanus*. After a year of
evaluation under alternate grazing (42 days each of grazing and rest) and with a stocking rate of 3.3 animals/ha, daily liveweight gains of 775 g/animal have been obtained (Table 5). However, in an experiment in Puerto Bermúdez, Peru, to evaluate C. macrocarpum CIAT 5065 in association with A. gayanus under grazing, both species had establishment problems. This was attributed to a lack of aggressiveness and competitive ability against weeds under the high-rainfall conditions of this site (Reátegui, 1986b).

In a seed-production experiment conducted in Tarapoto, C. macrocarpum CIAT 5065 had a longer vegetative cycle than C. brasilianum CIAT 5234 and C. pubescens (hybrid CIAT 438 and common) and its annual seed yield was 384 kg/ha (Table 8). Under similar environmental conditions in Moyobamba, Peru, C. macrocarpum CIAT 5065 gave higher seed yields (E. Díaz, personal communication). In Yurimaguas, C. macrocarpum appears to have problems in producing seed. Severe flower abscission is observed, possibly because of high rainfall (R. Dextre, personal communication).

Table 8. Seed-production potential of four Centrosema spp. accessions in Tarapoto, Peru.

<table>
<thead>
<tr>
<th>Species and CIAT accession no.</th>
<th>Days from planting to flowering</th>
<th>Annual seed yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. brasilianum CIAT 5234</td>
<td>90</td>
<td>1247</td>
</tr>
<tr>
<td>C. macrocarpum CIAT 5065</td>
<td>156</td>
<td>384</td>
</tr>
<tr>
<td>Centrosema hybrid CIAT 438</td>
<td>120</td>
<td>340</td>
</tr>
<tr>
<td>C. pubescens common</td>
<td>120</td>
<td>521</td>
</tr>
</tbody>
</table>

SOURCE: Adapted from Silva, 1986.


Preliminary results of a fertilization trial, using low solubility nutrient sources (rock phosphate and elemental sulfur) in Chipiriri, Bolivia, showed that C. macrocarpum CIAT 5065 responded to P and S applications, while C. brasilianum CIAT 5234 showed no response.
CIAT 5065 responded only to the highest P rate (35 kg of P/ha). Response to S fertilization was obtained at both low (10 kg of S/ha) and high (30 kg of S/ha) rates (Ferrufino, 1984).

Because *C. macrocarpum* has shown potential in the region, and in order to study the environmental adaptation of a wider germplasm base within the species, a new collection of 135 accessions was established in 1986 in small plots in Pucallpa. Thirty-three of these accessions were also planted in Tarapoto. Preliminary observations are showing that this new collection contains materials that are superior to the already existing introductions in dry-matter yield, ability to root at the nodes of creeping stems, and resistance to fungal diseases.

*Centrolemma brasiliarum*. The most widely studied accession in the region is CIAT 5234. Table 9 shows dry-matter production data for this accession and for CIAT 5712 at different sites. Yields of CIAT 5234

<table>
<thead>
<tr>
<th>Location</th>
<th>CIAT accession no.</th>
<th>DM (kg/ha every 6 weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum rainfall period</td>
</tr>
<tr>
<td>PERU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iscozain</td>
<td>5234</td>
<td>63&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Puerto Bermúdez</td>
<td>5234</td>
<td>950</td>
</tr>
<tr>
<td></td>
<td>5712</td>
<td>720</td>
</tr>
<tr>
<td>Satipo</td>
<td>5234</td>
<td>1034</td>
</tr>
<tr>
<td></td>
<td>5712</td>
<td>702</td>
</tr>
<tr>
<td>Pucallpa</td>
<td>5234</td>
<td>886</td>
</tr>
<tr>
<td>Tarapoto, IST</td>
<td>5234</td>
<td>336</td>
</tr>
<tr>
<td>Tarapoto, ESEP 1983</td>
<td>5234</td>
<td>707</td>
</tr>
<tr>
<td>BOLIVIA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yapacaní</td>
<td>5712</td>
<td>—</td>
</tr>
<tr>
<td>ECUADOR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coca</td>
<td>5234</td>
<td>—</td>
</tr>
</tbody>
</table>

<sup>a</sup> Cut every 5 weeks.

SOURCE: RIEPT (Red Internacional de Evaluación de Pastos Tropicales), unpublished data.
during the maximum rainfall season varied between 430 and 3109 kg/ha every 6 weeks in Puerto Bermúdez and Coca, respectively. At some sites, higher yields were observed during the minimum rainfall season, possibly reflecting severe *Rhizoctonia* attacks during the rainy season.

In the aforementioned (p. 435) acceptability test conducted in Pucallpa with 12 accessions of nine legume species, the four *C. brasilianum*, *C. macrocarpum*, and *C. pubescens* introductions were accepted moderately well by animals. Among them, *C. brasilianum* CIAT 5234 was very well accepted during the maximum rainfall season, but animal preference declined during the minimum rainfall period (IVITA and CIID, 1985).

In Tarapoto, *C. brasilianum* CIAT 5234 flowered sooner and produced more seed than two *C. pubescens* accessions and one of *C. macrocarpum* (Table 8). In Pucallpa, C. A. Reyes (unpublished data) observed that *C. brasilianum* CIAT 5234 flowered more abundantly than *C. acutifolium* CIAT 5112, *C. macrocarpum* CIAT 5062 and CIAT 5065, and *C. pubescens* common and hybrid CIAT 438.

In 1986, a new collection of 26 *C. brasilianum* accessions was introduced to Pucallpa. Preliminary observations (G. Keller-Grein, unpublished data) indicate that there are introductions superior to CIAT 5234 in establishment vigor and dry-matter production. This collection shows varying susceptibility to rhizoctonia foliar blight (RFB) which is the most limiting factor for this species in the humid tropics.

*Centrosema acutifolium*. The first evaluations were initiated with introductions CIAT 5112, CIAT 5277, and CIAT 5568. Among these, CIAT 5112 has been evaluated at the greatest number of sites and is showing promise because of good general adaptation and satisfactory dry-matter yields (Table 10). Although it yields almost 4000 kg/ha every 6 weeks during the maximum rainfall season in Coca, Ecuador, it tends to yield more dry matter during the minimum rainfall season.

In 1986, a new collection of 21 accessions, including the three accessions mentioned above, was introduced to Pucallpa. In general, this collection shows good adaptation to acid, low-fertility soils which are typical of the region. Preliminary observations indicate that accessions CIAT 5277, CIAT 5278, CIAT 15086, and CIAT 15088 are promising. The problems of introductions with less adaptability are largely related to foliar blight and leaf-eating insects (G. Keller-Grein, unpublished data).

<table>
<thead>
<tr>
<th>Location</th>
<th>CIAT accession no.</th>
<th>DM (kg/ha every 6 weeks)</th>
<th>Minimum rainfall period</th>
<th>Maximum rainfall period</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PERU</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iscozain</td>
<td>5112</td>
<td>308&lt;sup&gt;a&lt;/sup&gt;</td>
<td>185&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Puerto Bermúdez</td>
<td>5112</td>
<td>1185</td>
<td>373</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5568</td>
<td>855</td>
<td>303</td>
<td></td>
</tr>
<tr>
<td>Satipo</td>
<td>5112</td>
<td>1036</td>
<td>223</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5568</td>
<td>1233</td>
<td>626</td>
<td></td>
</tr>
<tr>
<td>Pucallpa</td>
<td>5112</td>
<td>880</td>
<td>666</td>
<td></td>
</tr>
<tr>
<td>Tarapoto, IST</td>
<td>5112</td>
<td>456</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Tarapoto, ESEP 1983</td>
<td>5112</td>
<td>678</td>
<td>766</td>
<td></td>
</tr>
<tr>
<td><strong>ECUADOR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coca</td>
<td>5112</td>
<td>1713</td>
<td>3895</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Cut every 5 weeks.

SOURCE: RIEPT (Red Internacional de Evaluación de Pastos Tropicales), unpublished data.

*Centrosema arenarium.* Introduction CIAT 5236 has been evaluated in five locations. The accession appears to have no potential in the region. In Puerto Bermúdez, for example, *C. arenarium* was poorly adapted (Reátegui, 1986a).

*Centrosema pascuorum.* Introductions CIAT 5171 and CIAT 5230 were evaluated in an adaptation trial in Pucallpa. Neither accession was suited to the environmental conditions: CIAT 5171 was susceptible to *Rhizoctonia* and CIAT 5230 had germination problems, causing slow establishment (Ordóñez and Reyes, 1983).

*Centrosema plumieri.* Accession CIAT 470 was established in Tarapoto in 1986 in small plots (G. Silva, personal communication). Results are not yet available.

*Centrosema schiedeanum.* Only accession CIAT 5066 was evaluated in the Pucallpa Ultisol. Good establishment and performance was observed during the first 8 months. After the second cut, however, the plants disappeared, their disappearance coinciding with the minimum rainfall season (Ordóñez and Reyes, 1983).
Centrosera virginianum. The adaptation of *C. virginianum* CIAT 474 and CIAT 5246 was studied in Pucallpa. Problems were observed from the beginning—germination and seedling vigor were very low (Ordóñez and Reyes, 1983).

**Limitations**

The review of work conducted with *Centrosera* in Peru, Bolivia, and Ecuador, suggests that the main environmental limitations are biotic and, to a lesser extent, climatic and edaphic.

Several researchers mention insect attacks, especially by leaf eaters such as chrysomelids, lepidopterans, and ants, mostly on *C. macrocarpum, C. pubescens, and C. acutifolium*, and especially during the maximum rainfall season. In Pucallpa, preliminary observations on *C. acutifolium*, *C. brasilianum*, *C. macrocarpum*, and *C. pubescens* in an oil-palm plantation show that preference by leaf eaters increases in shaded *Centrosera* (G. Keller-Grein and H. Ordóñez, unpublished data). In Moyobamba, Peru, during establishment, a severe attack by ants (*Atta* sp.) caused the total loss of common *C. pubescens* in associations with *A. gayanus* and *Brachiaria dictyoneura* (R. Díaz, personal communication).

A major disease that restricts *Centrosera* use in the region is RFB. The main host is *C. brasilianum* (A. Ferrusino, personal communication; H. Ordóñez, personal communication). RFB has also been observed in *C. acutifolium*, *C. macrocarpum*, and *C. pubescens*, but only at low levels. High susceptibility to *Cercospora* sp., the causal agent of leaf spot, has been observed in *C. pubescens* germplasm established under shade in oil-palm plantations in Pucallpa (H. Ordóñez, personal communication). Minor symptoms of bacteriosis (*Pseudomonas fluorescens* Biotype II) were detected in *C. acutifolium* and *C. brasilianum* at the same site (H. Ordóñez, personal communication).

High susceptibility of *C. pubescens* to the fungus *Cylindrocladium* sp. was observed in a grazing experiment in Pichilingue early in the rainy season. However, plants showed good regrowth and new leaves showed no disease symptoms (Hudgens, 1973).

High soil-water saturation can inhibit growth of *Centrosera*. At several evaluation sites there is a trend toward increased dry matter
during the minimum rainfall season for *C. macrocarpum*, *C. brasilianum*, and *C. acutifolium* (Tables 7, 9, and 10). This, however, may also be related to the lower solar radiation that occurs during the rainy season.

High rainfall and its erratic distribution throughout the year without a well-defined dry period usually affect seed production, particularly in *C. macrocarpum*.

An important limitation of *Centrosema* is that many species require special management to stimulate flowering and seed production. The use of a physical support, for example, requires increased investments that limit the establishment of large seed-production areas. Furthermore, nonuniform seed ripening, in conjunction with pod dehiscence, can cause seed losses. To avoid these losses, repeated passes of hand harvesting are required.

Another problem of *Centrosema* is that it can be difficult to establish, as several experiences in the region have shown (British Mission in Tropical Agriculture, 1979; Chávez Sión, 1974; R. C. Pérez, unpublished data).

**Prospects**

Agronomic studies in the region have been conducted with a wide range of *Centrosema* germplasm. Only *C. pubescens* (common and hybrid CIAT 438) and *C. macrocarpum* CIAT 5065 have reached a more advanced research stage. No species of this genus has been released commercially as yet. However, there are isolated cases in which promising materials are being tested at the farmer level under grazing and as a cover crop such as *Centrosema* hybrid CIAT 438 in Tarapoto and Yurimaguas, Peru.

Based on progress achieved so far, *Centrosema* hybrid CIAT 438, *C. macrocarpum* CIAT 5065, and *C. acutifolium* CIAT 5112 appear promising for the region. Regarding the last two species, preliminary results from a new collection are demonstrating that some new accessions have greater potential for the humid tropics than those previously tested. The forage quality (crude protein, P, Ca) of the three *Centrosema* species is higher than that of *Desmodium ovalifolium*, a species under advanced testing in the region, or *S. guianensis* cv. Pucallpa. Compared with *P. phaseoloides*, a species that is naturalized in the region, *Centrosema* hybrid CIAT 438 shows higher resistance to
trampling, is usually better liked by animals, and tolerates higher grazing pressures.

Future *Centrosera* research priorities in the region are as follows:

To intensify the collection of *Centrosera* germplasm native to Peru, Bolivia, and Ecuador—this region has been little explored.

To continue evaluating a wide genetic base of *Centrosera* spp. in one or a few representative sites, in order to eventually select new superior materials for more widespread agronomic trials.

To determine the mineral nutrient requirements of the better species and to study the need to inoculate promising germplasm with *Rhizobium*. Should inoculation be necessary, to develop adequate inoculants and inoculation techniques.

To continue identifying diseases and pests that affect *Centrosera* spp. in the region and to conduct studies on pathogen, pest, and plant relationships.

To study *Centrosera* establishment in degraded pastures, including soil preparation, planting methods, and weed control.

To measure the animal-production potential and persistence of *Centrosera* pastures in mixtures with grasses under different management systems.

To conduct studies related to the selection of sites with high seed-production potential and to multiply seed of promising germplasm in collaboration with the seed industry.

To study the potential of *Centrosera* spp. for livestock-forestry systems.

To expose promising germplasm to onfarm conditions early in the evaluation process.

References


Regional experience with Centrosema: Peru, Bolivia, and Ecuador


Regional experience with Centrosema: Peru, Bolivia, and Ecuador


Chapter 17

REGIONAL EXPERIENCE WITH
CENTROSEMA:
BRAZIL—HUMID TROPICS

E. A. S. Serrão, M. A. Moreno R., and J. B. da Veiga*

Abstract

Cattle-raising, especially of beef cattle, has been an expanding industry in the Brazilian humid tropics (Amazonian and Bahian regions)—an area of about 400 million hectares. Before the 1960s, cattle-raising relied almost exclusively on extensive use of native grassland. Since the 1960s, cattle-raising has been expanding into forest areas where grasses have been sown on more than 6 million hectares. This expanding process has triggered interest in forage legumes for improving pasture productivity and stability. *Pueraria, Centrosema, Stylosanthes, Desmodium,* and *Leucaena* have been the most promising genera.

Information is presented on the natural occurrence of *Centrosema*—at least nine species occur naturally in the region—and on the results of germplasm evaluation. *Centrosema* species have great potential for the region, comparable with that of *P. phaseoloides,* the most used legume. *Centrosema brasilianum, C. macrocarpum, C. acutifolium,* and *C. pubescens* are considered as the most promising species. The known and potential direct and indirect climatic and edaphic limitations to *Centrosema* are described.

Suggestions for research priorities are made. Objective, ordered, integrated, and uninterrupted research is stressed as essential if a

* Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), Centro de Pesquisa Agropecuária do Trópico Úmido (CPATU), Belém, PA, Brazil; Comissão Executiva do Plano da Lavoura Cacau e Cana (CEPLAC), Centro de Pesquisas do Cacau (CEPEC), Itabuna, BA, Brazil; and EMBRAPA/CPATU, respectively.
Centrosema-based pasture technology is to be efficiently developed for the Brazilian humid tropics.

Introduction

Cattle-raising, especially of beef cattle, is increasing in the Brazilian humid tropics which includes the Amazon region and the humid tropics of south Bahia (Figure 1). Together they cover an area of about 400 million hectares.

Figure 1. The Brazilian humid tropics (■) and Centrosema evaluation sites (■).
Before the 1960s, beef-cattle farmers of the Amazon region relied almost exclusively on extensive exploitation of native pasture ecosystems in the well-drained and poorly drained savannas and on the alluvial soils of flood plains. However, the use of well-drained and poorly drained savannas results in low cattle productivity because the quality of forage is, on the whole, poor. Alluvial soil grasslands, despite their high productivity and quality, are of limited usefulness because the higher areas of grasslands are flooded periodically by muddy river waters (Serrão, n.d.b; Serrão and Falesi, 1977; Serrão and Simão Neto, 1975). From the mid-1960s, when road constructions made the region accessible, more than 6 million hectares of forest were replaced by introduced pasture grasses for cattle-raising (Serrão, n.d.a). The most useful forage grasses introduced during this evolutionary process have been *Panicum maximum*, *Hyparrhenia rufa*, *Brachiaria decumbens*, *B. humidicola*, and *Pennisetum purpureum* (Serrão, n.d.a and n.d.b; Serrão and Falesi, 1977; Serrão and Simão Neto, 1975). Recently, *Andropogon gayanus* and *Brachiaria brizantha* have shown good potential for pastures in the humid tropic regions of Brazil (Camarão et al., 1986; da Veiga and Lima, 1985; Dias Filho, 1983; Serrão, n.d.a and n.d.b).

In south Bahia, the contribution of native pastures has been limited, while introduced grasses have played a very important role in the region’s cattle industry development. These grasses constituted the same species that were introduced to the Amazon region.

The nutritive limitations of pure-grass pastures and recognition of the role legumes can play in improving cultivated pastures have increased interest in the use of legumes. Of the legumes introduced, evaluated, and used in the region, the genera *Puercaria*, *Centrocoma*, *Stylosanthes*, *Leucaena*, and *Desmodium* have been the most promising and constitute the major genetic base for the selection of legumes for pasture formation in upland areas of the region (Serrão, n.d.a and n.d.b).

According to Serrão (n.d.a), of the total cultivated pastures (between 6 and 8 million hectares) in the Brazilian humid tropics, probably no more than 5% (350,000 ha) have been planted with forage legumes, primarily *P. phaseoloides*, followed by *C. pubescens*, and, on a smaller scale, *S. guianensis* and *L. leucocephala*. Serrão and de Conto (1988) estimate that, in this region, about 100,000 hectares of grass pastures have been planted in association with *C. pubescens* (Australian commercial varieties) in mixtures with other legumes, primarily *P. phaseoloides* and *S. guianensis*. This occurred mainly between the mid-1960s and mid-1970s under the influence of commercial seed companies.
from south Brazil. After this period, the lack of commercial seed and, probably, biological constraints, restricted expansion in the use of *Centroama*.

**The Brazilian Humid Tropics**

The Brazilian humid tropics (Figure 1) occupy about 50% of Brazil. The climate of the region is warm and humid, with four rainfall regimes (SUDAM, 1984): one regime, found in the northwest and northeast of the region, has an annual rainfall of more than 3000 mm; the northeast and west of the region receive between 2500 and 3000 mm; most of the region, but particularly its center, receives between 2000 and 2500 mm; and areas located in the northeast and south of the region at latitudes higher than 14° S receive less than 2000 mm.

In general, the region has at least two distinct periods during the year. One is characterized by frequent and abundant rainfall (rainy period) and the other by less frequent rains which sometimes result in a dry season (Bastos et al., 1986).

The average annual temperature ranges between 22 and 27 °C; the annual maximum, between 28 and 33 °C; and the annual minimum, between 17 and 23 °C (SUDAM, 1984). While the thermal fluctuation during the day is marked, the annual fluctuation is small (Bastos et al., 1986). Annual relative humidity varies between 60% and 90% (SUDAM, 1984) and monthly air-moisture distribution relates strongly to rainfall patterns, with high values recorded during periods of high rainfall (Noe-Dobrea and Santos, 1979).

The annual average number of sunlight hours ranges from 1400 to 2500, with distinct areas of concentration (Bastos et al., 1986). Water deficits and surpluses show large range variations. Water surpluses can drop almost as low as 100 mm and reach as high as 2400 mm. Water deficits range from nil to 600 mm (Bastos, 1972).

According to the Köppen classification, the following rainy tropical climates occur in the region: Af (no distinct dry season); Am (limited dry season); and Aw (fairly well-defined dry season). In areas where cattle are raised on cultivated pastures, climates Ami and Aw are the most common. In these cases, especially under climate Aw (which occurs mainly in the southern part of the region), the dry season can be a limiting factor for pasture growth.
According to Falesi (1986), nearly 92% of the Amazon region have dystrophic soils (acid with low fertility) and 8% have eutrophic soils (usually acid but fertile). The dystrophic soils are primarily Latosols (Oxisols) and Red-Yellow Podzolic soils (Ultisols), quartz sands (Entisols), Cambisols (Inceptisols), and Plintosols (Oxisols and/or Ultisols). In the eutrophic soil areas are Red-Yellow Podzolic soils, Eutrophic Cambisols (Inceptisols), Eutrophic “Terra roxa” soils (Alfisols, Ultisols, or Mollisols), Humic Gley soils (Entisols, Inceptisols), and alluvial soils (Entisols) (Amaral Filho et al., 1985). Beef-farming based on cultivated grasses is concentrated on acid and low-fertility soils, especially Oxisols and Ultisols.

The major part of the Amazon region is covered by humid tropical forests or hileia (Ducke and Black, 1954). Other types of vegetation are found in areas where the forest is interrupted such as caatingas (thorny underbrush), campos (savannas), campinas (grazing land with no large trees), and campos de várzea (seasonally flooded plains) (Pires, 1973). The greatest part of the region’s cultivated grasslands is found in humid tropical forests with diverse vegetation densities (do Nascimento and Homma, 1984; Serrão, n.d.a).

The Bahia humid tropics are similar to the more humid areas of the Amazon region in climate, soil, and vegetation. The cattle industry, the second most important economic activity in the region, is also tending toward cultivated-pasture production (da Silva et al., 1975).

**Natural Occurrence of *Centrosema***

The genus *Centrosema* has several species native to the Brazilian humid tropics. In the first botanical surveys carried out in the Amazon, Huber (1898) found *C. brasilianum*, *C. plumieri*, and other unidentified species growing in native grasslands on the Island of Marajó in the state of Pará. From several botanical surveys done in different areas of the Brazilian Amazon, Ducke (1949) listed the following eight Amazonian species of *Centrosema*: *C. pubescens*, *C. brasilianum*, *C. plumieri*, *C. platycarpum*, *C. vexillatum*, *C. venosum*, *C. triquetrum*, and *C. tapirapoaense*. In 1970, Cavalcante described a ninth native species: *C. carajasense*. In recent studies, on Marajó Island, das Neves and Cruz (1983) verified the widespread presence of *C. brasilianum*, and suggested that Marajó Island may be a significant center of diversity for this species.
In the humid tropics of Bahia, according to Lewis (1987), the following species occur naturally: *C. arenarium*, *C. brasilianum*, *C. pubescens*, *C. sagittatum*, and *C. virginianum*.

Overall, it appears that the humid tropics of Brazil is a good source of germplasm for the collection and agronomic improvement of *Centrosea*.

**Overview of *Centrosea* Research in the Region**

Over the past decade, research interest in *Centrosea* for pasture use in the region was awakened after its potential was realized and attempts were made by the private sector to establish pastures of traditional grasses in association with commercial *C. pubescens*.

In 1976, the Pasture Improvement Program in the Amazon (PROPASTO, i.e., Projeto Melhoramento de Pastagem da Amazônia) began evaluating *Centrosea* and other legumes on private ranches (EMBRAPA-CPATU, 1980). Initially, and until 1980, evaluation was concentrated on commercial and semicommercial legumes that were being introduced to the region by commercial firms. In 1980, evaluation expanded to include legume germplasm from different sources.

In the Amazon, *Centrosea* research has been carried out in Belém, Paragominas, São João do Araguaia, Conceição do Araguaia, and Marabá in Pará; Itacoatiara, in Amazonas; Porto Velho and Ji-Paraná, in Rondônia; and Rio Branco, in Acre. In Bahia, evaluation has been carried out in Itabela, Barrolândia, and Nova Canaã (Figure 1).

Table 1 summarizes the climatic characteristics of the different sites where *Centrosea* evaluation has been done, and presents some information on vegetation and soil types. Most of the sites had been subjected to previous treatments which included clearing and burning of forest biomass, planting grass (usually *P. maximum*), and pasture use for a variable number of years and subsequent degradation. Studies were then begun, aiming to reclaim the area with more stable and productive pastures.

Table 2 shows soil physical and chemical characteristics of the study sites. In general, the soils are acid and low in fertility (except at Nova Canaã in Bahia) and texture varies between sandy and clayey. In the process of establishing pastures after burning the original biomass, the
Table 1. Climate of *Centrosema* evaluation sites in the Brazilian humid tropics, with some details of vegetation and soil types.

<table>
<thead>
<tr>
<th>Locationa</th>
<th>Köppen climatic typec</th>
<th>Temperature (°C) Average</th>
<th>Range</th>
<th>Average relative humidity (%)</th>
<th>Average annual rainfall (mm)</th>
<th>No. of months with less than 60 mm rain</th>
<th>Original native vegetation</th>
<th>Soilb</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AMAZONIAN REGION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belém</td>
<td>Af</td>
<td>26</td>
<td>23-32</td>
<td>84</td>
<td>2170</td>
<td>None</td>
<td>Dense forest</td>
<td>SDYL</td>
</tr>
<tr>
<td>Paragominas</td>
<td>Ami/Awi</td>
<td>26</td>
<td>21-32</td>
<td>82</td>
<td>1950</td>
<td>1-3</td>
<td>Dense forest</td>
<td>HCDYL</td>
</tr>
<tr>
<td>Marabá</td>
<td>Awi</td>
<td>26</td>
<td>22-31</td>
<td>87</td>
<td>1930</td>
<td>2-3</td>
<td>Sparse forest</td>
<td>CDL</td>
</tr>
<tr>
<td>São João do Araguaia</td>
<td>Awi</td>
<td>26</td>
<td>20-31</td>
<td>78</td>
<td>1900</td>
<td>2-3</td>
<td>Dense forest</td>
<td>MTDYP</td>
</tr>
<tr>
<td>Conceição do Araguaia</td>
<td>Awi</td>
<td>25</td>
<td>18-32</td>
<td>80</td>
<td>1650</td>
<td>2-3</td>
<td>Sparse forest</td>
<td>HPDHL</td>
</tr>
<tr>
<td>Itacoatiara</td>
<td>Ami</td>
<td>27</td>
<td>23-32</td>
<td>82</td>
<td>2200</td>
<td>1-2</td>
<td>Dense forest</td>
<td>HCDYL</td>
</tr>
<tr>
<td>Porto Velho</td>
<td>Ami</td>
<td>25</td>
<td>21-32</td>
<td>86</td>
<td>2340</td>
<td>2</td>
<td>Dense forest</td>
<td>HCDYL</td>
</tr>
<tr>
<td>Ji-Paraná</td>
<td>Ami/Awi</td>
<td>25</td>
<td>23-32</td>
<td>83</td>
<td>2000</td>
<td>2-3</td>
<td>Dense forest</td>
<td>MTDYP</td>
</tr>
<tr>
<td>Rio Branco</td>
<td>Ami</td>
<td>24</td>
<td>20-31</td>
<td>86</td>
<td>1920</td>
<td>1-2</td>
<td>Dense forest</td>
<td>MTDYP</td>
</tr>
</tbody>
</table>

| **BAHIA HUMID TROPICS** | | | | | | | | |
| Itabela | Ami | 24 | 20-29 | 80 | 1350 | None | Dense forest | SDYL |
| Barrolândia | Af | 24 | 20-29 | 82 | 1450 | None | Dense forest | MTDYL |
| Nova Canaã | Awi | 22.5 | 17-28 | 75 | 1200 | 2-3 | Sparse forest | MTERYP |

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a. References for Belém are taken from Serrão et al. (1971) and Cruz et al. (1986); for Itabela from Moreno R. et al. (1986); for Barrolândia from Pereira and Moreno R. (1983); for Nova Canaã from Salviano (1981); and for all others from EMBRAPA-CPATU (1980).

b. Soils are described as follows: SDYL = Sandy dystrophic yellow Latosol; HCDYL = High-clay dystrophic yellow Latosol; CDL = Concretionary dystrophic Lateritic soils; MTDYP = Medium-textured dystrophic Red-Yellow Podzolic soils; HPDHL = High-phase dystrophic hydromorphic Lateritic soils; MTDYL = Medium-textured dystrophic yellow Latosols; MTERYP = Medium-textured eutrophic Red-Yellow Podzolic soils.

c. Af = no distinct dry season; Ami = limited dry season; Awi = well-defined dry season.
Table 2. Physical and chemical soil characteristics of the *Centrosera* evaluation sites in the Brazilian humid tropics.

<table>
<thead>
<tr>
<th>Location</th>
<th>AMAZONIAN REGION</th>
<th>BAHIA HUMID TROPICS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Depth (cm)</td>
<td>Sand</td>
</tr>
<tr>
<td>Rondônia</td>
<td>0-20 84</td>
<td>71 13</td>
</tr>
<tr>
<td>Paragominas</td>
<td>0-20 34</td>
<td>20 11</td>
</tr>
<tr>
<td>Marabá</td>
<td>0-20 34</td>
<td>20 11</td>
</tr>
<tr>
<td>São João do Araguaia</td>
<td>0-20 34</td>
<td>20 11</td>
</tr>
<tr>
<td>Conceição do Araguaia</td>
<td>0-20 34</td>
<td>20 11</td>
</tr>
<tr>
<td>Itacoatiara</td>
<td>0-20 34</td>
<td>20 11</td>
</tr>
<tr>
<td>Ji-Paraná</td>
<td>0-20 34</td>
<td>20 11</td>
</tr>
<tr>
<td>Porto Velho</td>
<td>0-20 34</td>
<td>20 11</td>
</tr>
<tr>
<td>Rio Branco</td>
<td>0-20 34</td>
<td>20 11</td>
</tr>
<tr>
<td>BAHIA HUMID TROPICS</td>
<td>0-20 34</td>
<td>20 11</td>
</tr>
<tr>
<td>Itacare</td>
<td>0-20 34</td>
<td>20 11</td>
</tr>
<tr>
<td>Barrolândia</td>
<td>0-20 34</td>
<td>20 11</td>
</tr>
<tr>
<td>Nova Canaã</td>
<td>0-20 34</td>
<td>20 11</td>
</tr>
</tbody>
</table>

1. References for Belfim are taken from Corrêa et al., 1971; for Itacare from Moreira et al., 1986b; for Barrolândia from Pereira de Moris, 1983; for Nova Canaã from Silva, 1981; and for all others from EMBRAPA-CPATU, 1980.
chemical characteristics of the soils change considerably (Falesi, 1976; Serrão et al., 1979); these changes are usually favorable, except for phosphorus content which, after a few years, becomes the most limiting nutrient for pasture production in the region (Serrão et al., 1979).

**Research Results**

*Centrosoema pubescens* (commercial)

**Agronomic trials under cutting.** Two varieties of *C. pubescens*, IRI 1282 and cv. Comum ("Common") were evaluated in a series of trials between 1976 and 1979.

In one study, these cultivars were compared with several other commercial and semicommercial legumes, sown with and without phosphate fertilization, and clipped periodically to a stubble height of 10-15 cm. Dry-matter (DM) production is given in Table 3. The great potential of *C. pubescens* for forage production is evident: it yielded equal to or higher than *P. phaseoloides*, the most important forage legume in the region. Another important consideration is the apparently low demand of *C. pubescens* for phosphate which makes it useful for the typical prevailing low-input pasture systems.

Table 3. Dry-matter production (t/ha) with (W) and without (No) fertilization of two commercial varieties of *Centrosoema pubescens*, and *Pueraria phaseoloides* (used as a control) in different locations in the Amazon region, Brazil.

<table>
<thead>
<tr>
<th>Location</th>
<th><em>C. pubescens</em> IRI 1282</th>
<th><em>C. pubescens</em> cv. Comum</th>
<th><em>P. phaseoloides</em></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W</td>
<td>No</td>
<td>W</td>
</tr>
<tr>
<td>Paragominas b</td>
<td>17.7</td>
<td>9.8</td>
<td>—</td>
</tr>
<tr>
<td>Maraba b</td>
<td>32.4</td>
<td>33.8</td>
<td>38.5</td>
</tr>
<tr>
<td>São João do Araguaia b</td>
<td>25.1</td>
<td>21.7</td>
<td>22.5</td>
</tr>
<tr>
<td>Itaocaiatarã c</td>
<td>12.5</td>
<td>12.6</td>
<td>9.6</td>
</tr>
<tr>
<td>Porto Velho b</td>
<td>22.6</td>
<td>18.8</td>
<td>20.5</td>
</tr>
<tr>
<td>Ji-Paraná b</td>
<td>31.6</td>
<td>25.8</td>
<td>—</td>
</tr>
<tr>
<td>Rio Branco c</td>
<td>14.5</td>
<td>11.9</td>
<td>13.0</td>
</tr>
</tbody>
</table>

a. In São João do Araguaia, Itaocaiatarã, Porto Velho, Ji-Paraná, and Rio Branco, fertilization was 50 kg of P₂O₅/ha; in Paragominas and Maraba it was 137.4 kg of P₂O₅/ha.

b. Accumulated production over about 3.5 years.

c. Accumulated production over about 3 years.

SOURCES: de Azevedo et al., 1982a and 1982b; Dias Filho and Serrão, 1982; EMBRAPA-CPATU, 1980; Gonçalves et al., 1982.
In another study, *C. pubescens* cv. Comum was planted with the most important grasses, in different locations, and given a base fertilization of 50 kg of P<sub>2</sub>O<sub>5</sub>/ha. Forage samples to determine botanical composition and DM yield were taken when the mixtures were ready for grazing. Yields of *C. pubescens* mixtures with erect and creeping grasses were adequate and comparable with those of *P. phaseoloides* (Table 4). *Centrosema pubescens* appeared more compatible with erect-growing grasses than did *P. phaseoloides* which tended to overcrowd the companion grass.

Table 4. Dry-matter (DM) production (t/ha) in mixtures of *Centrosema pubescens* cv. Comum or *Pueraria phaseoloides* (used as a control) with different grasses in various locations in the Amazon region, Brazil.

<table>
<thead>
<tr>
<th>Location</th>
<th>Grass-legume mixture</th>
<th>DM production</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Grass</td>
</tr>
<tr>
<td>Itacoatiara&lt;sup&gt;b&lt;/sup&gt;</td>
<td><em>P. maximum-C. pubescens</em></td>
<td>16.7</td>
</tr>
<tr>
<td></td>
<td><em>P. maximum-P. phaseoloides</em></td>
<td>11.1</td>
</tr>
<tr>
<td></td>
<td><em>H. rufo-C. pubescens</em></td>
<td>14.8</td>
</tr>
<tr>
<td></td>
<td><em>H. rufo-P. phaseoloides</em></td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td><em>B. humidicola-C. pubescens</em></td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td><em>B. humidicola-P. phaseoloides</em></td>
<td>6.5</td>
</tr>
<tr>
<td>Ji-Paraná&lt;sup&gt;c&lt;/sup&gt;</td>
<td><em>P. maximum-C. pubescens</em></td>
<td>15.7</td>
</tr>
<tr>
<td></td>
<td><em>P. maximum-P. phaseoloides</em></td>
<td>20.0</td>
</tr>
<tr>
<td>Conceição do Araguaia&lt;sup&gt;c&lt;/sup&gt;</td>
<td><em>P. maximum-C. pubescens</em></td>
<td>12.9</td>
</tr>
<tr>
<td></td>
<td><em>P. maximum-P. phaseoloides</em></td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td><em>B. humidicola-C. pubescens</em></td>
<td>15.0</td>
</tr>
</tbody>
</table>

<sup>a</sup> Figures in parentheses are legume percentages of total DM.

<sup>b</sup> Accumulated production over about 3 years.

<sup>c</sup> Accumulated production over about 2 years.

SOURCES: de Azevedo et al., 1982a and 1982b; Dias Filho and Serrão, 1982; EMBRAPA-CPATU, 1980; Gonçalves et al., 1982.

**Animal production.** Although grazing experiments have been carried out in the Brazilian humid tropics to measure animal performance from legume-based pastures (EMBRAPA-CPATU, 1980), *C. pubescens* has been included only as a component of a legume “cocktail.” Other legumes such as commercial *P. phaseoloides* and *S. guianensis*, were included and the contribution of each legume was not determined.

An experiment reported by Salviano (1981) in Bahia, seems to be one of the very few recorded in the literature where animal performance was...
measured, even though it were for only one year. Its objective was to compare the effect of nitrogen fertilization with that of legumes (which included *C. pubescens* cv. Comum) in *P. maximum* cv. Colonião pasture under different stocking rates. Table 5 shows that, both qualitatively (gain/animal) and quantitatively (gain/ha), there was some biological advantage in supplying nitrogen to the system by using P-fertilized legumes. Adding N fertilizer was not beneficial. There was a tendency toward decreasing animal gains with increasing stocking rate which was compensated by higher gains per hectare. The highest benefit from the legume-and-P treatment can be attributed in large part to *C. pubescens*, because its contribution to the total available forage in the pasture mixture reached 50%. Several years after the initiation of the study, this legume was still very much present in the pasture (F. G. Cardoso, personal communication), demonstrating its high persistence under grazing.

Table 5. Effect of nitrogen and phosphate fertilization, and legumes (including commercial *Centrocoma pubescens*) on animal production in Colonião (*Panicum maximum*) pastures in Nova Canaã, Bahia, Brazil\(^a\).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Stocking rate (animals/ha)</th>
<th>Average daily gains (kg)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>per animal</td>
<td>per hectare</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>0.8</td>
<td>0.354</td>
<td>0.283</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.4</td>
<td>0.482</td>
<td>0.675</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>0.345</td>
<td>0.690</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.394</td>
<td>0.549</td>
<td></td>
</tr>
<tr>
<td>Nitrogen (45 kg N/ha) + phosphorus (30 kg P(_2)O(_5)/ha)</td>
<td>0.8</td>
<td>0.458</td>
<td>0.410</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.4</td>
<td>0.405</td>
<td>0.567</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>0.345</td>
<td>0.690</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.403</td>
<td>0.557</td>
<td></td>
</tr>
<tr>
<td>Legumes(^b) + phosphorus (30 kg P(_2)O(_5)/ha)</td>
<td>0.8</td>
<td>0.512</td>
<td>0.410</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.4</td>
<td>0.461</td>
<td>0.646</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>0.426</td>
<td>0.851</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.466</td>
<td>0.636</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Effect as observed in 10-ha experimental pastures, under continuous grazing, 1980.

\(^b\) *C. pubescens* (availability within pasture was more than 50%) + *Macroptilium atropurpureum* + *Neonotonia wightii*.

New *Centrosea* germplasm

Germplasm was obtained from sources such as the Centro Nacional de Recursos Genéticos (CENARGEN) of EMBRAPA and the International Tropical Pastures Evaluation Network (RIEPT, i.e., Red Internacional de Evaluación de Pastos Tropicales) coordinated by CIAT. Screening began in the 1980s.

**Agronomic trials under cutting.** Within RIEPT, various experiments of the Regional Trial A type (Toledo and Schultze-Kraft, 1982) were carried out at various sites in the region to evaluate adaptation and forage production of new *Centrosea* germplasm.

In Paragominas, Pará, one trial included 65 forage legume accessions, of which 15 were of the genus *Centrosea* (Dias Filho and Serrão, n.d.). In Itabela, Bahia, another study included eight *Centrosea* accessions in a degraded pasture area (Moreno R. and Pereira, 1983) and five accessions in a recently cleared forest area (Moreno R. et al., 1986). The accessions studied were highly variable in forage production during both the wettest and driest periods (Table 6). In Paragominas, *C. macrocarpum* CIAT 5065 stood out in the whole experimental period, outyielding *P. phaseoloides* CIAT 9900. The greatest limitation of *C. macrocarpum* CIAT 5065 is its low seed production in the region (data not given) which justifies testing other ecotypes of this species. Other lines which grew well at Paragominas were *Centrosea pubescens* Itaguaí Sintético 80, *C. acutifolium* CIAT 5112, *C. brasiliananum* CIAT 5234, *C. pubescens* CIAT 5189, and *Centrosea* hybrid CIAT 438. Performance of *C. virginianum* CIAT 474, *C. pascuorum* CIAT 5230, and *C. brasiliananum* CIAT 491 was affected by lack of adaptation and an attack by an unidentified insect of the Homoptera order which caused severe leaf damage. *Rhizoctonia* foliar blight (RFB) was the most common disease in these studies. Only *C. pubescens* CIAT 5189 and *C. pascuorum* CIAT 5230 were not attacked, suggesting that they may possess genetic resistance to this important disease.

In Itabela, most accessions grew well, particularly on the cleared-forest site.

Studies were performed at various sites to evaluate new forage legumes under cutting at different regrowth ages (3, 6, 9, and 12 weeks) according to the RIEPT Regional Trial B methodology (Toledo and Schultze-Kraft, 1982). Table 7 presents data obtained in degraded-pasture areas (Paragominas, Pará, and Porto Velho, Rondônia), a
<table>
<thead>
<tr>
<th>Species</th>
<th>CIAT accession no.</th>
<th>Adaptation grade&lt;sup&gt;a&lt;/sup&gt; evaluated during year 1982</th>
<th>Forage production (t/ha)</th>
<th>Species</th>
<th>CIAT accession no.</th>
<th>Adaptation grade&lt;sup&gt;a&lt;/sup&gt; (Average of experimental period)</th>
<th>Forage production (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Maximum rainfall period</td>
<td>Minimum rainfall period</td>
<td></td>
<td></td>
<td>Maximum rainfall period</td>
<td>Minimum rainfall period</td>
</tr>
<tr>
<td>Paragominas, Jan. 1982 to Sept. 1983 (degraded pasture)&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td>Itabela, Bahia, Feb. 1981 to Apr. 1982 (degraded pasture)&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. macrocarpum</td>
<td>5065</td>
<td>E E</td>
<td>3.72</td>
<td>C. macrocarpum</td>
<td>5065</td>
<td>G</td>
<td>1.76</td>
</tr>
<tr>
<td>C. pascuorum</td>
<td>5230</td>
<td>P P</td>
<td>2.22</td>
<td>C. brasilianum</td>
<td>491</td>
<td>E</td>
<td>1.64</td>
</tr>
<tr>
<td>C. pubescens</td>
<td>5189</td>
<td>E G</td>
<td>2.08</td>
<td>C. brasilianum</td>
<td>5234</td>
<td>G</td>
<td>1.60</td>
</tr>
<tr>
<td>C. acutifolium</td>
<td>5112</td>
<td>G E</td>
<td>1.94</td>
<td>C. brasilianum</td>
<td>5180</td>
<td>G</td>
<td>1.29</td>
</tr>
<tr>
<td>C. brasiliannum</td>
<td>5180</td>
<td>E G</td>
<td>1.90</td>
<td>C. hybrid</td>
<td>438</td>
<td>G</td>
<td>1.15</td>
</tr>
<tr>
<td>C. pubescens Itaguaí Sint.</td>
<td>80</td>
<td>E E</td>
<td>1.86</td>
<td>C. schiedeanum</td>
<td>5066</td>
<td>G</td>
<td>1.04</td>
</tr>
<tr>
<td>C. acutifolium</td>
<td>5118</td>
<td>G G</td>
<td>1.81</td>
<td>C. pascuorum</td>
<td>5230</td>
<td>G</td>
<td>1.03</td>
</tr>
<tr>
<td>C. hybrid</td>
<td>438</td>
<td>E G</td>
<td>1.52</td>
<td>C. pascuorum</td>
<td>5171</td>
<td>F</td>
<td>0.89</td>
</tr>
<tr>
<td>C. brasiliannum</td>
<td>5234</td>
<td>E E</td>
<td>1.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. pascuorum</td>
<td>5171</td>
<td>G F</td>
<td>1.43</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. brasilianum</td>
<td>491</td>
<td>G G</td>
<td>1.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. schiedeanum</td>
<td>5066</td>
<td>G G</td>
<td>1.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. pubescens</td>
<td>5126</td>
<td>G G</td>
<td>1.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. brasilianum</td>
<td>494</td>
<td>G F</td>
<td>1.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. virginianum</td>
<td>474</td>
<td>F P</td>
<td>0.73</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P. phaseoloides</td>
<td>control</td>
<td>E G</td>
<td>2.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Rated as follows: E = excellent, G = good, F = fair, P = poor, with respect to plant size, yield capacity, cover, vigor, and general condition (insect and disease attack).

<sup>b</sup> Average forage production of one cut per period in 1982; fertilized with 50 kg P<sub>2</sub>O<sub>5</sub>/ha.

<sup>c</sup> Average forage production of one cut per period; fertilized with 50 kg P<sub>2</sub>O<sub>5</sub>/ha.

<sup>d</sup> Average forage production of three cuts during maximum rainfall period and two cuts during minimum rainfall period; fertilized with 50 kg P<sub>2</sub>O<sub>5</sub>/ha and 50 kg K<sub>2</sub>O/ha.

### Table 7. Maximum (Max.) and minimum (Min.) rainfall forage production of *Centrosea* spp. at different regrowth ages at various locations in the Brazilian humid tropics.

<table>
<thead>
<tr>
<th>Location, species and accession</th>
<th>Dry-matter production (t/ha) at:</th>
<th>3 weeks</th>
<th>6 weeks</th>
<th>9 weeks</th>
<th>12 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paragominas (degraded pasture)</strong>&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. pubescens</em> cv. Comum</td>
<td>0.25</td>
<td>—</td>
<td>0.29</td>
<td>—</td>
<td>0.46</td>
</tr>
<tr>
<td><em>C. hybrid</em> 438</td>
<td>0.40</td>
<td>—</td>
<td>0.58</td>
<td>—</td>
<td>0.82</td>
</tr>
<tr>
<td><em>P. phaseoloides</em> (control)</td>
<td>0.38</td>
<td>—</td>
<td>0.55</td>
<td>—</td>
<td>0.65</td>
</tr>
<tr>
<td><strong>Porto Velho (degraded pasture)</strong>&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. pubescens</em> cv. Comum</td>
<td>0.15</td>
<td>0.24</td>
<td>0.21</td>
<td>0.75</td>
<td>0.79</td>
</tr>
<tr>
<td><em>C. hybrid</em> 438</td>
<td>0.36</td>
<td>0.23</td>
<td>0.45</td>
<td>0.74</td>
<td>1.01</td>
</tr>
<tr>
<td><em>P. phaseoloides</em> (control)</td>
<td>0.26</td>
<td>0.23</td>
<td>0.51</td>
<td>0.52</td>
<td>1.15</td>
</tr>
<tr>
<td><strong>Porto Velho (recently cleared area)</strong>&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. brasilianum</em> 5234</td>
<td>1.97</td>
<td>0.00</td>
<td>2.86</td>
<td>2.03</td>
<td>1.09</td>
</tr>
<tr>
<td><em>C. brasilianum</em> 5247</td>
<td>1.75</td>
<td>0.00</td>
<td>1.71</td>
<td>3.92</td>
<td>1.05</td>
</tr>
<tr>
<td><em>C. macrocarpus</em> 5065</td>
<td>2.06</td>
<td>1.42</td>
<td>2.30</td>
<td>3.11</td>
<td>2.44</td>
</tr>
<tr>
<td><em>C. macrocarpus</em> 5062</td>
<td>1.63</td>
<td>1.41</td>
<td>2.31</td>
<td>4.47</td>
<td>2.62</td>
</tr>
<tr>
<td><em>C. hybrid</em> 438</td>
<td>1.62</td>
<td>0.79</td>
<td>2.29</td>
<td>2.43</td>
<td>3.25</td>
</tr>
<tr>
<td><em>C. pubescens</em> 5189</td>
<td>2.12</td>
<td>0.63</td>
<td>1.94</td>
<td>2.78</td>
<td>3.39</td>
</tr>
<tr>
<td><em>C. acutifolium</em> 5112</td>
<td>2.23</td>
<td>0.55</td>
<td>1.93</td>
<td>2.90</td>
<td>3.80</td>
</tr>
<tr>
<td><strong>Itabela (cleared forest)</strong>&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>C. brasilianum</em> 5234</td>
<td>0.80</td>
<td>0.06</td>
<td>1.51</td>
<td>0.51</td>
<td>2.34</td>
</tr>
<tr>
<td><em>C. brasilianum</em> 5180</td>
<td>0.06</td>
<td>0.13</td>
<td>0.23</td>
<td>0.11</td>
<td>0.29</td>
</tr>
<tr>
<td><em>C. macrocarpus</em> 5065</td>
<td>0.76</td>
<td>0.40</td>
<td>1.46</td>
<td>0.94</td>
<td>2.98</td>
</tr>
<tr>
<td><em>C. macrocarpus</em> 5062</td>
<td>0.89</td>
<td>0.23</td>
<td>1.09</td>
<td>0.61</td>
<td>2.46</td>
</tr>
<tr>
<td><em>C. pubescens</em> 5189</td>
<td>0.69</td>
<td>0.37</td>
<td>1.37</td>
<td>0.46</td>
<td>2.14</td>
</tr>
<tr>
<td><em>C. acutifolium</em> 5112</td>
<td>0.76</td>
<td>0.31</td>
<td>1.00</td>
<td>0.81</td>
<td>2.34</td>
</tr>
</tbody>
</table>

- **a.** Measured once during a maximum rainfall period (1983); fertilized with 50 kg P<sub>2</sub>O<sub>5</sub>/ha.
- **b.** Each period measured over 2 years during 1981-83; fertilized with 50 kg P<sub>2</sub>O<sub>5</sub>/ha.
- **c.** Measured during one period per year in 1983 and 1984; fertilized with 50 kg P<sub>2</sub>O<sub>5</sub>/ha.
- **d.** Measured during one period per year in 1983 and 1984; fertilized with 50 kg P<sub>2</sub>O<sub>5</sub>/ha and 50 kg K<sub>2</sub>O/ha.

**SOURCES:** Gonçalves, 1986; Gonçalves and Oliveira, 1983; Pereira et al., 1986; M. B. Dias Filho, personal communication.

Recently cleared-forest area (Porto Velho, Rondônia), and second-growth forest areas (Itabela, Bahia). In most cases, 12-week regrowth did not produce higher yields than 6-9 weeks regrowth, particularly during the minimum rainfall period. The trials also showed *C. acutifolium*, *C. brasilianum*, and *C. macrocarpus* as productive species.
Agronomic trials under grazing. A RIEPT Regional Trial C type (Paladines and Lascano, 1983) was conducted at Paragominas, Pará, to evaluate the balance and persistence of a mixture of *C. macrocarpum* CIAT 5065 with *Andropogon gayanus* CIAT 621 under different management conditions (da Veiga and Serrão, 1986). This trial consisted of a 5-hectare pasture with three grazing pressures: grass heights were 28, 52, and 74 cm after each grazing period. A rotational grazing system was used in which each pasture was grazed for 10-16 days and rested for 45-75 days.

The results obtained after 392 days are given in Table 8. Plant density values show that the contribution of the legume was very small. Judging from plant densities during the experiment, *C. macrocarpum* was sensitive to variations in grazing pressure. High grazing pressure (short grass residues) led to relatively higher legume presence in the pasture, probably because of reduced competition from the grass for light.

<table>
<thead>
<tr>
<th>Grass height (cm)</th>
<th>Forage availability (g DM/grass tussock)</th>
<th><em>C. macrocarpum</em> plant density (no./m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before grazing</td>
</tr>
<tr>
<td>28</td>
<td>805</td>
<td>2.6</td>
</tr>
<tr>
<td>52</td>
<td>888</td>
<td>2.6</td>
</tr>
<tr>
<td>74</td>
<td>1007</td>
<td>2.6</td>
</tr>
</tbody>
</table>

a. Results obtained during six grazing cycles in rotation (grazing periods of 10-16 days and rest for 47-75 days) for an experimental period of 392 days.
b. Average of grass height remaining at the end of a grazing period.
c. Average before initiating grazing period.


Another grazing experiment simultaneously used the same infrastructure described above (da Veiga and Serrão, 1986) to determine the persistence of *C. macrocarpum* CIAT 5737, CIAT 5740, and CIAT 5744 and *C. acutifolium* CIAT 5568, randomly planted in small plots within the experimental pastures, forming four new associations with *A. gayanus*. These associations were also subjected to
the same grazing management as the major trial. All accessions persisted poorly (Table 9). No effect of grazing pressures on legume persistence was seen, either between or within species.

Table 9. The effect of grazing pressure on the persistence of three *Centrosema macrocarpum* accessions and *C. acutifolium* in association with *Andropogon gayanus* in Paragominas, Pará, Brazil.

<table>
<thead>
<tr>
<th>Grass height</th>
<th>No. of <em>Centrosema</em> plants per 16-m row</th>
</tr>
</thead>
<tbody>
<tr>
<td>(cm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>C. macrocarpum</em> CIAT 5737</td>
</tr>
<tr>
<td></td>
<td>ID</td>
</tr>
<tr>
<td>28</td>
<td>252</td>
</tr>
<tr>
<td>52</td>
<td>181</td>
</tr>
<tr>
<td>74</td>
<td>238</td>
</tr>
<tr>
<td>Average</td>
<td>224</td>
</tr>
</tbody>
</table>

a. Results obtained during six grazing cycles in rotation (grazing periods of 10-16 days with 47-75 days of rest) during an experimental period of 392 days.

b. Average height of grass remaining at the end of each grazing period.

c. ID = initial density; FD = final density. Parentheses refer to survival percentages in relation to initial density.


**Success of *Centrosema* Research**

Unfortunately, research on the selection of *Centrosema* germplasm for the region has been relatively unsuccessful. The biggest contribution, through research activities at ranch level, has been to emphasize the importance of legumes as pasture components (EMBRAPA-CPATU, 1980). *Pueraria phaseoloides* and *C. pubescens* (the only species of *Centrosema* with commercial varieties in Brazil) have been recommended as important legumes and have been used in commercial pastures.

The principal reasons for the lack of success in selecting and releasing *Centrosema* spp. cultivars suitable for the region have been...
discontinuity in the evaluation of new germplasm on experiment stations; lack of seed of promising accessions in research stations for more advanced evaluation (the main bottleneck for evaluation continuity); lack of adequate integration and complementarity among the several institutions responsible for pasture research in the region; and low demand for legumes by the cattle industry in the region that traditionally uses pure-grass pastures. Most emphasis has been given to grass germplasm (because grasses are and will continue to be the major components of pastures) rather than to legumes.

In spite of these limitations, the importance of legumes (particularly *Centrosema*) is increasingly recognized. Improved research organization and technical assistance is needed in order to supply, in the short to medium term, the pasture needs of the cattle industry in the region. This process should be guided by the Centro de Pesquisa Agropecuária do Trópico Úmido (CPATU) of EMBRAPA in association with EMBRAPA-CENARGEN, international institutions (such as CIAT through RIEPT), and other Brazilian research units responsible for pasture research in the region.

**Centrosema Potential and Limitations for the Region**

E. A. S. Serrão (unpublished data) has observed the development of about 10,000 hectares of pastures sown with *P. maximum*, *B. humidicola*, and *B. decumbens* in association with mixtures of commercial *P. phaseoloides*, *C. pubescens*, and *S. guianensis* over the past 10 years, on a ranch where these mixtures were sown in the early 1970s. Despite mismanagement, somewhat frequent pasture burnings, and heavy incidence of RFB, *C. pubescens* has been the most persistent of the legumes and, especially where most of the grass has disappeared, it is apparently contributing substantially to animal performance. Its regeneration from seed is another important factor. This example indicates the potential of *Centrosema* for the region. Evaluation of the 500 *Centrosema* accessions held at CPATU's forage germplasm bank should lead to the development of better cultivars.

When the two best known species of *Centrosema*, that is, *C. pubescens* and *C. brasilianum*, are compared with other traditional legumes such as *P. phaseoloides*, several positive characteristics stand out: they are native to the region, therefore offering regional genetic
diversity for selection; they are potentially good seed producers—necessary in a region where seed is difficult to obtain; they have medium aggressiveness which makes them more appropriate for association with caespitose grasses; they are more resistant to fire and hence more persistent—necessary in a region where burning is part of traditional pasture management; and they are drought tolerant, making them more adaptable to a wider climatic range.

Despite its unquestionable potential, some environmental factors, mainly of a climatic and edaphic nature, can limit Centrosema as a pasture legume for the region. Soil fertility, particularly low phosphorus status, is probably the most limiting factor recorded in the literature (Falesi, 1976; Serrão et al., 1979). Phosphorus deficiency increases in importance 5-8 years after pasture establishment which, because it usually involves the clearing and burning of forest biomass, temporarily increases soil fertility (Falesi, 1976; Serrão et al., 1979). If the pasture mixture includes Centrosema, or if the legume is sown in an already established pasture, it is likely that phosphorus fertilization will be needed to replenish soil phosphorus.

No information exists on the importance of other macro- and micronutrients for forage legumes in the region. Nevertheless, C. pubescens cv. Comum regularly has been observed to be affected by potassium, sulfur, magnesium, and zinc deficiencies (E. M. Hutton, personal communication).

The humid tropical climate encourages the proliferation of diseases and pests. RFB is the most important disease of Centrosema in the region, followed by anthracnose caused by Colletotrichum gloeosporioides (Cruz et al., 1986; Dias Filho and Serrão, 1983; EMBRAPA-CPATU, 1980). Both diseases are important during the establishment phase (sometimes killing many seedlings) and on plants already established (reducing their productive persistence). In general, RFB is more prevalent in C. pubescens. Another, less important, disease that can sometimes damage Centrosema spp. is a leaf-spot disease caused by Cercospora spp. (Dias Filho and Serrão, 1983).

Although occurring sporadically, some insects may constitute a limiting factor for Centrosema. Diabrotica sp. has been the most frequently observed insect, especially on commercial C. pubescens (EMBRAPA-CPATU, 1980).

There are good possibilities for seed production of C. pubescens and C. brasiliatum; for example, in one large ranch in Paragominas, Pará,
satisfactory yields of commercial *C. pubescens* seeds have been obtained from *P. maximum-C. pubescens* pastures. However, local sources of *Centrosoema* seed are scarce. It is necessary to identify varieties, appropriate areas, and methods for seed production of *Centrosoema* and other legumes for pasture establishment.

**The Need for *Centrosoema* Research**

As was mentioned earlier, research in the region has been concentrated on grasses which are the major components of sown pastures. It appears reasonable that this priority should be maintained for some time, since the main problem still remains one of quantity rather than quality of forage.

Nevertheless, it is necessary to have a well-organized, integrated, and complementary regional research effort with the objective of a more efficient and generalized use of legumes in pastures. In this context, *Centrosoema* should play an important part. Research with *Centrosoema* should emphasize the following points:

**Basic research.** This should focus on the collection, introduction, and preservation of germplasm; characterization and initial evaluation of germplasm; monitoring of diseases and pests; and fixation and transfer of nitrogen.

**Applied research.** This should emphasize germplasm selection; *Centrosoema* agronomy (seasonal production of dry matter, seed-production potential, and compatibility with grasses); interactions between soil, plant, and animal (minimum nutrient requirements, plant and microbe interaction in soil, relative acceptability to animals, grazing tolerance, digestibility); establishment (methods, fertilization, weed control, establishment management); and pasture management and animal production. Applied research should emphasize the most promising *Centrosoema* species, of which large numbers of accessions are now available.

Finally, it is necessary to emphasize that, despite the recognized potential of *Centrosoema* in increasing pasture productivity in the region, its development requires objective, ordered, and uninterrupted aggressive research. Genetic variability loses its value when not used in an efficient manner. Seed production plays a fundamental role in supporting this process.
References

To save space, the following acronyms are used in place of publishers’ names:

CEPLAC = Comissão Executiva do Plano da Lavoura Cacaueira.
CIAT = Centro Internacional de Agricultura Tropical.
CPATU = Centro de Pesquisa Agropecuária do Trópico Úmido.
EMBRAPA = Empresa Brasileira de Pesquisa Agropecuária.
IPEAN = Instituto de Pesquisa e Experimentação Agropecuária do Norte.
UEPAE = Unidade de Execução de Pesquisa de Ambito Estadual.


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dez Azevedo, G. P. C.; Camarão, A. P.; da Veiga, J. B.; and Serrão, E. A. S.
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Pará. Research bulletin no. 46. EMBRAPA-CPATU, Belém, PA, Brazil.
21 p.

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Regional experience with Centrosema: Brazil—humid tropics

(SUDAM/PHCA), PHCA publication no. 39. Belém, PA, Brazil. 254 p. (Typescript.)


(Typescript.)


Chapter 18

REGIONAL EXPERIENCE WITH CENTROSEMA: BRAZIL—SAVANNAS

D. Thomas and M. I. de O. Penteado*

Abstract

Centrosema is one of a number of legume genera that are potentially capable of providing productive, adapted species for pasture improvement in the well-drained tropical savannas of central Brazil known as the “Cerrados.” A high proportion of the Centrosema literature for the Cerrados concerns the evaluation of commercial cultivars of C. pubescens in pot trials in the greenhouse, as spaced plants in rows, in small plots of pure legume or grass-legume associations under cutting or grazing, and in large-scale grazing experiments where animal performance was measured.

This paper discusses the adaptation of C. pubescens to climatic, edaphic, and biotic factors. It also reports on other species of Centrosema, particularly those evaluated at the two major screening sites: Centro de Pesquisa Agropecuária dos Cerrados (CPAC), Planaltina, Distrito Federal; and Centro Nacional de Pesquisa de Gado de Corte (CNPGC), Campo Grande, Mato Grosso do Sul. Brief mention is made of regional evaluation studies at other sites in the Cerrados, between latitudes 3° N and 22° S. Finally, future research priorities are described for both C. pubescens and a group of other Centrosema species.

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Introduction

The well-drained tropical savannas of central Brazil (known locally as "Cerrados") occupy about 180 million hectares, corresponding to 21% of the national territory (Figure 1). These areas are classified as isothermic savannas by Cochrane et al. (1985) and the vegetation has been described by Eiten (1972). The Cerrados are concentrated mainly in the states of Goiás, Mato Grosso, Mato Grosso do Sul, Minas Gerais, and the Distrito Federal around the capital city of Brasília. Almost 40% of the Brazilian cattle population occurs in the area, but livestock performance is usually poor (Thomas et al., 1983). However,
the potential for increased animal production through improved technology is considerable, and one economically attractive option is the use of legume-based pastures. Several legume genera, including *Centrosoema*, are potentially capable of providing productive, adapted species for pasture improvement in the Cerrados. According to Williams and Clements (this volume), the genus *Centrosoema* comprises 35 species of herbaceous tropical legumes. The genus is well represented in Brazil (Costa et al., 1978; da Rocha et al., 1979; Reid, 1977; Schultze-Kraft et al., 1986).

Despite the genetic diversity within the genus, only *C. pubescens* has attained economic importance as a forage plant and as a cover crop in plantation agriculture, mainly in Australia and Southeast Asia, respectively. Commercial cultivars of this species have been used widely in experimentation in the São Paulo state, and many have been established on farms there in the 1960s and early 1970s. Although no statistics are available on its use in agriculture, it is reasonable to assume that the species had no measurable impact on production at farm level. As a consequence of its use in research, a high proportion of the *Centrosoema* literature for the Cerrados concerns the commercial cultivars of *C. pubescens*. Often no mention is made of the source of seed of the commercial cultivar and one assumes that in most cases it is “common centro” from Australia. However, *C. pubescens* IRI 1282 collected in 1962 in the São Paulo state was reported by Shock et al. (1979) to have entered into commercial and wide distribution in Brazil. Also, in a few examples, the cultivar Deodoro has been used. This is a mixture of accessions which originated from the Estação do Ministério de Agricultura de Deodoro in the Rio de Janeiro state (A. Serpa, personal communication). Seed was multiplied in Rio de Janeiro and subsequently distributed to producers without official release.

This review has been divided into two parts: the first deals with *C. pubescens*, and the second with other species of the genus.

**Centrosoema pubescens**

**General**

The literature reports results from pot trials in the greenhouse, spaced plants in rows, small plots of pure legume or grass-legume associations under cutting or grazing, and large-scale grazing experiments where animal performance was measured. *Centrosoema*
*pubescens* was often sown in a mixture with as many as four other legumes. Obviously, it was impossible to determine the precise contribution of the species to productivity in these trials.

At only two sites were a significant number of accessions evaluated in preliminary small-plot field trials. These were at the Centro de Pesquisa Agropecuária dos Cerrados (CPAC), near Brasília in the Distrito Federal, and at the Centro Nacional de Pesquisa de Gado de Corte (CNPGC), Campo Grande, Mato Grosso do Sul. Both centers belong to the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA). Climatic data are presented in Table 1 for these two major screening sites, together with those for the Estação Central do Instituto de Zootecnia, Nova Odessa, São Paulo state (where considerable experimental work has been conducted with the commercial cultivars).

In CPAC, 19 accessions were tested (Thomas, 1985) and at CNPGC, 24 accessions (Porzecanski et al., 1979). More recently, Penteado (1986) has evaluated 15 accessions of *C. pubescens* at CNPGC out of a total number of 82 accessions. A collection of 51 *Centrosea pubescens* accessions also existed at the Instituto de Pesquisas IRI, Matão, São Paulo state (Shock et al., 1979). However, no evaluation data appear to be available for this site.

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Altitude (m)</th>
<th>Average annual rainfall (mm)</th>
<th>Mean annual temperature (°C)</th>
<th>Frost risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centro de Pesquisa Agropecuária dos Cerrados (CPAC), Planaltina, DF</td>
<td>15°36' S</td>
<td>47°42' W</td>
<td>1170</td>
<td>1570 (90% October to March)</td>
<td>21.3</td>
<td>No</td>
</tr>
<tr>
<td>Centro Nacional de Pesquisa de Gado de Corte (CNPGC), Campo Grande, MS</td>
<td>20°27' S</td>
<td>54°40' W</td>
<td>530</td>
<td>1000 (75% October to March)</td>
<td>22.4</td>
<td>Yes</td>
</tr>
<tr>
<td>Estação Central do Instituto de Zootecnia, Nova Odessa, SP</td>
<td>22°42' S</td>
<td>47°18' W</td>
<td>550</td>
<td>1580 (70% October to March)</td>
<td>21.9</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Adaptation to climate

The major part of the Cerrados occurs between latitudes 6° and 20° S, although small areas are found beyond these parallels. The elevation ranges from sea level to 900 m, with total annual rainfall varying between 1000 and 2000 mm. The dry season lasts 5-7 months (Thomas, 1985). Rainfall distribution is characterized by distinct wet and dry seasons, and 80% of the total precipitation falls between November and April. Short-term droughts commonly occur during the wet season. Average annual temperatures vary between 18 and 20 °C (de Azevedo and Caser, 1980) with frosts occurring periodically in southern areas of Mato Grosso do Sul, São Paulo, and Minas Gerais states.

Commercial *C. pubescens* is a legume for the wet tropics and flourishes in areas receiving more than 1250 mm of annual rainfall (Humphreys, 1980). It has rarely become well adapted to areas receiving less than 1000 mm of rainfall. *Centrosema pubescens* appears to have been tested in the southern half of the Cerrados between latitudes approximating 15 and 23° S. Many of the reports for commercial *C. pubescens* are from the Estação Central do Instituto de Zootecnia, Nova Odessa, São Paulo state. Although the rainfall across most experiment sites in any one year ranged from 989 to 1871 mm, average rainfall over a number of years usually exceeded 1200 mm. Under these conditions *C. pubescens* would be expected to grow well when other factors were not limiting. At southern latitudes, as in São Paulo state, out-of-season rainfall may be 15% or more of the annual total. Consequently, *C. pubescens* shows better dry-season tolerance than at sites where there is little out-of-season rainfall as in the Distrito Federal at latitude 15°35' S (Thomas, 1985).

Mean maximum and mean minimum temperatures range from 33.2 to 6.9 °C. In São Paulo state, temperatures as low as -2.8 °C have been recorded for short periods in the winter season. Frost damage on *C. pubescens* was recorded from Mato Grosso do Sul, São Paulo, and Minas Gerais by Porzecanski et al. (1979), de Andrade (1980), Paulino et al. (1981), M. I. de O. Penteado (unpublished data), and N. M. S. Costa (personal communication). However, Porzecanski et al. (1979) have shown that there is variation in tolerance to cold within the species.

Adaptation to soil conditions

Soils of the Cerrados and their characteristics are described by Goedert (1983) and Cochrane et al. (1985). Oxisols cover more than
50% of the area with the remainder consisting mostly of Entisols, Inceptisols, and Ultisols. Red-Yellow Latosols and Dark Red Latosols, most of the suborder Ustox (Oxisols), have been preferred for agriculture and cover 52% of the Cerrados (EMBRAPA-CPAC, 1976). Quartz Sands of the suborder Psammments (Entisols) occupy 20% of the region, and are likely to become more important agriculturally in the future. Red-Yellow Podzolics (Ultisols) are found on 5% of the Cerrados and are of some importance in São Paulo state. Other soil types also exist in São Paulo state which are much more fertile than those usually associated with the Cerrados region. However, data from these sites have not been included in this discussion. Most soils are deep, well-drained, and with low moisture-holding capacity. Both soil toxicity and deficiency problems are of primary concern. The effective cation-exchange capacity is low and aluminum saturation is often above 50%. Phosphorus is the most deficient plant nutrient, but low levels of nitrogen, potassium, sulfur, calcium, magnesium, and zinc also occur. Data giving characteristics of Cerrados soils used in studies with *C. pubescens* are presented in Table 2.

A number of fertilizer trials have been conducted with *C. pubescens* in the Cerrados and a summary of results is shown in Table 3. Lime, phosphorus, potassium, sulfur, and micronutrients have all given

<table>
<thead>
<tr>
<th>Soil type</th>
<th>pH (ppm)</th>
<th>P (ppm)</th>
<th>K (ppm)</th>
<th>Al (meq/100 g)</th>
<th>Ca + Mg (meq/100 g)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red-Yellow Latosols</td>
<td>4.7-5.2</td>
<td>1-3</td>
<td>21-79</td>
<td>0.4-2.1</td>
<td>0.2-1.3</td>
<td>Ghisi et al., 1982</td>
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<td>Paulino et al., 1981</td>
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<td>Soares and Vargas, 1974</td>
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<td>Vargas and Suhet, 1981</td>
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<td>de Vasconcelos et al., 1974</td>
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<tr>
<td>Dark Red Latosols</td>
<td>4.2-5.3</td>
<td>1-2</td>
<td>25-82</td>
<td>0.5-1.2</td>
<td>0.3-3.3</td>
<td>de Carvalho et al., 1971</td>
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<td>Ghisi et al., 1982</td>
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<td>Paulino et al., 1981</td>
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<td>Porzecanski et al., 1979</td>
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<td></td>
<td>Soares and Vargas, 1974</td>
</tr>
<tr>
<td>Quartz Sands</td>
<td>4.5-4.8</td>
<td>2</td>
<td>15</td>
<td>0.8-0.9</td>
<td>0.2-0.3</td>
<td>Ghisi et al., 1982</td>
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<td></td>
<td>Paulino et al., 1981</td>
</tr>
<tr>
<td>Red-Yellow Podzolica</td>
<td>4.6-5.0</td>
<td>1-2</td>
<td>21-38</td>
<td>0.8</td>
<td>0.2-0.3</td>
<td>Ghisi et al., 1982</td>
</tr>
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<td>Paulino et al., 1981</td>
</tr>
</tbody>
</table>
### Table 3. Summary of results of fertilizer experiments with *Centrosema pubescens* in Brazil.

<table>
<thead>
<tr>
<th>Type of trial</th>
<th>Soil type&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Lime or nutrient</th>
<th>Plant responses</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greenhouse and field</td>
<td>DRL and RYL</td>
<td>Lime</td>
<td>Increases in dry-matter (DM) yield, nitrogen (N) yield, N&lt;sub&gt;2&lt;/sub&gt; fixation, and nodulation</td>
<td>de França and de Carvalho, 1970&lt;br&gt;Soares and Vargas, 1974&lt;br&gt;Vargas and Suhet, 1981</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>DRL and RYL</td>
<td>Phosphorus</td>
<td>Increases in DM yield, N yield, and nodule weight</td>
<td>Couto and Sanzonowics, 1983&lt;br&gt;de Carvalho et al., 1971&lt;br&gt;de França and de Carvalho, 1970&lt;br&gt;Werner and de Mattos, 1972</td>
</tr>
<tr>
<td>Field</td>
<td>RYP</td>
<td>Potassium</td>
<td>Increases in DM production and crude-protein yield. In pure and mixed pastures with <em>Panicum maximum</em> and <em>Melinis minutiflora</em>. Outyielded <em>Macroptilium atropurpureum</em> cv. Siratro and <em>Neonotonia wightii</em></td>
<td>Monteiro et al., 1980&lt;br&gt;Werner et al., 1983</td>
</tr>
<tr>
<td>Greenhouse</td>
<td>DRL and RYL</td>
<td>Sulfur</td>
<td>Variable responses. DM yield, and N and S contents increased. In one trial no effect on DM yield or N&lt;sub&gt;2&lt;/sub&gt; fixation</td>
<td>Couto and Sanzonowics, 1983&lt;br&gt;de França and de Carvalho, 1970&lt;br&gt;Jones and Quagliato, 1970</td>
</tr>
<tr>
<td>Greenhouse and field</td>
<td>DRL and RYL</td>
<td>Micronutrients</td>
<td>Increases in DM yield and protein yield. In trials, mixtures of 2 to 5 micronutrients applied</td>
<td>Couto and Sanzonowics, 1983&lt;br&gt;de França and de Carvalho, 1970&lt;br&gt;Soares and Vargas, 1974&lt;br&gt;Werner et al., 1983</td>
</tr>
</tbody>
</table>

<sup>a</sup> DRL = Dark Red Latosols.<br>RYL = Red-Yellow Latosols.<br>RYP = Red-Yellow Podzolics.
variously increased responses in Cerrados soils in terms of dry-matter yield, nitrogen production, and nodulation. In the case of lime, it is unclear whether the response is to calcium or to the neutralization of free aluminum in the soil or to both. In most trials with micronutrients, mixtures were applied; however, responses to boron and molybdenum given singly were obtained by Soares and Vargas (1974) and Couto and Sanzonowics (1983).

There seems little doubt that in areas where annual rainfall exceeds 1000 mm, the main constraints to growth in commercial cultivars of *C. pubescens* are edaphic conditions. Appreciable amounts of lime and nutrients must be applied if these plants are to establish and persist on acid, infertile soils. However, new accessions evaluated by Schultzze-Kraft and Keller-Grein (1985) have proved remarkably variable in this respect, even though none was collected at acid-soil sites. Similar observations were made by Porzecanski et al. (1979), Penteado (1986), and N. M. S. Costa (personal communication). As Schultzze-Kraft and Keller-Grein (1985) have stated, the commercial cultivars give little idea of the diversity of the species in relation to edaphic factors.

**Adaptation to biotic factors**

There is no evidence that commercial cultivars have been attacked seriously by diseases or pests in the Cerrados. However, Thomas (1985) has observed at CPAC that other accessions of *C. pubescens* have shown a susceptibility to cercospora leaf spot, anthracnose, and the *Phoma-Rhizoctonia* complex. Little-leaf mycoplasma has also been noted at this location (J. M. Lenné, personal communication). The problems of diseases and pests are reported in more detail by Lenné et al., this volume.

**Agronomic evaluation**

Dry-matter yields for *C. pubescens* grown with or without a companion grass are reported in Table 4. Trials were conducted for as short as 1 to as long as 3 years, and in only one experiment (Andrade and Ferreira, 1981) was the species grazed. Yields differed appreciably and, as anticipated, were usually higher in pure stands of the legume. *Centrosema pubescens* consistently outyielded *Stylosanthes humilis* but performance compared with other legumes varied with the trial. At CPAC, Thomas and de Andrade (1984) observed that the commercial cultivar disappeared in the second year of an experiment under a close, 478
Table 4. Dry-matter yields reported for *Centrosema pubescens* grown with or without a grass, Brazil.

<table>
<thead>
<tr>
<th>State (with sources)</th>
<th>Soil type&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Annual rainfall (mm)</th>
<th>Duration of trial (months)</th>
<th>Annual DM yield (kg/ha)</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PURE STANDS</strong></td>
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<tr>
<td>Minas Gerais</td>
<td>RYL</td>
<td>1443</td>
<td>12</td>
<td>4501</td>
<td>2 cuts. N, P, and K applied. Yield equal to <em>Neonotonia wightii</em>, <em>Calopogonium mucunoides</em>, and <em>Macroptilium atropurpureum</em> cv. Siratro, but about 50% less DM than <em>Stylosanthes guianensis</em>.</td>
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<td>(de Vasconcelos et al., 1974)</td>
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<td>(de Mattos and Werner, 1975)</td>
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<tr>
<td>(Andrade, 1981)</td>
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<tr>
<td>Minas Gerais</td>
<td>DRL</td>
<td>—</td>
<td>12</td>
<td>2186</td>
<td>1 cut. P applied. Outyielded <em>G. striata</em> and <em>Centrosema vexillatum</em>, but not <em>M. atropurpureum</em> cv. Siratro.</td>
</tr>
<tr>
<td>(Pizarro and Carvalho, 1981)</td>
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<td>(Paulino et al., 1983)</td>
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<tr>
<td><strong>ASSOCIATIONS</strong></td>
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<td>(de Mattos and Werner, 1979)</td>
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<td>(Andrade and Ferreira, 1981)</td>
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<td>(Paulino et al., 1983)</td>
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</tbody>
</table>

<sup>a</sup> RYL = Red-Yellow Latosols; RYP = Red-Yellow Podzolics; DRL = Dark Red Latosols.
intermittent grazing regime with both *Brachiaria decumbens* and *Andropogon gayanus*. The soil was a Dark Red Latosol, with a pH of 4.5, low phosphorus, and high aluminum saturation. The species appears to be more compatible with tufted rather than with prostrate grasses (Pedreira et al., 1975), and combines particularly well with *Panicum maximum* (de Mattos et al., 1978).

**Animal production**

Data refer to liveweight gains only. In 13 of the 15 trials more than one legume was used with *C. pubescens*. Consequently, it was not possible to separate the contribution of this legume to animal performance from the other legumes in the majority of experiments, particularly as data on botanical composition were absent. Results for trials in which *C. pubescens* was used singly or with only one other legume are presented in Table 5. Trials where *C. pubescens* was used with two or more other legumes are reported by Andrade and Campos (1979), Lourenço et al. (1978, 1979, and 1980), Pedreira et al. (1975), Sartini et al. (1980), and Vilela et al. (1977b).

All of the experiments were of short duration and only two ran for 3 years. Some trials reported animal gains during only part of the year such as the dry season. Animal performance was very variable and there were effects of stocking rate and, in one case, of grazing system. The short-term nature of the trials limits their value, but consistently mixed pastures gave higher gains than those without a legume. Gains per hectare in these experiments also varied greatly from 40 to 612 kg in mixed pastures and from 39 to 531 kg in the pure-grass controls.

**Other Species of Centrosema**

**General**

In recent years, the Centro Internacional de Agricultura Tropical (CIAT) has acquired a large collection of species of *Centrosema* which, by the end of 1986, numbered 1930 introductions (R. Schultze-Kraft, personal communication). This is largely the result of intensive plant collection in collaboration with national institutions in tropical America. However, to date, small-plot field evaluation of a significant number of accessions in the Cerrados of Brazil appears to have taken
Table 5. Animal performance from pastures containing *Centrocoma pubescens*, Brazil.

<table>
<thead>
<tr>
<th>State (with source)</th>
<th>Grass-legume associations</th>
<th>Daily liveweight gain (g/head)</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>São Paulo</td>
<td><em>Melinis minutiflora</em> with <em>C. pubescens</em></td>
<td>161-336 (1st year) 641-757 (2nd year)</td>
<td>Trial 412 days. 3 stocking rates: 0.6, 1.2, and 1.8 an./ha. Rotational grazing.</td>
</tr>
<tr>
<td>Goiás (Primo et al., 1977)</td>
<td><em>Panicum maximum</em> var. <em>trichoglume</em> with <em>C. pubescens</em> and <em>Stylosanthes guianensis</em></td>
<td>500 (grass-legume) 300 (grass alone)</td>
<td>Trial 367 days. Stocking rates: 2.8 and, on <em>Hyparrhenia rufa</em> (control), 1.5 an./ha. Continuous grazing. 29% <em>C. pubescens</em> and 3% <em>S. guianensis</em>.</td>
</tr>
<tr>
<td>Goiás (Rolón et al., 1977b)</td>
<td><em>P. maximum</em> cv. Coloniño with <em>C. pubescens</em> and <em>Neonotonia wightii</em></td>
<td>370 (rotational) 270 (continuous)</td>
<td>Trial 290 days. Stocking rates: 2.8 (continuous) and 3.6 (rotational) an./ha. 9% <em>C. pubescens</em> and 1% <em>N. wightii</em>.</td>
</tr>
<tr>
<td>Goiás (Rolón et al., 1977a)</td>
<td><em>P. maximum</em> cv. Coloniño with <em>C. pubescens</em> and <em>Calopogonium mucunoides</em></td>
<td>300 (grass-legume) 190 (grass alone)</td>
<td>Trial 166 days. Stocking rates: 1.8 and 1.2 an./ha on association and control, respectively. Continuous grazing. 52% <em>C. mucunoides</em> and 10% <em>C. pubescens</em>.</td>
</tr>
<tr>
<td>Minas Gerais (Vilela et al., 1977a)</td>
<td><em>B. decumbens</em> with <em>C. pubescens</em> and <em>Leucaena leucocephala</em></td>
<td>546 (grass-legume) 397 (grass alone)</td>
<td>Trial 112 days (dry season). 1.25 animal units (AU)/ha (1 AU = 400 kg). Continuous grazing.</td>
</tr>
<tr>
<td>São Paulo (Sartini et al., 1979)</td>
<td><em>M. minutiflora</em> with <em>C. pubescens</em></td>
<td>444-682 (wet season) 306-400 (total period)</td>
<td>Trial 980 days. 3 stocking rates: 0.8, 1.6, and 2.4 an./ha. Rotational grazing.</td>
</tr>
<tr>
<td>São Paulo (Favoreto et al., 1983)</td>
<td><em>P. maximum</em> cv. Coloniño with <em>C. pubescens</em> and <em>N. wightii</em></td>
<td>680-730 (grass-legume) 570-670 (grass alone)</td>
<td>Trial 480 days. Stocking rates: 1.5 and 2.0 an./ha. Continuous grazing.</td>
</tr>
<tr>
<td>Minas Gerais (Vilela et al., 1983)</td>
<td><em>B. decumbens</em> with <em>C. pubescens</em> and <em>N. wightii</em></td>
<td>390 (grass-legume) 210 (grass alone)</td>
<td>Trial 112 days (dry season). Stocking rates: 1.96 and 1.90 AU/ha. Continuous grazing. 8% <em>C. pubescens</em> and 12% <em>N. wightii</em>.</td>
</tr>
</tbody>
</table>
place only at two sites: CPAC in the Distrito Federal, and CNPGC in Mato Grosso do Sul (Table 6). Small-plot grazing trials are also in progress at these locations. A collection of 95 accessions of *Centrosema* spp., that is, *C. arenarium* (1), *C. arenicola* (1), *C. brasiliananum* (17), *C. pascuorum* (7), *C. plumieri* (13), *C. sagittatum* (4), *C. schottii* (7), and *C. virginianum* (45); and 71 accessions of undefined *Centrosema* species was also reported from the Instituto de Pesquisas IRI, Matão in São Paulo state (Shock et al., 1979). However, no data appear to be available on the performance of these accessions.

**Table 6.** Collections of species other than *Centrosema pubescens* evaluated at the Centro de Pesquisa Agropecuária dos Cerrados (CPAC) and at the Centro Nacional de Pesquisa de Gado de Corte (CNPGC), Brazil.

<table>
<thead>
<tr>
<th>CPAC, Planaltina, DF</th>
<th>CNPGC, Campo Grande, MS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Species</strong></td>
<td><strong>No. of accessions evaluated</strong></td>
</tr>
<tr>
<td><em>C. brasiliananum</em></td>
<td>158</td>
</tr>
<tr>
<td><em>C. macrocarpum</em></td>
<td>58</td>
</tr>
<tr>
<td><em>C. acutifolium</em></td>
<td>7</td>
</tr>
<tr>
<td><em>C. graziolae</em></td>
<td>3</td>
</tr>
<tr>
<td><em>C. arenarium</em></td>
<td>2</td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>2</td>
</tr>
<tr>
<td><em>C. bifidum</em></td>
<td>1</td>
</tr>
<tr>
<td><em>C. plumieri</em></td>
<td>1</td>
</tr>
<tr>
<td><em>C. sagittatum</em></td>
<td>1</td>
</tr>
<tr>
<td><em>C. schiedeanum</em></td>
<td>1</td>
</tr>
</tbody>
</table>

**Total** | 234 | 222 |


**Evaluation at the Centro de Pesquisa Agropecuária dos Cerrados (CPAC)**

In addition to the 234 accessions (Table 6), a further 107 hybrids between *C. pubescens* and *C. macrocarpum* have been evaluated (E. M. Hutton and F. B. de Sousa, personal communication). In particular, two species, that is, *C. brasiliananum* and *C. macrocarpum*, have shown good adaptation to climatic and edaphic conditions (Thomas, 1985).
Introductions of *C. brasilianum* were very vigorous and rapidly colonized the plots. Most of the accessions were classified as late flowering (April onward) at this latitude (15°36' S). Seed-production potential in the species was high but tolerance of the dry season was moderate with some leaf loss. The major constraints were plant diseases: rhizoctonia foliar blight (RFB) was the most important and caused severe defoliation in highly susceptible accessions. None was resistant to the disease, but some accessions showed good tolerance. Other diseases observed in the species were phoma leaf spot, pseudocercospora leaf spot, and little-leaf mycoplasma (J. M. Lenné, personal communication). Three accessions, BRA-006025 (CIAT 5234), BRA-003662 (CIAT 5523), and BRA-006254 (CIAT 5824), are, at present, under intermittent grazing in small plots in association with *Andropogon gayanus* cv. Planaltina and *Brachiaria brizantha* cv. Marandú.

Introductions of *C. macrocarpum* have shown excellent vegetative vigor and good tolerance of the dry season. One accession, CIAT 5065, responded well to applications of phosphorus in quantities as much as 100 kg/ha (Figure 2), despite being well adapted to acid, infertile soils.

![Graph](image)

Figure 2. Response of five legumes to applications of phosphorus on an Oxisol at the Centro de Pesquisa Agropecuária dos Cerrados. (Taken from Couto, 1985.)
In contrast, accessions of *Zornia brasiiliensis*, *Stylosanthes macrocephala*, and *S. capitata* were markedly less responsive and produced less dry matter. This flexibility of response is significant in the Cerrados where pastures often follow annual crops and the residual soil fertility may be relatively high for pasture establishment. Species that can respond to this higher soil fertility are therefore useful. Although anthracnose, cercospora leaf spot, RFB, phoma leaf spot, “die-back” (*Cylindrocladium* sp.), and little-leaf mycoplasma have been noted in accessions (J. M. Lenné, personal communication), plant diseases as a major constraint appear to be less important than for *C. brasilianum*. There is little doubt that problems of flowering and seed production have limited the potential of existing introductions in the region. Nonstoloniferous types such as CIAT 5065, which do not produce seed as an alternative persistence mechanism, quickly disappear under grazing (D. Thomas and R. P. de Andrade, unpublished data). Considering the preliminary results from regional evaluation trials in tropical America, Schultze-Kraft and Keller-Grein (1985) suggest that *C. macrocarpum* would have more potential in forest ecosystems. In the Cerrados, the *C. pubescens* x *C. macrocarpum* hybrids (Hutton, 1985), which have a high seed-production potential (CIAT, 1984), may be more promising, if they are disease resistant.

In the Colombian savannas (Llanos), a few accessions (particularly CIAT 5277) of *C. acutifolium* have shown promise. A number of accessions, including CIAT 5277, were tested at CPAC but they have not shown the same potential as in Colombia. The poorer vigor and/or low seed yields were probably related to a lack of adaptation to the longer dry season at CPAC.

**Evaluation at the Centro Nacional de Pesquisa de Gado de Corte (CNPGC)**

The total *Centrosema* collection at this institution numbers 326 accessions. When hybrids and *C. pubescens* types are excluded, the collection consists of 222 introductions (Table 6). According to Penteado (1986), about 200 accessions are at present under evaluation or in seed increase. Nearly 40% of the collection consists of unidentified species, and attempts are being made to resolve the taxonomic problems and identify the significant number of *Centrosema* species. Some of them have been recently named as *C. acutifolium*. Although the collection is variable, many species such as *C. pascuorum*, *C. plumieri*, *C. sagittatum*, *C. schottii*, and *C. virginianum*, are known to show poor
adaptation to acid, infertile soils. These species originate from, usually, more fertile soils with a pH higher than 5.5 and, therefore, without aluminum stress (Schultze-Kraft and Keller-Grein, 1985).

Thirty accessions have been evaluated in some detail in small plots. These consisted of 23 accessions of *C. acutifolium* and other, unnamed, *Centrosema* species, together with one accession of each of *C. macrocarpum*, *C. vexillatum*, *C. brasilianum*, *C. plumieri*, *C. sagittatum*, and *C. schottii* (M. I. de O. Penteado, unpublished data). On the basis of characters such as dry-matter yield, vigor, regrowth potential, flowering, dry-season tolerance, cold tolerance, pests, diseases, and morphology four accessions of *C. acutifolium* were selected as superior and were appreciably more productive than the commercial controls. These accessions are similar to *C. acutifolium* GC 350 (CIAT 15532) which is in advanced testing at CNPGC. This accession grew well at CPAC but failed to flower. Thirty accessions have also been established with *Brachiaria decumbens*, *Panicum maximum*, and *Brachiaria brizantha* cv. Marandú for grazing studies.

**Regional evaluation**

Species of *Centrosema* have been included in regional evaluation trials over a wide range of environmental conditions in the Cerrados (Table 7). Unfortunately, the numbers have been too few to define precisely the limits of adaptation and the potential of the various species of *Centrosema*. In general, the performance of *C. macrocarpum* and *C. acutifolium* has been poor, compared with that of *Stylosanthes* species. The exceptions were *C. acutifolium* GC 350 (CIAT 15532) at Amarante (Piauí) and Campo Grande (Mato Grosso do Sul), *C. acutifolium* GO 300 (CIAT 5609) at Goiânia (Goiás), and *C. macrocarpum* CIAT 5065 at Goiânia (Goiás) and Sete Lagoas (Minas Gerais). However, at every site there were problems of flowering and seed production. As at CPAC, symptoms of phoma leaf spot and cercospora leaf spot were present on plants at many locations. At Sete Lagoas, *C. brasilianum* and *C. pubescens* were also attacked by RFB. Frost damage was recorded at Campo Grande in Mato Grosso do Sul (M. I. de O. Penteado, unpublished data).
Table 7. Regional trials sites in the Cerrados of Brazil where species other than *C. pubescens* are being evaluated.

<table>
<thead>
<tr>
<th>Location (state or territory)</th>
<th>Establishment year</th>
<th>Latitude</th>
<th>Altitude (m)</th>
<th>Precipitation (mm/year)</th>
<th>Soil type&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Species</th>
<th>No. of accessions evaluated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boa Vista (Roraima)</td>
<td>1983</td>
<td>30°15' N</td>
<td>90</td>
<td>1740</td>
<td>YL</td>
<td><em>C. macrocarpum</em></td>
<td>1</td>
</tr>
<tr>
<td>Macapá (Amapá)</td>
<td>1983</td>
<td>0°3' N</td>
<td>15</td>
<td>2500</td>
<td>RYL</td>
<td><em>C. macrocarpum</em></td>
<td>1</td>
</tr>
<tr>
<td>Amarante (Piauí)</td>
<td>1983</td>
<td>8°12' S</td>
<td>210</td>
<td>900</td>
<td>RYL</td>
<td><em>C. macrocarpum</em></td>
<td>1</td>
</tr>
<tr>
<td>Barreiras (Bahia)</td>
<td>1982 and 1984</td>
<td>11°50' S</td>
<td>600</td>
<td>1214</td>
<td>RYL</td>
<td><em>C. macrocarpum</em></td>
<td>1</td>
</tr>
<tr>
<td>Vilhena (Rondônia)</td>
<td>1983</td>
<td>12°44' S</td>
<td>600</td>
<td>2000</td>
<td>RYL</td>
<td><em>C. macrocarpum</em></td>
<td>1</td>
</tr>
<tr>
<td>Planaltina (Distrito Federal)</td>
<td>1982</td>
<td>15°36' S</td>
<td>1170</td>
<td>1570</td>
<td>RYL</td>
<td><em>C. macrocarpum</em></td>
<td>1</td>
</tr>
<tr>
<td>Jaciara (Mato Grosso)</td>
<td>1983</td>
<td>15°36' S</td>
<td>219</td>
<td>1700</td>
<td>DRL</td>
<td><em>C. macrocarpum</em></td>
<td>1</td>
</tr>
<tr>
<td>Goiânia (Goiás)</td>
<td>1983</td>
<td>16°41' S</td>
<td>730</td>
<td>1443</td>
<td>DRL</td>
<td><em>C. macrocarpum</em></td>
<td>1</td>
</tr>
<tr>
<td>Jataí (Goiás)</td>
<td>1980</td>
<td>17°53' S</td>
<td>670</td>
<td>1650</td>
<td>DRL</td>
<td><em>C. macrocarpum</em></td>
<td>3</td>
</tr>
<tr>
<td>Capinópolis (Minas Gerais)</td>
<td>1983</td>
<td>18°41' S</td>
<td>621</td>
<td>1542</td>
<td>DRL</td>
<td><em>C. macrocarpum</em></td>
<td>1</td>
</tr>
<tr>
<td>Felixlândia (Minas Gerais)</td>
<td>1983</td>
<td>18°45' S</td>
<td>614</td>
<td>1235</td>
<td>RYL</td>
<td><em>C. macrocarpum</em></td>
<td>1</td>
</tr>
<tr>
<td>Sete Lagoas (Minas Gerais)</td>
<td>1983</td>
<td>19°28' S</td>
<td>740</td>
<td>1400</td>
<td>RYL</td>
<td><em>C. macrocarpum</em></td>
<td>2</td>
</tr>
<tr>
<td>Campo Grande (Mato Grosso do Sul)</td>
<td>1982</td>
<td>20°27' S</td>
<td>530</td>
<td>1600</td>
<td>QS</td>
<td><em>C. macrocarpum</em></td>
<td>1</td>
</tr>
<tr>
<td>São Carlos (São Paulo)</td>
<td>1983</td>
<td>22°01' S</td>
<td>854</td>
<td>1495</td>
<td>RYL</td>
<td><em>C. macrocarpum</em></td>
<td>1</td>
</tr>
</tbody>
</table>

<sup>a</sup> YL = Yellow Latossols; RYL = Red-Yellow Latossols; DRL = Dark Red Latossols; QS = Quartz Sands.

Future Research

*Centroxea pubescens*

*Centroxea pubescens* is a valuable legume with a high nutritive value and a potential for high seed yields. This latter characteristic, together with its stoloniferous habit, enables the species to persist well under grazing. Unfortunately, the potential of the commercial cultivars is not realized on acid, infertile soils because of a lack of adaptation. Schultze-Kraft and Keller-Grein (1985) and other workers have shown that variation in adaptation to acid soils exists within the species. A large collection of *C. pubescens* now exists in the CIAT germplasm bank and should be systematically evaluated at different sites. An alternative approach has been the improvement of the species through plant-breeding. Hybrids between *C. pubescens* and *C. macrocarpum* have been produced which combine acid-soil tolerance with a high seed-production potential (CIAT, 1984). These hybrids now require further testing over a wider range of environmental conditions in the region and should be subjected to defoliation, preferably under grazing conditions. Of particular interest will be the hybrids’ resistance to diseases such as phoma leaf spot and RFB.

Other species of *Centroxea*

Evaluation work with other species of the genus is in its infancy and should be extended to a wider range of environments within the Cerrados. The regional trial network, already operating in Brazil and organized jointly by EMBRAPA and CIAT, is an ideal vehicle for this purpose. As previously mentioned, *C. macrocarpum* may have more potential as a species for forest ecosystems. Increased efforts should therefore be given to hybrids with *C. pubescens*. Productive, RFB-resistant accessions of *C. brasilianum* are required, and there is a paucity of information on the effects of defoliation and grazing. It is noteworthy that relatively few introductions of this species have been tested at CNPGC, so that increasing the number of accessions at this major screening site and at other locations throughout the region is desirable. *Centroxea acutifolium* has not shown the promise in the Cerrados that it had demonstrated in the Colombian Llanos; however, only a few introductions were tested. There is a good case for testing the complete collection of *C. acutifolium* at different sites in the Cerrados. Of the many other species of *Centroxea*, only a few have been tested and the numbers of introductions have been small. It would be
worthwhile to increase the germplasm of these other species, for example, *C. arenarium*. The few accessions tested so far indicate that the species is vigorous on acid, infertile soils and has good disease resistance. It also possesses a growth habit which is unlike most other species of *Centrocoma*. Because its distribution appears restricted to Brazil (Schultz-Kraft et al., this volume), it should be well adapted to Cerrados conditions.

Finally, there is an obvious need to generate more long-term data on animal production, including the effects of stocking rate and grazing system. The value of the relatively few trials with *C. pubescens* was limited by their short duration and the tendency to use legume mixtures. For other species of the genus no data on animal performance exist for the Cerrados.

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Chapter 19

REGIONAL EXPERIENCE WITH CENTROSEMA:
SUBTROPICAL AMERICA

A. E. Vorano, A. E. Kretschmer, Jr., O. Royo Pallarés, and J. L. Pérego* 

Abstract

In subtropical regions, frosts and low temperatures are key limitations to the growth of Centrosema. In USA, evaluation has concentrated at Fort Pierce, Florida, where 338 accessions of 11 species have been tested. In Argentina, 42 accessions of 10 species have been evaluated at Mercedes, Corrientes; 33 accessions of 4 species at Salta, Salta; and 4 accessions of 2 species at Corrientes, Corrientes. In Paraguay, during the last two years, 22 Centrosema accessions from CIAT, Colombia, have been tested.

In Florida, C. virginianum IRFL 1935 was persistent, although it never outperformed siratro during 3 years of evaluation. In Argentina, C. virginianum is a promising species, and 40 Argentine accessions have been collected. In Northeast Argentina, the two most promising accessions, MeF 2909 and MeF 4307, are being multiplied, even though there are other subtropical legumes that exceed their performance. In Northwest Argentina, C. virginianum accessions LN 4 (Santo Domingo) and LIF 587 (Misionera) outperformed siratro, and have been proposed as legumes for subtropical pastures in the Umbral al Chaco region and temperate valleys of Northwest Argentina.

* Instituto Nacional de Tecnología Agropecuaria (INTA), Salta, Argentina; University of Florida, Institute of Food and Agricultural Sciences (IFAS), Agricultural Research and Education Center, Ft. Pierce, FL, USA; INTA, Mercedes, Corrientes, Argentina; and INTA, Mercedes, Corrientes, Argentina, respectively.

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In Paraguay, preliminary results obtained at the Estación Experimental Barrerito suggest that two *C. macrocarpum* accessions are promising. At Carmen del Paraná, accessions of *C. pubescens*, *C. schiedeanum*, and a *C. pubescens* x *C. macrocarpum* hybrid were outstanding.

**Introduction**

Most *Centrosema* germplasm in subtropical South America has been tested at INTA’s (Instituto Nacional de Tecnología Agropecuaria) experiment stations in subtropical Argentina, and some evaluations have also been carried out in Paraguay. In subtropical North America, *Centrosema* spp. have been evaluated almost exclusively in southern Florida by the Agricultural Research and Education Center, Fort Pierce (ARECFP), Institute of Food and Agricultural Sciences (IFAS), University of Florida. A few studies with limited success have been carried out in Louisiana (A. M. Thro, personal communication) and Texas.

There are two species native to the North American subtropics (Schultze-Kraft et al., this volume). *Centrosema virginianum* is common in some subtropical parts of Mexico, particularly in the eastern lowlands. In the USA, it is distributed from Maryland south to Florida, through the other Gulf Coast States, west to Texas, and north to Oklahoma. At least 40 accessions from the USA exist in the main germplasm banks. *Centrosema arenicola* is restricted to central Florida (Gainesville), south along the west coast, and through the central ridge section toward Lake Wales. Its habitat is characterized by well-drained, deep, and sandy soils, with sparse scrub of oak and palmetto. No significant evaluation has been conducted with *C. arenicola* in subtropical America.

*Centrosema virginianum* is also widespread in subtropical South America (Schultze-Kraft et al., this volume). The first systematic collections of native *C. virginianum* germplasm were made in northwest Argentina in 1975 (Vorano, 1983). Previous work was largely confined to the collection of herbarium specimens for floristic surveys and taxonomic studies (Burkart, 1943; Cabrera, 1978), although an accession of *C. virginianum* was sent by INTA to Australia in 1970. In 1977, germplasm of *C. pubescens* and *C. plumieri* was introduced to northwest Argentina from Australia. Whether other exotic germplasm was introduced and screened in Argentina at an earlier date is not known.
Collecting native germplasm in northeast Argentina, Royo Pallarés et al. (1980) gathered seed from five *C. virginianum* samples and provided information on the preliminary characterization of these materials.

**Regional Characteristics**

The South American subtropics lie between the Tropic of Capricorn and latitude 30° S (Figure 1). They cover about 180 million ha and are characterized by a range of soils, climates, and production systems. The South American subtropical ecosystems have not been well defined as a whole, but, according to Royo Pallarés (1975) and Vargas G. and Vorano (1983), regions of interest for work with *Centrosoema* are as follows:

- temperate valleys such as the Argentine valleys of Jujuy, Lerma, and Sianca, which receive about 700 mm annual rainfall;
- subtropical forest with 400-2000 mm annual rainfall;
- Gran Chaco region, which comprises the plains between the Andes and the Paraguay and Paraná Rivers, and receives 500-1000 mm annual rainfall;
- Campos Sabanas region, which is poorly drained, with no bush vegetation, and 1000-1500 mm annual rainfall; and
- humid evergreen forest with well-drained soils and 1500-2500 mm annual rainfall.

The northern half of Mexico is located within the latitudinal subtropics, but about three quarters of this region is elevated above 1000 m and is unsuitable for growing subtropical legumes. The western foothills and Pacific lowlands are mainly dry (100-500 mm annual rainfall), and *C. virginianum* occurs naturally only in rare, favored sites such as near Alamos, Sonora, at latitude 27° N. The eastern subtropical lowlands of Mexico have a more favorable rainfall (400-800 mm), but a mid-summer drought commonly reduces rainfall effectiveness. *Centrosoema virginianum* is common in this area. In the USA, truly subtropical climates are restricted to the southern parts of Florida, Texas, and California, together with a narrow coastal strip at the extreme south of the remaining Gulf Coast States.
The subtropical region is characterized by frosts that affect plant growth. The frosts occur once or twice a year near the Tropic of Capricorn and more than 30 times a year near 30° S. Another characteristic of the subtropics is that there is often no clearly defined rainy season. Rain occurs normally almost every month, with higher rainfall in the warmer months and lower rainfall in winter. Data presented in Table 1 are examples of the climatic characteristics of the American subtropics.

The major climatic limitations to Centrosema's adaptation are frosts and low winter temperatures which reduce plant growth (Clements, this volume).
<table>
<thead>
<tr>
<th>Site and parameter</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Annual total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fort Pierce (27°25' N, 80°24' W)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall (mm)</td>
<td>55</td>
<td>75</td>
<td>77</td>
<td>62</td>
<td>136</td>
<td>190</td>
<td>185</td>
<td>168</td>
<td>204</td>
<td>177</td>
<td>57</td>
<td>52</td>
<td>1438</td>
</tr>
<tr>
<td>(%)</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>9</td>
<td>13</td>
<td>13</td>
<td>12</td>
<td>14</td>
<td>12</td>
<td>4</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>Max. temp. (°C)</td>
<td>23</td>
<td>25</td>
<td>26</td>
<td>28</td>
<td>30</td>
<td>32</td>
<td>32</td>
<td>33</td>
<td>32</td>
<td>29</td>
<td>27</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Min. temp. (°C)</td>
<td>10</td>
<td>12</td>
<td>13</td>
<td>16</td>
<td>19</td>
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<td>22</td>
<td>23</td>
<td>22</td>
<td>19</td>
<td>16</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td><strong>Mercedes (29°01' S, 58°01' W)</strong></td>
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</tr>
<tr>
<td>Rainfall (mm)</td>
<td>156</td>
<td>192</td>
<td>169</td>
<td>153</td>
<td>117</td>
<td>68</td>
<td>64</td>
<td>71</td>
<td>110</td>
<td>150</td>
<td>144</td>
<td>114</td>
<td>1512</td>
</tr>
<tr>
<td>(%)</td>
<td>10</td>
<td>12</td>
<td>11</td>
<td>10</td>
<td>7</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>7</td>
<td>9</td>
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<td>7</td>
<td>100</td>
</tr>
<tr>
<td>Max. temp. (°C)</td>
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<td>30</td>
<td>28</td>
<td>25</td>
<td>22</td>
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<td>20</td>
<td>22</td>
<td>25</td>
<td>27</td>
<td>31</td>
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</tr>
<tr>
<td>Min. temp. (°C)</td>
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<td>19</td>
<td>17</td>
<td>14</td>
<td>12</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>11</td>
<td>141</td>
<td>16</td>
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<tr>
<td><strong>Salta (24°51' S, 65°29' W)</strong></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Rainfall (mm)</td>
<td>176</td>
<td>148</td>
<td>93</td>
<td>24</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>25</td>
<td>61</td>
<td>121</td>
<td>664</td>
</tr>
<tr>
<td>(%)</td>
<td>26</td>
<td>22</td>
<td>14</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>18</td>
<td>100</td>
</tr>
<tr>
<td>Max. temp. (°C)</td>
<td>28</td>
<td>26</td>
<td>25</td>
<td>23</td>
<td>21</td>
<td>19</td>
<td>20</td>
<td>22</td>
<td>25</td>
<td>26</td>
<td>28</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Min. temp. (°C)</td>
<td>15</td>
<td>15</td>
<td>13</td>
<td>10</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>11</td>
<td>14</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

SOURCE: Unpublished data from local meteorological stations.
Experience with *Centrosema* in Florida, USA

**Germlasm and initial evaluations**

The ARECFP germplasm bank currently holds 270 *Centrosema* accessions, many of which are also maintained at the United States Department of Agriculture, Centro Internacional de Agricultura Tropical (CIAT), Colombia, and Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia. A total of 338 accessions of 11 species has been evaluated at Fort Pierce. Preliminary evaluation in 1960 showed that many of the accessions (including commercial *C. pubescens* from Australia) persisted through the south Florida winter (Kretschmer, 1962). Such initial evaluations are ongoing activities at ARECFP with many grass and legume genera. Cursory examinations are made of general plant growth, disease and insect susceptibility, flowering dates, and seed production.

**Characterization**

In order to determine the agronomic and morphological characteristics of over 50 *Centrosema* accessions of various species, a space-planted plant introduction trial with three replications was carried out (Kretschmer, 1977). Total yields over 2 years of the 29 *C. pubescens* accessions ranged from 900 to 6400 g/plant and flowering began in autumn after 291-340 days. No accessions produced ripe seed by December, while 17 accessions had ripe seed on April 12. This and other trials showed that the dates of first flower in spring are earlier and the amount of seed produced is higher when the winters are milder.

However, one major limitation to using *C. pubescens* in south Florida is inadequate seed production. *Centrosema schiedeanum* cv. Belalto was less productive than the commercial variety of *C. pubescens* in the cold season, showed less adventitious growth, flowered later in autumn, and produced less seed. The same was observed for *C. plumieri* entries. Frosts can cause death in established plants of all three species, thus preventing seed production in spring.

Yields of the most productive *C. virginianum* accessions were similar to those of the less productive of *C. pubescens* accessions, while initial flowering occurred much earlier in the autumn (260 to 313 days). Seed production of this species is adequate and commercially feasible. Studies of low-crown ecotypes are suggested for future research because...
Regional experience with Centrosema: subtropical America

of their advantage of being protected from even the most severe of south Florida's winters.

Mineral nutrition

Considerable research has been carried out on the response of commercial C. pubescens to calcium and phosphorus applications (Snyder and Kretschmer, 1974 and 1983; Snyder et al., 1978). The Spodosol used is typical of many soils in Florida which are light textured, very acid (pH 4.5 to 5), and low in total P and Ca, but low in Al. Maximum Centrosema yields were obtained with 2000-3000 kg of lime per ha, depending on soil P level. The estimated optimal P application levels ranged from 45 to 60 kg/ha, depending on the amount of lime that was applied.

Advanced trials with commercial C. pubescens (centro)

Studies have been conducted with commercial C. pubescens to determine its persistence in different grass mixtures (Kretschmer and Snyder, 1982). In one study, growth during the establishment year was lower for centro than for Macroptilium atropurpureum cv. Siratro and Stylosanthes spp. In cutting trials during the 1960s, annual yields of commercial centro in association with pangola grass (Digitaria decumbens) ranged from 7 to 10 t dry matter/ha, with a crude protein content of 7.4%-9.3%. Associations of siratro and S. humilis produced similar results (Kretschmer, 1977). In 1975 and 1976, mixtures of seven tropical legumes, including centro, and six grasses were compared. The annual yields of centro in 1975 were about 16 t/ha, that is, equal to yields of S. guianensis cv. Cook and much higher than those of S. guianensis cv. Endeavour, siratro, Neonotonia wightii cv. Tinaroo, Desmodium heterocarpon cv. Florida, and S. hamata cv. Verano (Kretschmer and Snyder, 1982). In 1976, centro plus grass produced 10.9 t/ha, outyielding the rest of the legumes, except D. heterocarpon. The high annual production from mixtures with centro was a result of good growing conditions in spring and autumn.

All plots were cut in July 1976 in order to determine the effect of deferred autumnal use of these legume-grass mixtures on yield, protein content, and digestibility. Half of each plot was harvested again in September and December, and the other half only in December (deferred). The regrowth interval of the first half was, therefore, almost 12 weeks, whereas the regrowth interval of the other, deferred, half was
22 weeks. The respective yields were 2.0 and 5.6 t/ha or 0.17 and 0.25 t dry matter/ha per week of regrowth. Crude-protein (CP) content of centro-grass mixtures was 14% and 15%, respectively, and in vitro organic-matter digestibility (IVOMD) was 54% and 42%, respectively. The total crude protein recovered was 280 and 840 kg/ha and total digestible nutrients were 1080 and 2350 kg/ha, respectively. It was concluded that, under Florida’s conditions, the autumnal deferred use of centro-grass mixtures would be a valuable management tool (Kretschmer and Snyder, 1982).

Based on previous evaluations, a 3-year small-plot experiment was begun in 1979 to determine the persistence of Centrosema spp. in association with pangola grass under cutting. The method used to determine persistence was a 1-to-9 rating system in which plot cover by Centrosema plants was estimated according to a scale where 1 = no plants; and 9 = 100% coverage. The Centrosema germplasm that was tested included seven C. pubescens accessions, five C. virginianum accessions, eight C. pascuorum accessions, and three C. schottii accessions. Rating-averages for species, for commercial centro, and for the best C. virginianum accession (IRFL 1935) were compared with siratro (Table 2).

Commercial C. pubescens reached an estimated coverage of 50% in June 1980 and 1981, and then decreased to 10% or less. It was slightly better than the average of the seven C. pubescens accessions; no other C. pubescens accession was consistently superior to the commercial variety. Centrosema virginianum was the most persistent Centrosema

<table>
<thead>
<tr>
<th>Species</th>
<th>Nov</th>
<th>Mar</th>
<th>June</th>
<th>Sept</th>
<th>June</th>
<th>Sept</th>
<th>Dec</th>
<th>June</th>
<th>Nov</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. pascuorum (8 accessions)</td>
<td>2.8</td>
<td>2.4</td>
<td>3.0</td>
<td>3.1</td>
<td>1.7</td>
<td>2.2</td>
<td>1.0</td>
<td>1.5</td>
<td>1.2</td>
</tr>
<tr>
<td>C. pubescens (7 accessions)</td>
<td>2.4</td>
<td>3.2</td>
<td>3.1</td>
<td>3.5</td>
<td>4.9</td>
<td>1.7</td>
<td>1.6</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>C. schottii (3 accessions)</td>
<td>2.0</td>
<td>2.5</td>
<td>1.4</td>
<td>2.7</td>
<td>3.3</td>
<td>1.0</td>
<td>1.1</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>C. virginianum (4 accessions)</td>
<td>3.0</td>
<td>4.6</td>
<td>4.6</td>
<td>3.3</td>
<td>4.3</td>
<td>2.7</td>
<td>3.5</td>
<td>2.6</td>
<td>2.7</td>
</tr>
<tr>
<td>C. pubescens commercial (control)</td>
<td>2.8</td>
<td>3.8</td>
<td>4.8</td>
<td>3.8</td>
<td>5.8</td>
<td>2.3</td>
<td>2.0</td>
<td>1.8</td>
<td>1.5</td>
</tr>
<tr>
<td>C. virginianum IRFL 1935 (control)</td>
<td>4.3</td>
<td>6.5</td>
<td>7.8</td>
<td>5.3</td>
<td>7.8</td>
<td>5.5</td>
<td>6.5</td>
<td>4.6</td>
<td>4.6</td>
</tr>
<tr>
<td>M. atropurpureum cv. Siratro (control)</td>
<td>4.0</td>
<td>2.8</td>
<td>6.0</td>
<td>8.0</td>
<td>8.0</td>
<td>8.8</td>
<td>7.8</td>
<td>7.5</td>
<td>8.0</td>
</tr>
</tbody>
</table>

a. Rating scale: 1 = no plants; 2, 3, 4 = low intermediate; 5 = 50%; 6, 7, 8 = high intermediate; 9 = 100% plot cover.
b. Values throughout the table are means for the number of accessions indicated in parentheses.

SOURCE: A. E. Kretschmer, Jr., unpublished data.

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species, the outstanding accession being the control IRFL 1935. This accession had plant populations significantly higher than those of commercial *C. pubescens*, and maintained about 50% coverage at all evaluation periods and suffered no reduction with time. *Centroserma pascuorum* and *C. schottii* were not competitive with pangola grass. No *Centroserma* accession was as persistent as siratro which reached almost 75% coverage after 3 years.

Crude-protein content of siratro, commercial *C. pubescens*, and *C. virginianum* IRFL 1935 from some harvested plots ranged 13%-19%, 15%-20%, and 11%-18%, respectively; and IVOMD ranged 50%-59%, 49%-53%, and 46%-56%, respectively. Crude-protein and IVOMD of the associated pangola grass ranged 2.8%-5.6% and 35%-52%, respectively.

**Experience with *Centroserma* in Paraguay**

The more or less continuous and systematic introduction of forage germplasm into subtropical South America dates back to the early 1950s. The Instituto Agronómico Nacional in Caacupé, Paraguay, was one of the first institutions to evaluate *Centroserma*. The Servicio Técnico Interamericano de Cooperación Agrícola introduced and evaluated *C. pubescens* on sandy Ultisols. This species was classified among the best performing legumes and was sporadically used as a cover crop in citrus plantations.

As a result of later *Centroserma* evaluations (under the auspices of the World Bank), Milford (1969) recommended that commercial *C. pubescens* be planted in association with *Panicum maximum* (Colonial) in “slashed” forests with over 1500 mm annual rainfall. At present, trials of *Centroserma* are being carried out by the Programa Nacional de Investigación y Extensión Ganadera (PRONIEGA) of the Ministerio de Agricultura y Ganadería, within the International Tropical Pastures Evaluation Network (RIEPT). Evaluation is conducted principally at two sites, Barrerito and Carmen del Paraná.

*Centroserma acutifolium*, *C. brasilianum*, and *C. macrocarpum* are being evaluated at the Estación Experimental Barrerito which is located in a “campos” ecosystem that receives 1400 mm annual rainfall and has an annual average temperature of 23 °C. *Centroserma macrocarpum* was superior in adaptation and forage production but produced no seed and was susceptible to frosts although showing good regrowth in spring.
Centrosema: biology, agronomy, and utilization

(PRONIEGA, 1985 and 1986). In cutting trials that measured summer-winter productivity, C. macrocarpum CIAT 5062 and CIAT 5065 had the highest yields of 15 legumes and were outyielded only by commercial Pueraria phaseoloides.

Twenty-two accessions of several Centrosema species are also being evaluated at Campo Experimental Carmen del Paraná. This site is again located in a campos ecosystem, 330 km south of Asunción, receives an annual rainfall of 1750 mm, and has an annual average temperature of 21 °C. Accessions that have been classified as promising are, at present, C. pubescens CIAT 442, C. schiedeanum cv. Belalto, and hybrids CIAT 5930, CIAT 5932, CIAT 5933, and CIAT 5934 (C. pubescens x C. macrocarpum). In a trial to measure the productivity of 32 forage legumes, the highest yields were obtained with C. macrocarpum CIAT 5620 and CIAT 5744, hybrids CIAT 5930 and CIAT 5932, and C. pubescens CIAT 5126 (PRONIEGA, 1986).

Under the restricted drainage conditions of the Campo Experimental Eusebio Ayala, the outstanding accessions were C. brasili-anum CIAT 5234 and C. acutifolium CIAT 5278 (Valinotti and Molas, 1986; PRONIEGA, 1986).

No tropical legume has so far been recommended for planting in Paraguay. However, in the opinion of PRONIEGA staff, Centrosema is a genus within which useful species can be found.

Experience with Centrosema in Rio Grande do Sul, Brazil

In southern Brazil, the Centrosema genus has received very little evaluation (J. Saibro, personal communication). Only C. pubescens was introduced and its performance was limited by severe frosts. It is not being recommended for planting and no evaluations are being conducted. Centrosema virginianum occurs naturally in Rio Grande do Sul (Schultze-Kraft et al., this volume) but living collections appear not to have been made.
Regional experience with Centroema: subtropical America

Experience with Centroema in Argentina

Northwest Argentina

As part of the Agricultural Development Project NOA X-ARG/76/003-FAO/INTA, a network of introduction nurseries was established for the five provinces of Northwest Argentina. They represent a surface area of about 455,000 km². Four *C. pubescens* accessions, including cv. Belalto (which is now considered to be *C. schiedeanum*) and one *C. plumieri* accession, were evaluated in a replicated trial at three sites in northern Salta province (Orán, El Castigado, and Coronel Cornejo). Subsequently, research was concentrated on the collection and evaluation of native *C. virginianum* germplasm.

**Evaluation of *C. pubescens* and *C. plumieri***. *Centroema pubescens* produced a dense, 50-cm-tall, soil cover 4.5 months after planting. Plants were leafy, with abundant pilosity—which probably caused the cattle to prefer perennial soybean (*Neonotonia wightii*) and siratro. *Centroema* flowered well but late (end of April) so that pods did not reach maturity. Tolerance to frosts was low, and was observed only when plants were well established and frosts were light (-0.5 °C). The severe frosts that can occur in Orán reduced plant populations by eliminating those plants that had immature crowns. Damage to mature plants by frosts at -3 to -5 °C was characterized by either no regrowth or partial regrowth from those crown buds that survived. *Centroema pubescens* tolerated short dry periods during the cold season only if the plants had grown well during the rainy and warm season. Prolonged dry periods, however, stopped growth and caused plants to shed leaves.

The best growth was observed on deep and fertile alluvial soils, with over 18 ppm available P, and a pH of 7.0-7.5. These soils are used for citrus, sugarcane, and vegetables. When inoculated with Australian *Rhizobium* strains, *C. pubescens* nodulated very well in these soils. Establishment was good in well-prepared soils. Where soil preparation was light, establishment was slower and coverage was incomplete.

*Centroema pubescens* also showed tolerance to partial flooding, outperforming siratro and perennial soybean, although not *Vigna luteola*, *Melilotus alba*, and *Macroptilium lathyroides*.

Regarding *C. plumieri*, only one accession was evaluated in Coronel Cornejo and Orán. It established and grew more slowly than *C.
pubescens. It flowered sparsely in early May and produced no seed. Because of severe frosts of -4 °C, almost no persistence was observed during the second year. The few surviving plants of the plot were eliminated by the strong summer weed competition that occurs throughout all subtropical Argentina.

*Centrosea pubescens* (including cv. Belalto, now considered to be *C. schiedeanum*) and *C. plumieri* are poorly adapted and have limited, if any, possibilities in Northwest Argentina. In contrast, other introduced and native legumes show outstanding performance in the temperate valleys of Jujuy, Lerma, and Sianca and in the Umbral al Chaco (the most western part of the great Chaco region).

**Evaluation of native *C. virginianum* germplasm.** Between 1975 and 1980, 27 accessions of *C. virginianum* were collected in Northwest Argentina and three in south Bolivia (Vorano, 1983). These accessions were first examined in a greenhouse and in pots in the field. The six most leafy and frost-tolerant accessions, together with the control accession LIF 587 (Misionera), a vigorous, leafy ecotype from Zaimán, Misiones Province (S. Lacorte, personal communication), were selected for further testing.

They were evaluated in small plots with two replications for 3 years (1981-83). Observations were made on vigor, leafiness, frost tolerance, regrowth ability after frosts and at the beginning of the growing season, seed production, and disease and insect attacks. A 0-to-4 scale was used, where 4 signified the best relative performance. The sum of all ratings was used as a discriminative criterion to select accessions for further intensive evaluations (Table 3). The outstanding accessions were Santo Domingo (LN 4) and Misionera (LIF 587). The nutritional quality of the harvested material was analyzed in late February to early March. While no large differences between the seven accessions were observed, LN 4 had the highest forage-quality values (Table 4).

Macroplots for further evaluation and seed production were established with the outstanding accessions LN 4 and LIF 587. In spite of high dehiscence, the accessions produced 186 and 228 kg seed/ha, respectively. No differences were observed between accessions in acceptability to cattle under mob-grazing. Both showed resistance to fire which was used once a year to control weeds and undesirable grasses. They also showed tolerance to flooding in a clayey and cold soil with internal and external drainage problems. In this same paddock, siratro disappeared during the second year because it was unable to resist
Table 3. Evaluation, according to a rating scale\(^a\), of seven *Centrocoma virginianum* accessions at Salta, Argentina (3-year average).

<table>
<thead>
<tr>
<th>Accession</th>
<th>Vigor</th>
<th>Leafiness</th>
<th>Regrowth</th>
<th>Tolerance to frosts</th>
<th>Seed production</th>
<th>Cumulative score</th>
</tr>
</thead>
<tbody>
<tr>
<td>LN 4 (Santo Domingo)</td>
<td>4.0</td>
<td>3.5</td>
<td>4.0</td>
<td>3.5</td>
<td>4.0</td>
<td>19.0</td>
</tr>
<tr>
<td>LN 229 (Leales)</td>
<td>2.5</td>
<td>2.5</td>
<td>3.0</td>
<td>1.5</td>
<td>2.5</td>
<td>12.0</td>
</tr>
<tr>
<td>LN 780 (Castellanos)</td>
<td>3.0</td>
<td>3.0</td>
<td>2.5</td>
<td>4.0</td>
<td>3.0</td>
<td>15.5</td>
</tr>
<tr>
<td>LN 859 (Casino)</td>
<td>3.0</td>
<td>2.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.5</td>
<td>14.5</td>
</tr>
<tr>
<td>LN 962 (Yatasto)</td>
<td>2.5</td>
<td>2.5</td>
<td>3.0</td>
<td>1.5</td>
<td>2.5</td>
<td>12.0</td>
</tr>
<tr>
<td>LN 965 (Tres Cerritos)</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>3.5</td>
<td>2.5</td>
<td>12.0</td>
</tr>
<tr>
<td>LIF 587 (Misionera)</td>
<td>4.0</td>
<td>4.0</td>
<td>2.5</td>
<td>1.5</td>
<td>4.0</td>
<td>16.0</td>
</tr>
</tbody>
</table>

\(^a\) Rating scale: 0 = very poor; 1 = poor; 2 = intermediate; 3 = good; 4 = excellent.

SOURCE: A. E. Vorano, unpublished data.

Table 4. Forage quality of seven *Centrocoma virginianum* accessions grown at Salta, Argentina.

<table>
<thead>
<tr>
<th>Accession</th>
<th>Crude protein (%)</th>
<th>Ether extract (%)</th>
<th>Acid detergent fiber (%)</th>
<th>IVOMD(^a) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LN 4 (Santo Domingo)</td>
<td>24.9</td>
<td>4.6</td>
<td>26.0</td>
<td>67.8</td>
</tr>
<tr>
<td>LN 229 (Leales)</td>
<td>21.7</td>
<td>4.3</td>
<td>26.2</td>
<td>65.2</td>
</tr>
<tr>
<td>LN 780 (Castellanos)</td>
<td>23.9</td>
<td>4.3</td>
<td>25.9</td>
<td>66.8</td>
</tr>
<tr>
<td>LN 859 (Casino)</td>
<td>23.0</td>
<td>4.1</td>
<td>28.2</td>
<td>64.5</td>
</tr>
<tr>
<td>LN 962 (Yatasto)</td>
<td>22.6</td>
<td>3.9</td>
<td>28.2</td>
<td>65.1</td>
</tr>
<tr>
<td>LN 965 (Tres Cerritos)</td>
<td>20.4</td>
<td>4.2</td>
<td>29.7</td>
<td>64.5</td>
</tr>
<tr>
<td>LIF 587 (Misionera)</td>
<td>21.9</td>
<td>4.2</td>
<td>30.4</td>
<td>65.3</td>
</tr>
</tbody>
</table>

\(^a\) IVOMD = In vitro organic-matter digestibility.

SOURCE: A. E. Vorano, unpublished data.
floodling or attacks from *Rhizoctonia* and *Oidium* fungi. *Centroama virginianum* accessions were not affected by these fungi or by insects.

In grazing trials of *C. virginianum* in mixtures with grasses of contrasting growth habit, accession LN 4 was planted with *Chloris gayana* (caespitose and highly competitive) and *Sorghum alnum* (erect). These two grasses were intensively used in Northwest Argentina for upland cultivated pastures at the time of trial establishment. During the first year, the mixture with *C. gayana* was satisfactory, with 75% of the area covered by the grass and 25% by *Centroama*. During the second year the grass eliminated the legume, and by the end of the growing season only isolated weak *Centroama* plants were left. These, in turn, disappeared at the beginning of the third growing season. The mixture with *S. alnum*, however, was compatible and stable. The proportion during the first year was 60% grass and 40% legume; it remained stable until the third year when *Centroama* started to increase after *S. alnum* was attacked by bacteria. *Centroama virginianum* seeded profusely, disseminated by seed, and so colonized sites neighboring the original plot.

In 1984, a 1-ha pasture of *C. virginianum* LN 4 in association with green panic (*Panicum maximum* var. *trichoglume*) was established. Simultaneously, LN 4 was sown at a seeding rate of 2 kg/ha into an adjacent hectare of native grasses, mainly *Paspalum* spp. From 1985 onward, the paddocks were rotationally grazed in order to evaluate the effect of cattle on the pastures. *Centroama* proved to be persistent. Its persistence was higher than that commonly experienced with siratro which was, until then, the most promising legume in the region. In the native grass pasture, *C. virginianum* spread vigorously, contributing as much as 20% of the forage. Forage quality was therefore excellent. Data presented in Table 5 were obtained from forage samples harvested in late February.

**Northeast Argentina**

*Species evaluation.* Probably the first *C. pubescens* accession tested in this region was Sombrerito Forrajera (SF 609), introduced by the Estación Experimental Agropecuaria Sombrerito (Corrientes) of INTA. Vallejos (1981) commented, “It produces abundant green forage but its cycle is too long, exceeding 256 days, thus limiting seed production.” More recently, at the Estación Experimental Agropecuaria of INTA in Corrientes, Goldfarb and Gándara (n.d.) evaluated four *Centroama* accessions on Molisols: *C. pubescens* SF 8131 (CIAT 438), *C.
Table 5. Forage quality of grazed pastures\textsuperscript{a} containing *Centro sperma virginianum* LN 4 (Santo Domingo), green panic, and native *Paspalum* spp. at Salta, Argentina.

<table>
<thead>
<tr>
<th>Species</th>
<th>Crude protein (%)</th>
<th>Ether extract (%)</th>
<th>Acid detergent fiber (%)</th>
<th>IVOMD\textsuperscript{b} (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. virginianum</em> LN 4 (Santo Domingo)</td>
<td>26.1</td>
<td>4.7</td>
<td>25.3</td>
<td>68.1</td>
</tr>
<tr>
<td><em>Panicum maximum</em> var. <em>trichoglume</em> (green panic)</td>
<td>9.6</td>
<td>1.2</td>
<td>39.2</td>
<td>52.0</td>
</tr>
<tr>
<td><em>Paspalum</em> spp.</td>
<td>10.0</td>
<td>1.8</td>
<td>35.8</td>
<td>53.0</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Samples were harvested in late February 1985.
\textsuperscript{b} IVOMD = In vitro organic-matter digestibility.

SOURCE: A. E. Vorano, unpublished data.

*virginianum* SF 8157, *C. virginianum* SF 837 (CPATU 376), and *C. virginianum* SF 838 (CPATU 377). Records were taken of phenology, pest and disease incidence, yield, and other characteristics. It was concluded that frosts and low seed production were the most limiting factors and that *Centro sperma* was unlikely to be recommended in the near future. There are no *Centro sperma* research priorities for the northwestern part of the Corrientes Province.

However, within the same ecological region, Ciotti (1986) evaluated the accessions *C. brasili anum* CIAT 5234 and *C. macrocarpum* CIAT 5065 in a sandy soil on the field station of the Facultad de Ciencias Agrarias, Universidad Nacional del Nordeste, located at 27°30' S and 59°10' W. Both species showed rapid establishment and flowered abundantly but produced no seed during the first year. *Centro sperma brasili anum* produced seed during the winter season of the second year and was less affected by frosts and cold temperatures than *C. macrocarpum*. This work suggests that *C. brasili anum* CIAT 5234 may have potential for the Corrientes region.

In the most southern part of the campos ecosystem, the Estación Experimental Agropecuaria Mercedes of INTA evaluated about 4800 forage germplasm accessions between 1960 and 1986. The station is located in the central region of the Corrientes Province. This region is slightly undulating, with rocky outcrops, and is covered by herbaceous
vegetation (no shrubs) that consist mostly of grasses such as *Paspalum notatum*, *Andropogon lateralis*, and *Sporobolus indicus*. Soils are superficial hydromorphic Planosols deficient in phosphorus, and Mollisols.

Forty-two *Centrosea* accessions were evaluated: *C. pubescens* (8 accessions), *C. virginianum* (13), *C. macrocarpum* (6), *C. sagittatum* (3), *C. brasiliun* (2), *C. plumieri* (2), *C. schiedeanum* (1), *C. schottii* (1), *C. arenarium* (1), and unidentified *Centrosea* spp. (5). These materials were obtained by correspondence, visits to experiment stations, and germplasm collection trips. The first preliminary evaluations showed that *C. virginianum* was superior to the other *Centrosea* species evaluated, including *C. pubescens*, with respect to growth, persistence, and productivity (Pérego and Royo Pallarés, 1982; Royo Pallarés and Pérego, 1981).

*Centrosea virginianum* evaluations. Ten *C. virginianum* accessions and one of each of *C. brasiliun* and *C. pubescens* were observed in small plots for 3 years. The trial was conducted at two sites (Mercedes and Virasoro), but data given (Table 6) refer only to Mercedes.

No disease problems were found with any of the accessions. The most promising accessions, especially for regrowth capacity, were MeF 4307 and MeF 2909. Accessions MeF 2943 and MeF 3034 were outstanding for vigor, leafiness, and seed production, but their regrowth capacity was lower than that of MeF 4307 and MeF 2909. MeF 2909 and MeF 4307, however, also showed high seed production which, in general, was severely affected by summer droughts that occurred at the beginning of seed-setting. Insect attacks on pods were not observed. Pods showed a high degree of dehiscence. Except for accessions *C. virginianum* MeF 3707, MeF 4307, and MeF 2909, and *C. pubescens* MeF 4416, all the materials were highly susceptible to summer droughts, reacting with almost complete defoliation. Tolerant accessions showed leaflet curling. Pod-setting was seasonally defined and began in March to April for *C. virginianum*, and May for *C. brasiliun* MeF 4434. Pod ripening in MeF 4434 was affected by the first frosts.

*Centrosea virginianum* is currently being evaluated in association with *Digitaria decumbens* (pangola grass) and under two grazing pressures during the summer period at the Estación Experimental Agropecuaria Mercedes. This association is being compared with associations of the same grass with the legumes *Galactia striata*, *Vigna adenantha*, and *Lotononis bainesii*. In these mixtures, legume content decreased rapidly, whereas *C. virginianum* increased its contribution
Table 6. Evaluation, according to a rating scale\(^a\), of 10 *Centrosema virginianum* accessions and one each of *C. brasiliannum* and *C. pubescens* at Mercedes, Corrientes, Argentina (3-year average).

<table>
<thead>
<tr>
<th>Species</th>
<th>MeF no.</th>
<th>Growth vigor(^a)</th>
<th>Leafiness(^a)</th>
<th>Frost tolerance(^a)</th>
<th>Drought tolerance(^a)</th>
<th>Regrowth capacity(^a)</th>
<th>Seed production</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>C. virginianum</em></td>
<td>2909</td>
<td>3.3</td>
<td>2.7</td>
<td>1.0</td>
<td>3.0</td>
<td>4.0</td>
<td>Mar-Apr 240</td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>2943</td>
<td>3.2</td>
<td>3.3</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>April 384</td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>3034</td>
<td>3.3</td>
<td>3.3</td>
<td>1.0</td>
<td>2.0</td>
<td>2.0</td>
<td>April 297</td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>3387</td>
<td>1.8</td>
<td>1.8</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>April 57</td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>3707</td>
<td>1.4</td>
<td>1.3</td>
<td>1.0</td>
<td>5.0</td>
<td>2.0</td>
<td>April 219</td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>3728</td>
<td>1.6</td>
<td>1.2</td>
<td>1.0</td>
<td>2.0</td>
<td>1.0</td>
<td>April 63</td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>3733</td>
<td>2.1</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>2.0</td>
<td>April 81</td>
</tr>
<tr>
<td><em>C. virginianum</em> (CIAT 5104)</td>
<td>4116</td>
<td>2.5</td>
<td>2.9</td>
<td>1.0</td>
<td>1.0</td>
<td>2.0</td>
<td>Mar-Apr 47</td>
</tr>
<tr>
<td><em>C. virginianum</em> (IRFL 1935)</td>
<td>4220</td>
<td>1.9</td>
<td>2.1</td>
<td>1.0</td>
<td>1.0</td>
<td>2.0</td>
<td>Mar-Apr 26</td>
</tr>
<tr>
<td><em>C. virginianum</em></td>
<td>4307</td>
<td>3.4</td>
<td>3.2</td>
<td>1.0</td>
<td>3.0</td>
<td>3.0</td>
<td>April 383</td>
</tr>
<tr>
<td><em>C. pubescens</em></td>
<td>4416</td>
<td>1.3</td>
<td>1.8</td>
<td>1.0</td>
<td>4.0</td>
<td>1.0</td>
<td>Feb-Apr 5</td>
</tr>
<tr>
<td><em>C. brasiliannum</em></td>
<td>4434</td>
<td>1.7</td>
<td>1.7</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>May 0</td>
</tr>
</tbody>
</table>

\(^a\) Rating scale, where 1 = deficient; and 5 = excellent.

under both grazing pressures. Rapid recovery and good reseeding was observed, showing that *C. virginianum* has potential when associated with pangola grass.

**Limitations.** The main limitation of *Centrosema* species in Northeast Argentina is their high susceptibility to frosts. While most species do not survive, *C. virginianum* shows good regrowth after cool periods. However, it has no tolerance to poorly drained soils and is also affected by summer droughts. *Centrosema virginianum* shows low establishment vigor but appears to be free of diseases. It nodulates freely in all soils where it has been tested. No studies have been conducted on its response to fertilizers, but its good colonizing performance in places where it reseeds itself suggests that its requirements are low. Although affected by summer droughts and a high degree of dehiscence, seed production is acceptable.

*Centrosema* has not been commercially planted in the region and no cultivar has been released. *Centrosema virginianum* is still in the small-plot evaluation stage with animals. Seed of accessions MeF 2909 and MeF 3034 is currently being multiplied to evaluate animal production. *Centrosema virginianum* is grouped with other native herbaceous forage legumes that have potential for the rocky areas of Mercedes, Corrientes, that is, *Vigna adenantha*, *Desmodium uncinatum*, *D. incanum*, and *Macroptilium erythroloma*.

**Conclusions and Future Projections**

The potential of *Centrosema* in subtropical America is most likely to be in the warmer subtropical regions such as Paraguay and Northwest Argentina. The excellent performance of *C. virginianum* in Salta, where it proved superior to siratro, suggests that this species may be an option for improving subtropical upland pastures of the Chaco region and temperate valleys.

In subtropical Florida, *C. virginianum* IRFL 1935 has been the most persistent *Centrosema* accession. In Mercedes, Corrientes, *C. virginianum* accessions MeF 4307 and MeF 2909 were outstanding compared with other *Centrosema* materials. Seed is being multiplied in both regions to proceed with evaluation under grazing. However, in these regions there are species of other legume genera that appear more promising such as *Macroptilium atropurpureum* in Florida and *Vigna adenantha* in Mercedes.
Future work with *Centrosera* in the subtropics should concentrate on searching for materials that are more resistant to low temperatures and have better establishment vigor. Management strategies to increase persistence in pastures must also be developed.

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Chapter 20

REGIONAL EXPERIENCE WITH 
CENTROSEMA: AUSTRALIA

J. K. Teitzel, D. G. Cameron, P. Anning, and T. G. Stockwell*

Abstract

Species of Centrosema were first evaluated in Australia during the early 1930s. These studies led to active commercial use of centro (C. pubescens) by the early 1950s. Centro is still the most widely used pasture legume in the Australian humid tropics where its previously narrow edaphic range was expanded by the discovery and correction of soil mineral deficiencies. There are examples of grass-centro pastures which have now been grazed commercially for more than 30 years.

The Australian Centrosema collection contains more than 1300 accessions of about 30 species. Well over half the accessions represent C. pubescens and C. virginianum, while 11 other species are represented by less than 10 accessions each. About half the entire collection has been grown out, at least in nursery rows. Selection for improved cool-season growth resulted in the release of cv. Belalto for the high-rainfall tropics. More recently, in the monsoonal dry tropics, two cultivars of C. pascuorum, cvs. Cavalcade and Bundey, were commercially released. A line of C. virginianum performed creditably under grazing in the moist subtropics but commercial release is not intended.

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Despite several decades of testing, the agronomic potential of the genus is still incompletely understood for Australian conditions. Moreover, the economic potential of commercially available cultivars has yet to be realized. Commercial acceptance would be accelerated by cultivars which were easier to establish, less sensitive to mineral deficiencies, and more resistant to heavy grazing.

Introduction

The first recorded introductions of Centrosema species to Australia were received between 1930 and 1936. They were two samples of *C. pubescens* from Java and Trinidad (Barnard, 1969), two of *C. plumieri* from Mauritius and Trinidad, and two of *C. virginianum* from Denmark and British Honduras. The first two species had been widely used overseas as cover crops in the tropical plantation areas (Whyte et al., 1953), while the third species was sometimes planted as an ornamental. These were grown in the plant introduction nursery at Lawes immediately each cleared quarantine and at Fitzroyvale, Rockhampton, from 1936 onward. Most of the introductions were rated as good but not outstanding (Miles, 1949). In 1939, a third sample of *C. pubescens* was received from New Guinea and passed to the then Queensland Department of Agriculture and Stock. Its value was quickly recognized when it was grown at South Johnstone on the wet tropical coast of north Queensland (Schofield, 1941).

With the resumption of research at South Johnstone in the postwar years, centro (*C. pubescens*), along with stylo (*Stylosanthes guianensis* var. *guianensis*), and puerco (*Pueraria phaseoloides*), was included in the first tropical legume-grass grazing studies in Australia (Graham, 1948 and 1951). The performance of centro in these plantings resulted in its rapid recommendation for commercial use on the wet tropical coast and its testing went even farther afield. It had already been planted near Brisbane in 1942 (Schofield, 1945).

By mid to late 1950s centro was being planted in many commercial pastures throughout Queensland (Walsh, 1958). These plantings included many of the early aerially sown pastures on pulled and burnt brigalow (*Acacia harpophylla*) forest areas, at least in central Queensland (Sillar, 1963). By the early 1960s, it was realized centro was not suited to the 600 to 800 mm annual rainfall brigalow lands. However, it proved much more useful in the higher (1000 to 1600 mm) rainfall areas nearer the coast in central and southeast Queensland. It
Regional experience with Centrosema: Australia

was successful as far south as the Cooroy-Nambour district (Douglas, 1959) where, by 1962, there were 120 hectares planted (Douglas, 1962) and on the Mackay wet coast (Goodchild, 1955).

By 1954, commercial quantities of seed were being imported and, during the 5 years before 1962, about 40 tonnes of seed came from Ceylon, Malaysia, and Indonesia (Barnard, 1969). Centro thus became the first of the summer-growing perennial tropical legumes to be widely used. After 1962, the emerging suite of subtropical perennial legumes, especially siratro (Macroptilium atropurpureum) and the desmodiums (Desmodium intortum and D. uncinatum), replaced it in planting mixtures in southern and Mackay areas (Douglas and Luck, 1964). As a result, its use was usually restricted to the northern wet tropical coast where it was so well adapted that it is still among the most important forage plants (Teitzel and Burt, 1976). As well on the Mackay wet coast, in well-drained areas with above 1600 mm annual rainfall, a number of the early plantings are still persisting and are highly valued pastures (Bishop and Walker, 1980).

While seed production was considered possible in Queensland (Verhoeven, 1958), and the first commercial harvest of nearly 1 tonne in 1958 was recorded by Gude (1959), no local seed-production industry has developed. The imported seed was cheaper than that produced locally and only occasional local harvests were ever made. In later years, the import of centro seed was restricted by quarantine authorities to that from New Guinea (Harding and Cameron, 1972).

Until recently, only species from the C. pubescens group have been used, but now two cultivars of C. pascuorum are entering the market.

This paper reviews the expansion of the Australian Centrosema collection and the evaluation and breeding programs that have been carried out. It discusses known environmental constraints of the commercial cultivars, their commercial impact, and future research priorities for Centrosema in Australia.

Target Environments

To date, the Centrosema species have been targeted at a range of separate environments in northern Australia. These have ranged from the humid tropics to the monsoonal dry tropics, dry tropics, moist subtropics, and dry subtropics (Tables 1 and 2). Soils have varied from
Table 1. Regional testing of *Centroptema* species in Australia and their generalized performance.

<table>
<thead>
<tr>
<th><em>Centroptema</em> species</th>
<th>No. of accessions</th>
<th>Origin or source (with no. of accessions)</th>
<th>Testing type and site</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>acutifolium</td>
<td>11</td>
<td>Brazil (9), Colombia (2)</td>
<td>N: SS</td>
<td>P-V</td>
</tr>
<tr>
<td>angustifolium</td>
<td>1</td>
<td>Brazil</td>
<td>Q: KN</td>
<td>NE</td>
</tr>
<tr>
<td>arenarium</td>
<td>2</td>
<td>Brazil</td>
<td>N: SS</td>
<td>F</td>
</tr>
<tr>
<td>arenicola</td>
<td>1</td>
<td>Florida</td>
<td>N: SS</td>
<td>P</td>
</tr>
<tr>
<td>brachypodum</td>
<td>2</td>
<td>Brazil</td>
<td>N: SS, MA, WT</td>
<td>F-G</td>
</tr>
<tr>
<td>bracteosum</td>
<td>1</td>
<td>Brazil</td>
<td>N: SS, MA, WT</td>
<td>P at SS; NE at MA</td>
</tr>
<tr>
<td>brazillianum</td>
<td>54</td>
<td>Brazil (37), Colombia (5), Venezuela (9), unknown (2), Suriname (1)</td>
<td>N: NB, SS, MA, MG, NW, DA, TA, BO, BB, WT; O: BH, CQ, AR, CP, TA; Q: MG, MA, NB, TA, DD, DW, KU, VR; G: KN</td>
<td>P-V; NP at SS, BH; P in CQ</td>
</tr>
<tr>
<td>coriaceum</td>
<td>2</td>
<td>Brazil</td>
<td>N: SS</td>
<td>P</td>
</tr>
<tr>
<td>grazielae</td>
<td>10</td>
<td>Brazil (7), Colombia (3)</td>
<td>N: SS, BB, BO</td>
<td>F; NP at SS</td>
</tr>
<tr>
<td>macrocarpum</td>
<td>14</td>
<td>Brazil (8), Colombia (5), Mexico (1)</td>
<td>N: SS, MK</td>
<td>F</td>
</tr>
</tbody>
</table>

(Continued)
<table>
<thead>
<tr>
<th>Centrosema species</th>
<th>No. of accessions</th>
<th>Origin or source (with no. of accessions)</th>
<th>Testing type$^b$ and site$^c$</th>
<th>Performance$^d$</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>pascuorum</em></td>
<td>71</td>
<td>Brazil (37), Ecuador (1), Honduras (3), El Salvador (1), Mexico (2), Venezuela (22), bred (5)</td>
<td>N: NB, BB, BO, SS, W, DA, CQ, CL, MA, MG, WT, YP, MK; O: BH, MG, YP, DB, CQ, KN, TA; Q: MG, NB, TA, MA, YP, AR, CP, VR, KU, DD, DW, TA; G: KN</td>
<td>P-V; P at southern sites; F-V at northern sites</td>
</tr>
<tr>
<td><em>plumieri</em></td>
<td>32</td>
<td>Brazil (8), Colombia (4), Panama (1), Venezuela (3), Dominican Rep. (3), El Salvador (1), Mexico (3), Guatemala (2), Mauritius (1), Malaya (1), Fiji (1), Trinidad (1), Belgium (1), local (2)</td>
<td>N: BO, BB, CQ, LG, SS, DA, KU, MA, NB, WT; O: DB, SS, AR, CP, DD; Q: KN</td>
<td>P-V; P on DB; NP in a number of plantings incl. KN</td>
</tr>
<tr>
<td><em>pubescens x macrocarpum</em></td>
<td>3</td>
<td>Bred in Colombia</td>
<td>N: SS</td>
<td>F</td>
</tr>
<tr>
<td><em>pubescens x acutifolium</em></td>
<td>1</td>
<td>Bred in Brazil</td>
<td>N: SS</td>
<td>F</td>
</tr>
<tr>
<td><em>pubescens</em></td>
<td>345</td>
<td>Brazil (56, 12 bred), Colombia (51, 14 bred), Panama (25), Venezuela (34), Dominican Rep. (3), El Salvador (2), Mexico (31), Guatemala (9), Cuba (25), Ecuador (14), Belize (4), West Indies (8), Bolivia (1), SE Asia (19), West Africa (8), East Africa (11), Guyana (1), Suriname (1), Fiji (1), local (14), Costa Rica (1)</td>
<td>N: SS, BO, BB, NB, MA, TA, WT, MK, CQ, NW; Q: YP, TA, MG, WT; O: AR, CP; G: WT, DA, DD, KN, KU</td>
<td>P-V</td>
</tr>
<tr>
<td><strong>Centrosema</strong></td>
<td><strong>No. of accessions</strong></td>
<td><strong>Origin or source (with no. of accessions)</strong></td>
<td><strong>Testing type$^b$ and site$^c$</strong></td>
<td><strong>Performance$^d$</strong></td>
</tr>
<tr>
<td>----------------</td>
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</tr>
<tr>
<td><em>rotundifolium</em></td>
<td>3</td>
<td>Brazil</td>
<td>N: BB, SS, WT, TA</td>
<td>P; NP at SS</td>
</tr>
<tr>
<td><em>sagittatum</em></td>
<td>3</td>
<td>Brazil (1), Argentina (1), Honduras (1)</td>
<td>N: SS, BB</td>
<td>F-G</td>
</tr>
<tr>
<td><em>schiedeanum</em></td>
<td>13</td>
<td>Mexico (6), Colombia (2), Panama (3), Costa Rica (2)</td>
<td>N: SS, BB, MK, NW, WT, TA; O: DB; Q: WT, YP, MA, MG; G: WT</td>
<td>P-V; P on DB; NE in NW</td>
</tr>
<tr>
<td><em>schottii</em></td>
<td>6</td>
<td>Mexico (4), Ecuador (1), Brazil (1)</td>
<td>N: NB, BB, SS, CQ, NW, DA, TA, MA, WT; O: BH, CQ, AR, TA; Q: NB, TA, DD, DW, KN, Ku, TA, VR; G: TA</td>
<td>P-G; P on DB; F in MA; MG, NW; F in TA</td>
</tr>
<tr>
<td><em>vegillatum</em></td>
<td>1</td>
<td>Colombia</td>
<td>N: SS</td>
<td>P</td>
</tr>
<tr>
<td><em>virginianum</em></td>
<td>105</td>
<td>Brazil (31), Argentina (17), Mexico (11), Colombia (10), USA (4), Puerto Rico (1), Honduras (3), Bolivia (2), Paraguay (1), Venezuela (2), Cuba (1), Dominican Rep. (1), West Indies (20), Denmark (1)</td>
<td>N: BB, LG, SS, BO, TA, DA, NB, CQ, DD, MA, MK, NW, CL, WT; O: DB, MA, NW, AR, CP, DD, VR, CQ; Q: MA, MG, YP, NB, BB, BO, WT, LA, SS, TA, KN, Ku; G: BB, SS</td>
<td>P-V; Often NP at SS; P on DB, in north (MA, MG), and CQ</td>
</tr>
<tr>
<td>Centrosema species</td>
<td>No. of accessions</td>
<td>Origin or source (with no. of accessions)</td>
<td>Testing type\textsuperscript{b} and site\textsuperscript{c}</td>
<td>Performance\textsuperscript{d}</td>
</tr>
<tr>
<td>-------------------</td>
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<td>------------------------------------------</td>
<td>---------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>sp.</td>
<td>11</td>
<td>Venezuela (5), Panama (1),</td>
<td>N: DA, SS, MA;</td>
<td>P-G;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>El Salvador (2), Guyana (1),</td>
<td>O: BH, TA</td>
<td>NP in BH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Grenada (1), local (1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{a} This information has been distilled from published data (see Reference List) and various personal communications from H. G. Bishop, M. J. Blumenthal, G. J. Calder, A. G. Cameron, R. L. Clem, R. J. Clements, T. J. Hall, J. M. Hopkinson, T. H. McCooker, C. H. Middleton, R. G. Silcock, I. B. Staples, R. J. Williams, W. H. Winter, and A. E. Wynn, as well as unpublished data from J. K. Teitzel and T. G. Stockwell.

\textsuperscript{b} Testing type: (after Winter et al., 1985).
Qualitative data (e.g., flowering date, growth rate): N = nursery; O = observation plot.
Q = Quantitative data (e.g., dry-matter yields, plant populations, quality, seed yields).
G = Grazing experiments.

\textsuperscript{c} See Table 2.

\textsuperscript{d} Performance: (after Winter et al., 1985).
P = poor growth
F = fair growth
G = good growth
V = very good growth
NP = not persistent
NE = no establishment
<table>
<thead>
<tr>
<th>Location</th>
<th>Average annual rainfall (mm)</th>
<th>Soil type(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BH Bowen hinterland (includes Havilah and Myuna)</td>
<td>600-700</td>
<td>Black cracking clays</td>
</tr>
<tr>
<td>DW Daly Waters</td>
<td>650</td>
<td>Red earth</td>
</tr>
<tr>
<td>KN Katherine District</td>
<td>950</td>
<td>Red earth Gn 2.11, 2.12; Yellow Podzolic Gn 2.74</td>
</tr>
<tr>
<td>KU Kununurra Area (includes Kimberley Research Station)</td>
<td>750</td>
<td>Grey clay Ug 5.34; Deep sand Uc 4.21; Red earth Gn 2.14</td>
</tr>
<tr>
<td>MG Mt. Surprise and Mt. Garnett (includes Boomerang, Meadowbank, Tirrabella, Ben Avon, Woodleigh, Rosella Plains, Pinnarendi, Mistletoe, and Forest Home)</td>
<td>700-800</td>
<td>Red earth; yellow duplex; Krasnozem; red duplex black; granite sands</td>
</tr>
<tr>
<td>NW Northwest Queensland (includes Cloncurry, Toorak, Glenore, Normanton, Corella Park, Milgara, Warrenvale, Muttonhole, and Croydon)</td>
<td>400-800</td>
<td>Yellow duplex; yellow earth; grey clay; loamy red earth; brown clay</td>
</tr>
<tr>
<td>TA Townsville area (includes Landsdown Research Station and Bluff Downs)</td>
<td>900</td>
<td>Red Podzolic Gn 3.15</td>
</tr>
<tr>
<td>VR Victoria River District</td>
<td>650</td>
<td>Grey silty loam; Red clay loam; Euchrozem Gn 3.12; Black earth Ug 5.12</td>
</tr>
</tbody>
</table>

(Continued)
## Table 2. (Continued)

<table>
<thead>
<tr>
<th>Location</th>
<th>Average annual rainfall (aar) (mm)</th>
<th>Soil type*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MONSOONAL DRY TROPICS (3-6 months growing season)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AR Adelaide River (includes Mt. Bundey Research Station and Tortilla Flats)</td>
<td>1250</td>
<td>Lithosol Gn 2.61, 2.81; Red earth Gn 2.21; Soloth Dy 3.31; Solodic Dy 3.53; Yellow earth Gn 2.61, 2.62, 2.64</td>
</tr>
<tr>
<td>CP Coastal plains</td>
<td>1400</td>
<td>Black cracking clay Ug 5.4, 5.5; Humic Gley Uc 5.23, 5.61, (Gn 2.81); Grey clay Ug 5.17, 5.24; Red earth 2.4</td>
</tr>
<tr>
<td>DA Darwin area (includes Berrimah Research Farm)</td>
<td>1600</td>
<td>Lithosol; Red earth Gn 2.14, etc.; Yellow earth Gn 2.24, 2.64</td>
</tr>
<tr>
<td>DD Douglas Daly area</td>
<td>1100</td>
<td>Red earth Gn 2.11, 2.12; Yellow Podzolic Gn 2.74</td>
</tr>
<tr>
<td>MA Mareeba area (includes Walkamin, Southedge, Parada, and Kairi Research Stations)</td>
<td>1030</td>
<td>Yellow duplex; Krasnozem; Sandy Solodics</td>
</tr>
<tr>
<td>YP Cape York Peninsula (includes Wrotham Park, Highbury, Mt. Carbine, Brooklyn, Sudley, Kalinga, and Koolburra)</td>
<td>800-1000</td>
<td>Yellow earth; yellow duplex; grey clay; yellow Solodic</td>
</tr>
</tbody>
</table>

(Continued)
<table>
<thead>
<tr>
<th>Location</th>
<th>Average annual rainfall (aar) (mm)</th>
<th>Soil type*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WET TROPICS (6-12 months growing season)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MK Mackay (includes Tedlands)</td>
<td>1660</td>
<td>Sandy Solodic; fertile alluvium</td>
</tr>
<tr>
<td>WT Wet tropical coast (from Ingham to Cairns)</td>
<td>1500-3500</td>
<td>Sand; sandy loam; silty clay loam; sandy light clays Dy 3.41, Gn 3.11, Gn 2.21, Gn 2.84, Uc 4.2, Um 6.33, 6.34</td>
</tr>
<tr>
<td><strong>CAPRICORNIA (700-1000 mm aar)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CQ Central Queensland (includes Biloela Research Station, Moura, Moranbah, Marlborough, Fitzroyvale, and Rockhampton)</td>
<td>700-1000</td>
<td>Black earth; Grey brown clay; loams; Solodics; red earths</td>
</tr>
<tr>
<td><strong>DRY SUBTROPICS (&lt; 900 mm aar)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BO Boonah</td>
<td>870</td>
<td>Black earths Ug 5.13</td>
</tr>
<tr>
<td>CL Charleville Pastoral Laboratory</td>
<td>500</td>
<td>Deep sand</td>
</tr>
<tr>
<td>DB Darling Downs (includes Bringalily, Wandoan, and Wellcamp)</td>
<td>650-700</td>
<td>Grey cracking clay Ug 5.24; Black earths Ug 5.1; sandy Solodics</td>
</tr>
<tr>
<td>LG Lawes and Gatton</td>
<td>770</td>
<td>Black earth Ug 5.15</td>
</tr>
<tr>
<td>NB Narayen and Brian Pastures</td>
<td>720</td>
<td>Yellow Podzolic Dy 3.41; Black earth Ug 5.15</td>
</tr>
</tbody>
</table>

(Continued)
Table 2. (Continued)

<table>
<thead>
<tr>
<th>Location</th>
<th>Average annual rainfall (aar) (mm)</th>
<th>Soil type&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOIST SUBTROPICS (≥ 1000 mm aar)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BB Beerwah and Beerburrum</td>
<td>1650</td>
<td>Gleyed PodzolicDy 3.41; Deep sand</td>
</tr>
<tr>
<td>SS Samford and Strathpine (includes Moggill)</td>
<td>900-1200</td>
<td>Gleyed Podzolic</td>
</tr>
</tbody>
</table>

<sup>a</sup> According to Northcote, 1971.

SOURCES: See footnote a. in Table 1.
heavy clays to light sands in a range of drainage situations. Most have been acid with a low mineral nutritional status. In the high rainfall areas at least, correction of mineral deficiencies has meant that conventional soil groupings (Tables 1 and 2) have been of little value for extrapolating plant performance characteristics (Teitzel, 1979).

On the wet tropical coast (lat. 16° to 19° S, average annual rainfall 1500 to 5000 mm) grass-only pasture planted at the turn of the century had declined markedly in vigor by the 1930s. A search for corrective measures led to pioneering work with tropical legumes (Graham, 1951; Schofield, 1941); then to commercial plantings of common centro (C. pubescens) on the more fertile alluvial and volcanic soils used for agriculture at that time. Expansion of the beef industry to infertile, shallow, acid, and mineral-deficient soils and recognition of a need for pasture legumes with improved cool-season growth, led to a wider range of introductions during the 1960s (Grof and Harding, 1970).

With the expansion of the Australian Centrosema collection since the late 1960s (Clements et al., 1983), testing in a wider range of environments was undertaken. In particular, the need for pasture legumes in the vast areas of monsoonal and seasonally dry tropics (typically 3-6 months wet season and 6-9 months drought) in Queensland and Northern Territory, led to field-testing representatives from the expanding Centrosema gene pool in a range of sites (Tables 1 and 2).

In subtropical Queensland, there has also been widespread testing and, with C. virginianum, plant breeding. This area has a less distinct dry season but a much cooler winter, with frosts common, and winter rainfall frequent. Frost resistance and an ability to grow in the cool season are therefore desirable characteristics for a pasture plant.

**Australian Centrosema Collection**

By the late 1960s, there were fewer than 200 Centrosema accessions in the Australian collection. This number has now increased to more than 1300 from 30 species. About half the accessions, from the 20 species listed in Table 1, have been grown out, at least in nursery rows (Clements, 1985). The whole collection contains more than 500 representatives of C. pubescens and more than 200 of C. virginianum. Species represented by 20 to 100 accessions are C. brasilianum, C. macrocarpum, C. pascuorum, C. plumieri, C.

Commercially Released Cultivars

One of the inadequacies of common centro, the material that came into use during the 1950s, is its temperature sensitivity, resulting in poor cool-season growth. It also suffers from diseases and insect attack during the cool season. This led to the selection of a cultivar, Belalto, released in 1971 (Barnard, 1972) which outyielded common centro and certain other Centrosema lines during two consecutive cool seasons. Additionally, Belalto was little affected by cercospora leaf spot and red spider mite (Tetranychus sp.) (Grof and Harding, 1970). Belalto is now regarded as belonging to C. schiedeanum.

Expansion of the Australian gene pool led to the testing of a wider range of Centrosema accessions across a number of environments away from the humid tropics. Some of this work highlighted the potential of C. pascuorum lines in monsoonal dry tropics environments. One line bred by Clements et al. (1986) was found to possess a desirable combination of consistently high herbage yield over sites and years and good seed production. It also provides 22% more herbage and 118% more seed than its best parent (Stockwell et al., 1986). It was released as cv. Cavalcade in 1984 (New releases . . ., 1985). Soon afterward, another line of very similar appearance, but with smaller seed and a later flowering time, was released as cv. Bundey. Bundey is considered to be more suited to the wetter areas of the “Top End” of Northern Territory (Stockwell, 1985).

There are no other accessions approaching commercial release, although C. brasilianum (Anning, 1982) and C. virginianum lines have shown some promise in the dry tropics. Centrosema virginianum has also performed creditably under grazing trial conditions in a subtropical, coastal, lowland environment (Jones and Clements, 1987). However, it is considered that this performance was not convincing enough to support a proposal for commercial release (R. M. Jones, personal communication).
Selection Programs

The early work of Schofield (1941) consisted largely of small-plot sward-clipping experiments with different application rates of lime and single superphosphate. There were also some palatability studies in feeding pens. The first grazing evaluations began in 1946 and consisted of commonly grazed small plots (Graham, 1951). It was not possible to measure animal liveweight performance in the Australian humid tropics until 1948 when a weighbridge was installed at South Johnstone. This work led to a number of commercial plantings of common centro in association with a range of grasses, giving 30 years or more of commercial grazing experience with the cultivar in the Australian humid tropics.

The evaluation which led to the release of cv. Belalto was largely a sward-clipping experiment with *Centrosoema* accessions selected from their performance in space-planted nursery plots (Grof and Harding, 1970). Since that time, there has been a number of grazing observations with Belalto. The largest of these was a grazing systems study which was recently terminated after 12 years of soil, plant, and animal monitoring. Pasture systems containing Belalto centro consistently outperformed equivalent systems containing common centro (J. K. Teitzel, unpublished data).

Grof (1970) attempted to breed cultivars superior to Belalto. However, selected lines subsequently failed to demonstrate superiority in mixed sward evaluations (C. H. Middleton, personal communication).

Testing of other *Centrosoema* accessions (Tables 1 and 2) has been carried out in the dry tropics of Queensland by Anning (1982), Anning et al. (1981), and other QDPI and CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia) officers (Tables 1 and 2); in monsoonal dry tropics by Cameron et al. (1984), Clements et al. (1984), Stockwell (1982), Stockwell et al. (1986), and Winter (1978); in subtropical Queensland by Cameron and Mullaly (1969), Clements (1977 and 1983a), Jones and Clements (1987); and at three sites (each representing one of the above three broad regional groupings) by Clements et al. (1984). The species tested were *C. pubescens*, *C. plumieri*, *C. virginianum*, *C. pascuorum*, *C. brasilianum*, *C. grazielae*, *C. acutifolium*, *C. macrocarpum*, *C. grandiflorum*, *C. schiedeanum*, and *C. schottii*. These studies involved evaluations in nursery rows, followed by sward-clipping experiments with the more promising accessions.
Records usually noted dry-matter yield, plant N and P content, flowering, seeding, persistence, cold and frost tolerance, and spread.

At Katherine, Northern Territory, W. H. Winter (personal communication) reports that *C. pascuorum* remained the dominant pasture component after 5 years' stocking at 3.3 steers/ha during the dry season (June to November, inclusively) when it was able to consistently produce liveweight gains of 20 to 50 kg/head.

**Environmental Constraints**

Commercial common centro is classically a legume for the wet tropics. Although it will grow in areas receiving as little as 1000 mm of rain per annum (Humphreys, 1974; Wilson and Lansbury, 1958), its performance is much better in the high rainfall areas (Barnard, 1969; Goodchild, 1955; Walsh, 1958).

Of the species studied by 't Mannetje and Pritchard (1974), common centro showed the most dramatic response to change in temperature. At a daylength of 14 hours, centro yield at day and night temperatures of 26-15 °C was only 16% of that at 32-24 °C. Below screen temperatures of 25.6 °C (maximum) and 12.8 °C (minimum), growth was severely restricted (Bowen, 1959a). Common centro also, unlike the desmodiums and glycine (*Neonotonia wightii*), showed no growth depression at high temperatures within the range used by Sweeney and Hopkinson (1975). However, growth rates, as were those of all the legumes they tested, fell away rapidly as temperatures fell to 24-19 °C and lower.

Frost causes severe damage to common centro, although regrowth may occur in well-established stands if crown and stem bases have been sufficiently well covered (Barnard, 1969; Douglas, 1962; Schofield, 1945). In more southerly latitudes (New South Wales), lack of cold tolerance causes common centro to act as an annual (Cameron, 1958). The more recently released *C. schiedeana*um cv. Belalto is much more productive during the cool season than is common centro (Grof and Harding, 1970). This probably reflects its relatively high altitude origin.

Working with a range of *C. virginianum* accessions, Clements and Ludlow (1977) found differences in the ability to survive mild field frosts. This correlated with the latitude of origin. The height to the cotyledon node was also negatively correlated with the latitude of origin and winter field survival. In fact, frost survival resulted mainly by avoidance rather than frost tolerance per se.
Ability to withstand water stress is also important in Australian situations and, according to Ludlow et al. (1983), five accessions of *Centrosea* from four species responded to water stress differently to siratro. Siratro can avoid dehydration but actually has low tolerance to internal water deficits. The *Centrosea* spp. were able to tolerate leaf water potentials as low as -8 to -12 MPa compared with only -1.9 MPa for siratro. Of the *Centrosea* spp., *C. pascuorum* tolerated the highest stress and *C. pubescens* the least stress, as was expected.

Common centro has been grown over a wide range of soil types (Humphreys, 1974), but there was a general belief that it was best to plant centro on the more fertile soils and stylo on the poorer soils (Teitzel et al., 1974b). More recently, however, observations of commercial mixed (grass-centro-stylo) pastures have revealed that with the correction of the soil mineral deficiencies listed by Teitzel (1979), centro has become the dominant legume on even the poorest soils. This had occurred before anthracnose (*Colletotrichum gloeosporioides*) infestations became a problem with stylo. The edaphic requirements of Belalito appear similar to those of common centro.

*Centrosea pascuorum* has also shown good edaphic adaptation (Clements et al., 1983) and, as noted above, can tolerate very high internal water deficits (Ludlow et al., 1983). Both commercially released cultivars, Cavalcade and Bundey, have survived prolonged waterlogging and partial submersion on seasonally flooded lands in the monsoonal dry tropics of Northern Territory. Because of its later flowering, cv. Bundey is considered to have advantages in the more deeply flooded areas (Stockwell, 1985). Accessions of *C. pascuorum*, however, have not performed as well at similar latitudes in the dry tropics of Queensland (Anning, 1982; Clements et al., 1984). It failed to persist in the subtropics and humid tropics.

The belief about planting sites for common centro and stylo has led to a further belief among Australian workers that the genus *Centrosea* is not as well adapted as *Stylosanthes* to infertile soils. However, from recent experience in the humid tropics, it is possible that inexpensive correction of mineral deficiencies would alter this perception. The mineral nutritional status of most Australian pasture soils is still poorly understood, particularly in relation to trace-element sensitive genera such as *Centrosea*. Further research may expand the edaphic range of *Centrosea*. 

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Other Limitations

Some of the most widely perceived weaknesses of Centroïdes cultivars are related to an apparent need for higher management inputs. Alternative Stylosanthes cultivars have been easier to establish without cultivation, and with lower fertilizer inputs on cultivated seedbeds. It is also usually considered that Centroïdes cultivars are too palatable for uncontrolled grazing in remote areas. However, they have not been devastated by pests or diseases, although there have been moderate infestations of cercospora leaf spot and red spider mite in the commercial centros, especially common centro. A root-knot nematode (Meloidogyne sp.) has infested C. pascuorum, but is considered to be a problem only in experiments involving widely spaced plants (Clements et al., 1983). Leaf viruses and occasional, heavy Rhizoctonia infestations have been observed on a number of Centroïdes species, including C. pubescens and C. pascuorum. These require careful monitoring, but at the moment are not considered serious limitations.

Economic Impact

Common centro and Belalto are the two most important legumes in the Australian humid tropics. For reasons mentioned earlier, Belalto is the preferred cultivar but because commercial quantities of seed are not available, it is not widely used. Centro (Belalto or common) is the recommended legume for planting in association with Riversdale Guinea grass (Panicum maximum) on well-drained lands, with Hamil Guinea grass (P. maximum) on moderately drained lands, and with Para grass (Brachiaria mutica) on poorly drained lands.

Establishment and management practices for these pasture mixtures have been outlined by Teitzel et al. (1974a, 1974b, and 1974c). Slow establishment, partly because of a high proportion of hard seed (Verhoeven, 1958), makes it desirable to scarify the seed and prepare a firm, moist, weed-free seedbed. Because of semispecificity in Rhizobium requirement, seed should be inoculated with the appropriate strain of Rhizobium (Bowen, 1959b). Bruce (1967) estimated an annual input of 138 kg of N/ha from inoculated centro grown with Guinea grass.

Accurate sowing and some coverage of the seed with soil is recommended. Requirements for fertilizer dressings range from 200 kg of single superphosphate/ha for rain-forest land classes to 500 kg of
superphosphate with 100 kg of potassium chloride, 10 kg of copper sulfate, and 10 kg of zinc sulfate/ha for soils derived from granite that previously supported a natural vegetation of grassy sclerophyll woodland (Teitzel et al., 1974a). Once established, centro-Guinea grass pastures have consistently produced an annual 500 to 600 kg of liveweight gain/ha at stocking rates of 2.5 to 3 steers/ha (Lascano et al., this volume). There are commercial examples which are now more than 30 years old.

Such stability was highlighted during the period of low beef prices during the 1970s when overstocking (a result of reluctance to sell cattle at low prices) and underfertilizing (a consequence of inadequate cash flow) resulted in widespread pasture degradation. Since that time, provided sufficient centro had remained (about 1% to 2% botanical composition, evenly distributed), large areas of commercial pastures have been rejuvenated by slashing weeds, applying necessary maintenance fertilizers, and grazing leniently during the first wet season after fertilizer application. The typical maintenance fertilizer programs, outlined by Teitzel (1979), consisted of reapplying 30 kg of soluble P/ha every 2 years and adding specified trace elements every 5 years.

Despite such instances of long-term performance, there are only about 30,000 ha of pasture containing centro in Australia. This is largely a result of a lack of farmer confidence and economic circumstances of the recent past. Many of the plantings during the 1960s failed because of inadequate knowledge of fertilizer requirements. Still more confidence was lost during the period of poor beef prices and pasture degradation during the 1970s. With the improvement in beef prices since then, studies such as those by Teitzel et al. (1986), have shown that pastures of Brachiaria decumbens or B. humidicola fertilized with nitrogen have been more profitable than Guinea-centro pastures. Hence, degraded pasture lands were often not replanted in centro. This could be expected to change with a reduction in beef prices or large increases in the price of nitrogen fertilizer.

Commercial release of C. pascuorum cultivars has been much more recent and the total planted areas is still only about 100 ha. Hence, the economic impact is negligible even though the areas to which they appear adapted are considerable.

At this stage, the release of a Centrosema cultivar in the subtropics is not planned.
Research Priorities

Despite its relatively long history of domestication (for a tropical legume), the agronomic potential of the genus Centrocerma is still largely unexplored for Australian conditions. Moreover, the full economic potential of commercially available cultivars has yet to be realized.

For the dry tropics, the most immediate needs probably revolve around fully determining the areas of usefulness and defining the minimal input strategies for safely establishing and grazing the two C. pascuorum cultivars. In particular, the mineral nutritional status of many of the target soils is still poorly understood. As Centrocerma cultivars are regarded as sensitive to mineral deficiencies, soil-screening studies (such as that summarized by Teitzel [1979] for the humid tropics) would be important. There is also a dearth of information on the economic benefits to be derived from growing the cultivars. Comments have been made that they have an important role in swampy areas of the dry tropics, especially in providing deferred grazing for weaners. However, there has been no real attempt at quantifying or modeling the likely benefits from an anticipated range of values.

The situation is more advanced in the humid tropics where the two perennial cultivars have performed well in association with Guinea grass. However, there may be early commercial benefits in examining relatives of Belalto for accessions with superior seed production. There is also a great need for cultivars which will form stable associations under grazing with vigorous prostrate grasses such as Brachiaria decumbens, B. humidicola, and Digitaria decumbens.

A number of the species listed in Table 1 such as C. arenarium, have yet to be grown in drier environments, to which they appear most likely to be adapted. There are also variations in cold tolerance and drought resistance in several species within the C. pubescens group (that is, C. pubescens, C. macrocarpum, C. grandiflorum, C. schiedeanum, and C. acutifolium) which need to be fully explored for potential exploitation—if necessary with a breeding program (Clements, 1985).

In all regions there is a need for cultivars which are easier to establish, less sensitive to mineral deficiencies, and more resistant to heavy grazing than are the existing Centrocerma cultivars. Useful additional improvements would be increased tolerances to drought, fire, and low temperatures.
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Chapter 21

REGIONAL EXPERIENCE WITH CENTROSEMA: TROPICAL ASIA AND PACIFIC

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Abstract

Regional experience with 12 Centrosema spp., emphasizing the potential of Centrosema pubescens and related species (such as C. macrocarpum) and C. pascuorum, is summarized. The environmental constraints to the adaptation of C. pubescens are detailed for climatic, edaphic, physiographic, and, especially, biotic factors. The main regional role of C. pubescens is in plantation agriculture, integrated with animal production. Research priorities for plant improvement, seed production, and Centrosema management in plantations are briefly discussed.

Regional Characteristics

Tropical Asia and the Pacific encompass great diversity of farming systems, soils, and climates. The main systems involving forages are rice-based agriculture (Humphreys, 1986) in which cattle and buffalo, raised for draught and meat, feed mainly on crop residues, weeds of crop lands, uncultivated wastelands, and shrubs; plantation agriculture (Rika, 1986) in which forage is grown with coconut palms, immature rubber or oil palm, or perennial fruit crops such as cashew; and savanna

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(Singh et al., 1985), predominantly watershed grasslands induced by slash-and-burn agriculture, and swamp grasslands. Ranch pastures are a minor component.

The main soil types (Table 1) of Thailand, Malaysia, and Indonesia are Ultisols in which the Orthic Aquasols have good physical characteristics and drainage, but low base saturation, and increasing acidity and aluminum with depth (Blair et al., 1986b). By contrast, the Cambisols (Ochrepts/Tropepts) are the dominant soils of South Pacific. Soils formed on uplifted coral reefs may be enriched with volcanic ash; the older volcanic deposits are often steep and highly weathered, while recent volcanic activity has given rise to fertile soils such as on Vanuatu and Tanna (Shelton et al., 1986).

Köppen climate types, described briefly, comprise the tropical rainy climates Af, Am, and Aw and warm rainy Cfa or dry-winter Cwa

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<th>Table 1. Area of major soil types in Southeast Asia and the South Pacific islands, excluding Australia and New Zealand.</th>
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$^a$ FAO = Food and Agriculture Organization of the United Nations, Rome, Italy. USDA = United States Department of Agriculture, Washington, DC.

SOURCE: Blair et al., 1986b.
climates occurring in the highlands (Trewartha, 1968). Details of climates specific to pasture-growing regions of particular countries can be found in recent conference proceedings such as Blair et al. (1986a), FFTC (1984), and IGC (1985).

Species Testing

*Centrosera plumieri* was originally used as a plantation cover and green manure crop. It is recorded as naturalized in Java in 1863 (Burkhill, 1935) and was displaced by *C. pubescens* about 1925. Most studies relate to *C. pubescens* but, in the past decade, considerable small-plot testing of a wide range of species and accessions under cutting or intermittent grazing and cutting has been undertaken. The following notes primarily summarize performance at Ciawi, Panawangan, Gowa, and Kabaru in Indonesia; Serdang and Sungai Baging in Malaysia (Wong et al., 1982); Khon Kaen in Thailand; and the Solomon Islands.

*Centrosera acutifolium*

This species shows promise in the humid tropics, where resistance to *Rhizoctonia* has been superior to other species.

*Centrosera arenarium*

This erect subshrub has withstood repeated cutting at Ciawi and Panawangan (3 dry months), and has given good yields and moderate seed production.

*Centrosera brasiliannum*

Three lines were nonpersistence in Malaysia, with fair to poor nodulation, *Rhizoctonia* susceptibility, and poor productivity. Susceptibility to pests and diseases was also evident at Khon Kaen and in Jawa Barat (West Java).

*Centrosera grazielae*

This species at the moist Ciawi site grew well in the first year but not subsequently, and performed poorly at other Indonesian sites.
Centrosema macrocarpum

This perennial species is the highest producing species in the humid tropics of Indonesia. CIAT 5733, CIAT 5730, and CIAT 5065 gave the best persistence of yield of 12 lines evaluated in Malaysia. It has also shown promise at Songkhla in south Thailand on an acid soil (P. Jewtrakul, personal communication, 1986) and in Sumatera Barat (West Sumatra) (Thompson and Evensen, 1986). This species appears very tolerant of acid soils, high levels of exchangeable Mn, and low nutrient availability, and exhibits better leaf retention in the dry season at Khon Kaen than C. pubescens. Productivity of this twining species remains high if used in a cut-and-remove system with rests every 12-14 weeks. Flowering and seed setting are low in equatorial regions, but further studies on seed production at higher latitudes such as Khon Kaen (lat. 16° N), may overcome these difficulties and lead to a considerable increase in farmers’ use of Centrosema on soils too acid and too dry for current C. pubescens commercial material.

Centrosema pascuorum

Eleven lines of this annual were evaluated at Khon Kaen. Over 2 years, actual legume yields were 0.5-7.4 (CPI 55697), 8.7 (CPI 75115), and 9.2 t/ha (CPI 40060), relative to 7.3 t/ha for C. pubescens (Topark-Ngarm and Moolsiri, 1983). However, performance of two lines in five northeast Thailand sites compared unfavorably with Stylisanthes spp. (Topark-Ngarm et al., 1980). Centrosema pascuorum was unsuccessful in Malaysia, West Java, and south Thailand, and appears to perform poorly in acid soils with high Mn and low nutrient availability. In the monsoonal tropics of eastern Indonesia, however, this species has shown high yields, good seed production, and satisfactory seedling regeneration. It is, therefore, in advanced species testing for this region. Cutting and grazing management requirements which favor seed production and seedling regeneration may be more exacting than in the case of other short-lived species which have a more prostrate habit such as S. humilis cv. Khon Kaen.

Centrosema plumieri

One early generation intraspecific hybrid obtained from R. J. Clements (CPI 41014 x 28108) was unsuccessful in Malaysia. Its performance was moderate at Ciawi and poor at Panawangan, but it
was sufficiently promising on a more fertile soil in Sulawesi Selatan (South Sulawesi) to be retained for further testing.

**Centrosema pubescens**

This species has shown the widest adaptability within the genus *Centrosema*. It was the most successful legume over five sites in the Solomon Islands (Gutteridge and Whiteman, 1978a). Considerable intraspecific variation (de la Vía and Engle, 1986) is available for plant improvement, although there are constraints to adaptation.

**Centrosema sagittatum**

This has proved to be very persistent at Indonesian sites. However, production was only moderate because of problems with nodulation and virus infection.

**Centrosema schiedeanum**

The material tested was similar in performance and adaptation to *C. pubescens*.

**Centrosema schottii**

In Indonesia, this is not well adapted to acid, infertile soils with low P and high Mn, but yield, seed production, and persistence were good on more neutral soils in the seasonally wet tropics. Two different lines were nonpersistent, poorly nodulated, and nonproductive in Khon Kaen and Malaysia. The *Bradyrhizobium* strain CB 1923 did not effectively nodulate with this species and further evaluation is needed if effective nodulation is to be attained.

**Centrosema virginianum**

Five lines tested in Malaysia included one productive but nonpersistent line that became infected with *Rhizoctonia*. The yield of another line, CPI 55695, was low at Khon Kaen. In Indonesia, yield declined with time in the humid tropics but increased in a monsoon climate. Seed yields were moderate only and other species are preferred for further evaluation.
Constraints to the Adaptation of *Centrosera pubescens*

**Climatic constraints**

*Centrosera pubescens* is mainly successful in the Köppen Af and Am climates.

**Moisture.** A collection of 1173 accessions of native or naturalized legumes in eastern Indonesia made by K. L. Mehra for IBPGR (International Board for Plant Genetic Resources) has been used to compare the length of dry season at the sites of collection of *C. pubescens* with that of the whole collection (Figure 1). *Centrosera pubescens* was more prevalent than all legumes in those moister site categories of 0-1 months of dry season and in those drier sites with 4-6 months of dry season. The driest site in which *C. pubescens* occurred was Flores Island which has 970 mm rainfall per year and an 8-month dry season. The species therefore shows considerable adaptability.

![Diagram](image)

*Figure 1. Comparison of distribution of Centrosera pubescens with distribution of all legume species collected in Indonesia in terms of length of dry season and soil pH at site of collection. ----- All legumes (1173 accessions); ------- *C. pubescens*. (From K. L. Mehra, personal communication, 1986.)*
**Temperature.** In Hawaii, Eriksen and Whitney (1982) noted that, relative to other legumes such as Desmodium intortum, *C. pubescens* showed a poor capacity to use solar radiation during cool periods when soil temperature was below 23 °C. *Centrosema pubescens* is usually less productive and less persistent in the cool elevated or higher latitude situations, but is tolerant of high temperatures (Sweeney and Hopkinson, 1975).

**Shade.** The main use of *C. pubescens* in tropical Asia and the Pacific is in plantation agriculture, but its shade tolerance is only moderate. *Centrosema pubescens* behaves as a sun species and exhibits a linear decrease in growth with increase in shade, in contrast to Calopogonium caeruleum, *C. mucunoides*, and *D. ovalifolium* which all showed, in one Malaysian experiment, a quadratic response and maximum growth at 57% sunlight (Wong et al., 1985). Shade reduces the nitrogen content and nodulation of *C. pubescens* which also shows inferior adjustment of specific leaf area. However, the attributes associated with adaptation to shade are of secondary interest to the absolute yield performance and persistence under shade, which are often satisfactory for *C. pubescens* (Chen and Othman, 1984; Gutteridge and Whiteman, 1978a), because of its intrinsic and elite genetic vigor.

**Edaphic and physiographic constraints**

**Soil acidity and associated factors.** The Indonesian distribution of naturalized *Centrosema pubescens*, although predominantly occurring on soils with pH 6-8, includes areas with soils with pH 4-5 (Figure 1). In Malaysia, optimal performance appears on soils with pH 5.5-6.0. Pot and field studies on several inland Oxisols and Ultisols of the Melaka, Munchong, Bungar, Rengam, and Durian soil series have shown responses to molybdenum and to lime applications of 200-400 kg/ha (Tham and Kerridge, 1982). In Thailand, *C. pubescens* has not performed as well as *Stylosanthes* spp. on soils of low pH and poor fertility. Field experience in Indonesia suggests *C. pubescens* does not tolerate high Mn content, despite Andrew and Hegarty’s greenhouse study (1969) which found that the Mn-toxicity threshold of *C. pubescens* (1600 ppm in tops) was the highest of eight tropical legumes evaluated.

In the Solomon Islands, on coralline rubble soils with high pH (8.0, 1:2.5 soil:water), Fe deficiency was evident, and *C. pubescens* was more poorly adapted than *Macroptilium atropurpureum* or *M. lathyroides* (Gutteridge, 1978a).
Availability of major nutrients. Many reports of superior performance of *C. pubescens* are from sites of good soil fertility. In Thailand, *C. pubescens* gives good yield and persistence at Pak Chong on red clay soils with a pH of 6.6, OM at 2.72%, P at 19 ppm, and K at 288 ppm (Juntirapong, 1986; Nada and Sirikiratayanond, 1979), but at Chiang Mai, on a soil with a pH of 5.5, OM at 2.12%, P at 5.5 ppm, and K at 130 ppm, performance was moderate compared with that of *Stylosanthes* spp. (C. Samphet, personal communication, 1980).

Low P supply is regarded as a major constraint to yield and persistence in the Solomon Islands (Shelton et al., 1986), in Bali (Steel and Humphreys, 1974), and on the sandy soils (bris soils) of eastern Malaysia. At Keluang in Johore, *S. guianensis* dominated in a mixture with *C. pubescens* and *Pueraria phaseoloides* at low levels of P application in the second and third year, but not at high P levels (Eng et al., 1978a). In Bali, *C. pubescens* was very responsive to P application in terms of dry-matter yield, nitrogen content, and efficient use of P (Steel and Humphreys, 1974). *Centroserma pubescens* was found to have a higher requirement for P than *Crotalaria usaramoensis* or *D. intortum* on Indonesian Latosols (Haryanto et al., 1981).

Sulfur deficiency is widespread in Asia and the Pacific. This problem is exacerbated by the use of compound fertilizers that do not contain S. Strong positive responses in *C. pubescens* were reported from South Sulawesi (Blair et al., 1978) and the Guadalcanal Plains of the Solomon Islands (Watson and Whiteman, 1981b). In the latter instance, there was an interesting negative relationship between the incidence of cercospora leaf spot and S supply.

A further disease and nutrient interaction in the Solomon Islands was reported by Gutteridge and Whiteman (1978b). They noted that the incidence of *Rhizoctonia solani* was reduced if K was adequate. Of five legumes tested, *C. pubescens* presented an average capacity to use native K (Gutteridge, 1981). On Malaita soils, an application of K at the rate of 75-100 kg/ha was needed to maximize *C. pubescens* yield, but leaching of K was not significant below 15 cm (Gutteridge, 1978b).

**Drainage.** *Centroserma pubescens* is recommended for many low-lying situations (Smith and Whiteman, 1985b). Although it is not as resistant to flooding as *Macroptilium lathyroides* or *Aeschynomene americana*, it is more tolerant of impeded drainage than *M. atropurpureum* or *Neonotonia wightii*.
Biotic constraints

Cutting and grazing. The distinction between the effects of cutting and grazing has special significance for the persistence of *C. pubescens*. The variation in seasonal and species selectivity, the usual preference of ruminants for green grass, and the recycling of nutrients under grazing may favor *C. pubescens*. However, the sparseness of low-set buds for regrowth is a disadvantage in cut-and-remove systems where, in Sri Lanka (Waidyanatha et al., 1984) and Sarawak (Ng, 1976; Ng and Wong, 1976), either poor persistence or low *C. pubescens* content was evident.

The effects of grazing on *C. pubescens* depend, firstly, on whether conditions are shaded: legume proportion is favored by shade such as under coconut palms in the Solomon Islands where the grasses were lost, despite strict control and variation of stocking method (Smith and Whiteman, 1985a; Watson and Whiteman, 1981a).

Secondly, the nature of companion legumes determines the outcome of selectivity and also reflects relative resistance to grazing. At Keluang *P. phaseoloides* was lost before *C. pubescens* as stocking rate was increased (Eng et al., 1978a). In the Solomon Islands, *P. phaseoloides*, *C. pubescens*, and *Mimosa pudica*, respectively, were favored by stocking rates of 1.5, 2.5, and 3.5 an./ha (Watson and Whiteman, 1981a).

Thirdly, the character of the companion grasses may decide legume content. In the benign, well-watered climate of the Guadalcanal Plains, Solomon Islands, *C. pubescens*, after 6 years in association with *Brachiaria mutica*, comprised 50% of the yield and with *B. decumbens*, 25% (Smith and Whiteman, 1985b). Animal production in earlier years was related to legume content in a quadratic function, 15% constituting a desirable minimum. The daily rate of liveweight gain averaged 0.47, 0.38, and 0.28 kg per head on *B. mutica*, *B. decumbens*, and *Panicum maximum* pastures, respectively (Watson and Whiteman, 1981c). *Brachiaria humidicola* was less compatible with *C. pubescens* (Smith and Whiteman, 1985b). There are reports of low legume content in *B. decumbens* pastures, but in western Bali, with *B. decumbens*, *C. pubescens* was maintained at 26%–21% until it was overgrazed and drought-stricken; it subsequently recovered well (Rika et al., 1981). It was estimated that this pasture could support five yearlings/ha with an average biomass throughout of 800 kg/ha. Similarly in a grazing experiment in south Thailand at Lamoe, *B. decumbens* dominated in
the first year but subsequently \textit{C. pubescens} became dominant (S. Duryaprapan, personal communication, 1982).

Fourthly, the level of grazing pressure will usually show a negative relationship with \textit{C. pubescens} content. \textit{Centrosema pubescens} may be well maintained at intermediate stocking rates such as 2.7 an./ha on the Guadalcanal Plains (Smith and Whiteman, 1985b; Watson and Whiteman, 1981c) or 2-4 an./ha of the Kedah-Kelantan breed at Keluang (Eng et al., 1978a).

\textbf{Pests and diseases.} Reference was made earlier (p. 550) to the susceptibility of \textit{C. pubescens} to \textit{Rhizoctonia solani} and cercospora leaf spot and the interaction of their incidence with soil fertility. In Malaysia, the ladybird beetle \textit{Epilachna indica} is especially damaging.

\textbf{Species compatibility and weed control.} Seedling vigor of \textit{C. pubescens} is less than that of some other legumes such as \textit{P. phaseoloides} (Ng and Wong, 1976; Waidyanatha et al., 1984; Wong and ‘t Mannedtje, 1981) or \textit{S. guianensis} (Siota et al., 1977). Moderate rhizobial specificity is sometimes expressed in positive field inoculation responses, as in Laos (Thomas and Humphreys, 1970) and Fiji (Partridge, 1975). These factors influence the initial compatibility of \textit{C. pubescens} with other planted species and the incidence of weeds. \textit{Centrosema pubescens} is tolerant of 2,4-D but is highly sensitive to 2,4,5-T and picloram (Steel and Whiteman, 1980).

\textbf{Use of \textit{Centrosema pubescens} in Farming}

A significant investment of scientific resources in the region has been directed at estimating animal production from \textit{C. pubescens} pastures. Such research has indicated substantial increases in output, relative to pastures deficient in legumes. There have been evaluations of oversown natural pastures in Bali (Rika, 1986) and eastern Indonesia (Ibrahim et al., 1985), the Philippines (Siota et al., 1977), and the Solomon Islands (Smith and Whiteman, 1985b). Evaluations were also made of fully improved open pastures in Johore, Malaysia (Eng et al., 1978b), the Guadalcanal Plains (Watson and Whiteman, 1981c), and Fiji (Roberts, 1970). Despite these demonstrations, the main role of \textit{C. pubescens} has been confined to plantation agriculture. It has had limited success as a base for commercial ranch operations in Malaysia and Indonesia, and small farmers prefer to plant grasses, to cut legume shrubs, or to use
more defoliation-resistant legumes such as *S. hamata* or *S. humilis* cv. Khon Kaen in Thailand, or *D. heterophyllum* in Fiji (Partridge, 1979).

Of those pastures evaluated, *C. pubescens* has been a significant component of pastures grown under coconuts in south Thailand (S. Duryaprapan, personal communication, 1982), Bali (Rika et al., 1981), Western Samoa (Reynolds, 1981), and the Solomon Islands (Watson and Whiteman, 1981a; Smith and Whiteman, 1985a); and under oil palm in Malaysia (Chen and Othman, 1983). Its significant role in plantation agriculture is illustrated by the use of about 925 t seed of *C. pubescens* in Malaysia from 1972-76, while 300 t seed of mixed covers containing *C. pubescens* are estimated as used each year in Thailand (P. Jewtrragul, personal communication, 1986). The use of sheep in rubber plantations in Malaysia and Thailand is expected to increase, following the recent recognition of their role in weed control.

**Research Needs**

**Plant improvement**

For *C. pubescens* and related species, it is necessary to identify germplasm that demonstrates elite behavior in regrowth after defoliation, leaf retention in the dry season, tolerance to acid and low-P soils, resistance to *Rhizoctonia, Cercospora*, and *Epilachna*, and lack of rhizobial specificity. It is also necessary to evaluate effectively nodulating *C. schottii* and *C. sagittatum* lines, and to search for virus-resistant accessions of *C. sagittatum*. Testing *C. pascuorum* in Köppen Aw climates should be continued.

**Seed production**

Systems of seed production of *C. macrocarpum* selections should be investigated at intermediate latitudes. Seed quality of *C. pubescens* produced in the humid tropics also merits attention.

**Plantation agriculture**

*Centrosema* accessions collected from forest and forest-margins should be identified and tested for performance under shade. Grass-legume competition under shade as modified by defoliation, the
nitrogen economy of shade legumes, and shade effects on nutritive value and plant anatomy merit critical research. The effects of stocking rate and stocking method with sheep on the incidence of weeds in *C. pubescens* pastures under rubber require further research.

**Acknowledgments**

The senior author wishes to acknowledge the support from the Australian Development Assistance Bureau.

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Regional experience with Centrosema: tropical Asia and Pacific


Regional experience with Centrosema: tropical Asia and Pacific


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Chapter 22

REGIONAL EXPERIENCE WITH CENTROSEMA: SUB-SAHARAN AFRICA

J. R. Lazier and J. N. Clatworthy*

Abstract

Centrosema pubescens has probably been tested in all countries of sub-Saharan Africa and associated island states in which it was likely to have some chance of adaptation. Most African experience of the genus has been based on this species.

Centrosema pubescens has become naturalized in the wetter areas of western and central Africa and has been reported as promising in a wide range of environments. However, it is little planted outside the research stations. The greater productivity of Stylosanthes guianensis and Pueraria phaseoloides has inhibited its use. However, when locally developed lines of S. guianensis were eliminated by anthracnose in the late 1970s, interest was revived in C. pubescens.

Considerable research has been done on C. pubescens, particularly in mixtures with grasses. It was found valuable as a green manure and/or cover crop. It was also successful as a living mulch for maize, suppressing weeds, and contributing to sustained high maize yields with only small additions of nitrogen.

Trials with other Centrosema species showed that C. pascuorum is promising in Nigeria, Ethiopia, and South Africa; C. schottii in southern Ethiopia; C. plumieri in Tanzania and Zaire; C. virginianum in Kenya and South Africa; and C. brasielianum in Senegal and Nigeria.

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Introduction

Research in sub-Saharan Africa on the genus *Centrosema* has tended to follow the lead of research organizations on other continents, partly because the genus is not native to Africa. Researchers have therefore been dependent on exotic sources of seed for testing. Commercial *C. pubescens*, termed centro in this chapter, has been available for many years and most sub-Saharan African experience is based on this species.

In recent years, with the advent of large collections of *Centrosema* at the Centro Internacional de Agricultura Tropical (CIAT), Colombia, and Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, a greater range of species and genotypes has been screened by national programs in Africa, reflecting the interest, particularly of CIAT, in the genus. The countries mentioned in this paper are presented in Figure 1.

*Centrosema pubescens*

*Centrosema pubescens* has undoubtedly been tested at least once in all of the forty countries of sub-Saharan Africa and associated island states where it was likely to have some chance of adaptation. Although early work frequently found it to be adapted and productive, other legumes were usually more productive, for example, *Pueraria phaseoloides* in wetter areas in Ghana (F. N. A. Odoi, personal communication) and *Stylosanthes guianensis* (stylo) in Côte d'Ivoire (Picard and Fillonneau, 1971) and Burkina Faso (Sikora, n.d.). Research on centro thus normally ceased after small-plot yield trials, and forage research usually concentrated on *S. guianensis*. With the elimination of *S. guianensis* as a viable forage legume by anthracnose in the late 1970s (Lazier, 1984), interest in *C. pubescens* revived and even extended to other members of the genus.

Because much of the African information on *Centrosema* is unpublished, fragmentary, or published in relatively inaccessible literature, this review is partly written as a catalog, with individual regions and/or experiments reviewed in turn. However, generalizations are made in the conclusion. Readers seeking a brief overview of site characteristics where *Centrosema* performed well are referred to Table 1.

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Figure 1. The African continent, showing political boundaries of sub-Saharan Africa. Countries with names in bold face are mentioned in text.
Table 1. Range of characteristics of sites at which good performance of Centrosema species has been reported in sub-Saharan Africa.

<table>
<thead>
<tr>
<th>Species</th>
<th>Latitude</th>
<th>Annual rainfall (mm)</th>
<th>Altitude (m)</th>
<th>Soil type</th>
<th>Total number of sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. arenarium</td>
<td>8° N</td>
<td>Irrigated</td>
<td>1650</td>
<td>basic tufa</td>
<td>1</td>
</tr>
<tr>
<td>C. brasiliannum</td>
<td>11°-14° N</td>
<td>300-1100</td>
<td>~700</td>
<td>—</td>
<td>2</td>
</tr>
<tr>
<td>C. hybrid</td>
<td>18° S</td>
<td>800</td>
<td>1200</td>
<td>silty</td>
<td>1</td>
</tr>
<tr>
<td>C. macrocarpum</td>
<td>8°-11° N</td>
<td>Irrigated</td>
<td>500-1650</td>
<td>basic tufa</td>
<td>2</td>
</tr>
<tr>
<td>C. pascuorum</td>
<td>12°-26° S</td>
<td>650-1500</td>
<td>~1300</td>
<td>clay</td>
<td>8</td>
</tr>
<tr>
<td>C. plumieri</td>
<td>0°</td>
<td>1800</td>
<td>~500</td>
<td>—</td>
<td>3</td>
</tr>
<tr>
<td>C. pubescens</td>
<td>15°-18° S</td>
<td>450-2000</td>
<td>~1700</td>
<td>Vertisols to</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>sandy loams</td>
<td></td>
</tr>
<tr>
<td>C. schiedeanum</td>
<td>8° N</td>
<td>Irrigated</td>
<td>1650</td>
<td>basic tufa</td>
<td>1</td>
</tr>
<tr>
<td>C. schottii</td>
<td>5° N</td>
<td>600</td>
<td>1500</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>C. virginianum</td>
<td>1°-25° S</td>
<td>700-900</td>
<td>700-1650</td>
<td>—</td>
<td>5</td>
</tr>
</tbody>
</table>

SOURCE: Compiled by authors.

Adaptation

Trials have demonstrated that centro can grow in climates ranging from humid to semiarid, and in cooler environments at medium altitudes (1000 to 1700 m) or higher latitudes. However, it has performed best and become naturalized under rainfed conditions in the more humid areas of lowland Africa where rainfall is usually higher than 1100 mm and where there are fewer than 5 months of continuous dry season. In drier areas, it has yielded well in the wet season, but poorly in the dry season when good quality feed is in shortest supply. Dry-season yields can be dramatically increased by the use of irrigation. However, the cooler temperatures associated with the dry season in much of subhumid and semiarid Africa inhibit growth. Other readily available legumes such as Desmodium intortum and D. uncinatum, are more productive under these conditions.

In Ghana, centro grows best in regions of high rainfall in the coastal belt (R. Rose-Innes, personal communication; Wilson and Lansbury, 1958). It has become naturalized in the coastal and forest regions, occurring commonly along roadsides (F. N. A. Odoi, personal communication).

In Côte d’Ivoire, in early testing in three climatic zones, centro had lower productivity than stylo, and the lowest water-use efficiency of the lines tested (Talineau, 1970). It was, however, recommended for use as...
an annual forage, in rotations, and for intensive fodder production (Cadot, 1971). It showed most promise in the Bouaké, Gagnoa, and Abidjan areas (G. Roberge, personal communication), and has become naturalized in the native grasslands from the coast to about 300 km inland (T. Armbruster, personal communication). It grew poorly at Badikaha in 1985, perhaps because of poor fertility or poor nodulation (Buxant and Kouame, 1985).

In Senegal, introduced by IRAT (Institut de Recherches Agronomiques Tropicale & des Cultures Vivrières, France) in 1965 and tested over 2 years, centro was considered to be one of the best legumes introduced (LNERV, 1980 and 1981). It is considered to have particular potential in the Casamance region of southern Senegal which receives higher rainfall (G. Roberge, personal communication). In 1966, it was sown on grey hydromorphic soils and produced 45 t of fresh matter per ha in one cut after receiving a generous application of fertilizer, 8 t dry matter (DM)/ha in two cuts, and 9 t DM/ha in three cuts (Birie-Habas cited in Diatta, n.d.). In the Senegal River Valley, 209 t of fresh matter were obtained over 26 months after high fertilizer inputs (Balsce and Costiaux cited in Diatta, n.d.) and 50 t of fresh matter/ha 5-6 months after sowing (Duclos cited in Diatta, n.d.). It is also reported as having done well at Kolda (Grandemer et al., 1981; Pichon et al., 1982), Sangalkam (Roberge et al., 1981), and Dakar (Valenza et al., 1980). Boudet (1975) recommended it for the sub-Saharan and Guinea savanna areas, and for Vertisols in the Sahelian zone. It was one of the better adapted legumes in Chad under irrigation (IEMVT, 1979).

In Nigeria, centro was shown to be productive in rain forest and derived savanna areas (Ahlgren et al., 1959; Moore, 1962), and reported as promising for northern Nigeria (Agishi, 1971; Akinola, 1975) and the Guinea savanna (Agishi, 1980; McIlroy, 1962). Under irrigation in northern Nigeria, it was less productive than pigeonpea or sorghum (Akinola, 1975). It has become naturalized in areas in which it has been sown, as far north as the derived Guinea savanna.

Centro was introduced to Zaire from Brazil as a cover crop and was considered to be of promise for farming systems in the humid tropic region, the Yangambi vegetation zone in Haut-Zaïre, and the Sudano-Zambesian and Guinea areas (4 months dry season and 1400 mm rainfall) (Risopoulos, 1966). It is currently being tested in a range of environmental zones (J. Gobbe, personal communication).

In Kenya, after initial screening of a broad range of forages in the major environmental zones, centro was recommended for the warm,
wet, medium-altitude region (1500-1700 m altitude and 1250-2000 mm rainfall); the hot, dry, lowland areas (150-900 m altitude and 450-850 mm rainfall); and the hot, humid, coastal region (0-150 m altitude and 1000-1250 mm rainfall) (Ibrahim and Orodho, 1983).

In Ethiopia, centro was initially promising in the medium-altitude region at Bako (1550 m altitude and 1250 mm rainfall) and Awasa (1700 m and 950 mm rainfall) (FAO, 1975).

In Madagascar, centro was tested in 1966 and yields of as much as 16 t/ha were recorded in an area of 1250 mm rainfall (J. H. Rasambainarivo, personal communication).

In Tanzania, centro is recommended for subhumid to semiarid to arid zones (Lwoga et al., 1985). B. Walker (personal communication) reports that it grows at Ukirigrou near Mwanza on Vertisols. It is considered as a useful pasture legume for such soils receiving more than 900 mm rainfall. It has also been one of the better legumes screened for persistence at the Malya Range Station, 120 km east of Mwanza, on loamy sand soil which receives between 450 and 650 mm of rainfall (Kapinga, 1986).

Reported as having potential in Zambia by Verboom (1965), *C. pubescens* was included with siratro (*Macroptilium atropurpureum*), *Neonotonia wightii*, and *S. guianensis* in a list of promising species for Zambian conditions at Mount Makulu, 10 km south of Lusaka (van Rensburg, 1967). A replicated yield trial of these legumes, and *Desmodium intortum*, was established. In five harvests over 2 years, siratro and *N. wightii* usually had higher yields than centro. In spite of a severe drought in December 1965, all but *D. intortum* performed well. Centro also produced reasonably vigorous growth at the Misamfu (Northern Province) and Msekera (Eastern Province) Regional Research Stations (van Rensburg, 1967).

Centro is also reported as being used in pastures under coconuts in Mozambique (Timberlake and Dionisio, 1985); as a cover crop on estates at Nkhata Bay, Malawi (Hodges, 1983); and as naturalized in Central Cuvette, Congo (Blouard and Behaeghe, 1961).

**Nitrogen fixation and nodulation**

African research has shown that centro can fix significant quantities of nitrogen when grown in mixture with grasses, resulting in higher soil and grass nitrogen levels. There have been positive N$_2$ fixation responses...
to the addition of P, and negative responses to liming. Centro usually
nodulates freely with native rhizobium populations.

Moore (1960), in Nigeria, estimated the N₂ fixation in a Cynodon
plecostachyus-C. pubescens association in a replicated grazing trial.
The pure grass had 2280 kg of N/ha to a depth of 30 cm, while the
mixture had 2900 kg of N/ha. Nitrogen fixation by centro averaged
125 kg/ha annually. Further research showed that an annual 280 kg of
N/ha could be fixed by centro in a C. plectostachyus sward (Moore,
1962). The N content of the pure grass was 1.8%, while that of the grass
in the mixture was 2.4%. The addition of P resulted in more N₂ fixation
and, where centro was present, there were higher levels of N in the soil.
Agboola (1970) found higher nitrification rates under centro swards
than under pure grasses. The fixation rates were found to be higher in
sandy loam soils than in loamy sand soils. Higher trace-element
concentrations in the sandy loam soil may have been the cause (Fayemi
et al., 1970). Nodulation and N₂ fixation were greatest in a soil with a
pH of 6.0 and decreased with increase in pH (Odu et al., 1971).

In Ghana, centro was tested with other legumes in plots of three soil
types, limed and unlimed. Along with other parameters, the amount of
nitrogen fixed by plants in their first 60 days of growth was determined.
The nitrogen fixed varied between 8 and 75 kg/ha and 18 and
131 kg/ha for the limed and unlimed soils, respectively. The least fertile
soil, a brownish red sandy loam, had much lower yields than the other
two (a pellic Vertisol and a gray earth gleic Solonchak). Liming reduced
the number of nodules on centro in two of the soils (Dennis, 1977).

In Côte d'Ivoire, a comparison of centro with Vigna unguiculata
showed that centro had more nodules, but acetylene reduction
measurements demonstrated that it fixed less nitrogen. The nodules
were never more than 150 mm underground and, as they were very
sensitive to soil dehydration, fixation decreased abruptly with the onset
of the short dry season. Fixation was less than that of Lablab
purpureus, Vigna radiata, Macroptilium lathyroides, V. unguiculata, S.
guianensis, and more than that of M. atropurpureum. Nitrogen fertilizer
(300 kg/ha of 10-18-18) was added during the trial (Messager and
Samson, 1982).

In Zambia and Burkina Faso, no improvements in yields were
reported from inoculation with Rhizobium (Sikora, n.d.; van Rensburg,
1967). Centro was also reported to nodulate freely in Uganda (Amadu,
1971).
Establishment

While oversowing of centro in natural pastures and rangelands has not usually been successful, it has established readily in well-prepared seedbeds. The recommended sowing rates vary widely, depending on the planting method.

The establishment and persistence of legumes, including centro, in Nigerian rangelands by strip-sowing or oversowing has been poor because of the lack of controlled grazing and burning on communal grazing lands (Saleem, 1985). Adegbola (1964) noted that it was expensive to establish centro by cuttings and that seed was usually readily available.

Various sowing rates have been recommended in Nigeria where centro showed particular promise. These rates range from 4.5-6 kg/ha (Blair-Rains, 1963) to 11-13 kg/ha (Ahlgren et al., 1959). Blair-Rains advised lower rates for row-sowing. Rates as low as 0.8 kg/ha have been recommended in West Africa (Blouard and Behaeghe, 1961). Boudet (1975) recommended that it be planted in rows spaced at 50 to 100 cm at a rate of 3–4 kg/ha.

A depth-of-planting study (Adegbola, 1964) showed that centro should not be planted more than 5 cm below the surface in order to obtain a stand of greater than 50%. In Ghana, on a tropical black earth, optimal germination was achieved at depths from 0 to 2.5 cm (Larbi, 1979).

Pests and diseases have not been reported as significant constraints to the establishment and growth of *C. pubescens*.

Mixtures with grasses

Centro has been found to combine well with grasses in the environments to which it is best adapted. These grasses include, among others, *Pennisetum purpureum*, *Panicum maximum*, *C. plectostachyus*, and *Andropogon gayanus*.

In Nigeria, various authors have reported centro as combining well with a number of grass species such as *Chloris gayana* and *A. gayanus*, in the rain forest and derived savanna areas; and *Pennisetum purpureum*, *Panicum maximum*, and *Cynodon plectostachyus* in rainforest environments (Adegbola and Onayinka, 1966; Ahlgren et al., 1959; Bogdan, 1977; McIlroy, 1962; Moore, 1962). In the southern
Regional experience with Centrocentra: sub-Saharan Africa

Guinea savanna, it has combined well with *P. maximum* (Boudet, 1975; Onayinka, 1973; Onayinka and Akinyemi, 1974).

In the coastal forest zone around Agege, field trials that lasted for more than 18 months were carried out with eight unfertilized grasses in combination with centro. Substantially higher DM yields were produced by the *A. gayanus* mixture, regardless of season and cutting interval (Adegbola and Onayinka, 1966).

At Zaria, in northern Nigeria, centro was either broadcast or drilled between rows of *Brachiaria brizantha* sprigs and fertilized with N-P-K (20:10:10) at a rate of 300 kg/ha. Total yields were less than those of *B. brizantha* mixtures with *N. wightii*, *M. atropurpureum*, *S. guianensis*, and *S. humilis* (SIAR, 1975).

At Shika, in a cutting trial lasting 2 years, centro was the best of eight legumes combined with *B. decumbens*. Yields were best when centro seed was broadcast rather than drilled. Eight-week harvests gave larger yields than 6-week harvests. High or low grass-planting densities did not affect the yields (Akinola, 1981). Centro also combined well with *A. gayanus* and produced the highest legume yields under an 8-week cutting cycle (Akinola and Onifade, 1981). In the Guinea savanna, at Mokwa, it combined well with *P. maximum* var. *trichoglume* (SIAR, 1975).

At Ibadan, centro and *S. guianensis* were grazed in mixtures with *Cynodon plectostachyus* and *Digitaria decumbens*. Whereas *S. guianensis* disappeared, centro persisted for 2 years in the mixtures (Okorie et al., 1965; Olubajo, 1969). After 3 years, centro formed 10%-17% of the swards (Oyenuga and Olubajo, 1975a).

In Ghana, centro mixtures, with *Cynodon plectostachyus*, *D. decumbens*, *C. nlemfuensis* (Antwi, 1976a and 1976b), and the native species *Asystasia gangetica* and *Brachiaria lata*, have been grazed under tree crops (Wilson and Lansbury, 1958). Under cutting, mixtures of centro with *A. gayanus* and *D. decumbens* were also productive (Asare, 1976?; Tetteh et al., 1976).

In the Yangambi Plateau, Zaire, centro combined well with *S. guianensis*, *Brachiaria ruziziensis*, *Setaria anceps*, *Melinis minutiflora*, and *Chloris gayana*. Specific mixtures of species which would cover the ground in 2-3 months were recommended for different environmental and management conditions. In the Lower Congo, centro was also said to combine well with *Imperata cylindrica* (Risopoulous, 1966).
In East Africa, centro has persisted in Tanzania in a mixture with \textit{C. plectostachyus} under grazing for 5 years on a Vertisol near Mwanza (B. Walker, personal communication). It has also been reported as growing successfully with \textit{Cenchrus ciliaris} (Bogdan, 1977) and with a \textit{Brachiaria} species (J. A. Kategile, personal communication) at Morogoro.

In Burundi, centro grows well with \textit{P. purpureum} which is well adapted to the region (Astere, 1985).

When oversown on natural \textit{Hyparrhenia filipendula} grassland and established pasture in Zambia centro was not rated as promising (van Rensburg, 1969). In a mixture with \textit{Cynodon dactylon} and alone at Chitedze Research Station in Malawi, it was not as successful as the pure \textit{C. dactylon} control and its yields were lower than those of other legumes in the trial (Dzowela, 1985).

In Uganda, centro has been successfully combined with \textit{H. rufa} and \textit{P. maximum} (Bogdan, 1977; Stobbs, 1966). Various mixtures with \textit{S. guianensis} and grasses have been used for grazing at Serere Research Station (Otím, 1975; Otím and Laboke, 1975).

**Fertilizer responses**

The application of P fertilizer has been usually found necessary to maintain or increase centro yields. It has also been linked with increased liveweight gains and improved yields of subsequent crops. Gypsum, N, K, and lime have also been found to produce yield increases.

In Nigeria, good mixtures of centro with \textit{C. plectostachyus} and \textit{P. purpureum} were maintained by the addition of 125 kg/ha of superphosphate (McIlroy, 1962). The forage production of centro was doubled and a good stand was maintained when fertilizer (22 kg/ha of \textit{P}$_2$O$_5$ and 67 kg/ha of K$_2$O) was added in split applications (Ahlgren et al., 1959).

In Tanzania, 80 kg/ha of P$_2$O$_5$ increased DM yields only by 126 kg DM/ha, while gypsum and lime produced higher increases (Bogdan, 1977). The application of P to a centro-\textit{C. gayana} mixed sward increased the yield only in the first cutting, while N increased it in both the cuttings taken. Potassium had no direct effect alone, but in combination with N and P there were significant interactions. When P, K, Ca, Mg, and Mn were added as single elements, their concentrations in the tissues usually increased (Materu, 1979). A study of the same mixture found no significant residual effects of N-P-K application on
yields, but soil P was significantly increased. Nitrogen increased the yields of mixed centro-\textit{C. plectostachyus} pastures linearly with increasing rates of application. A slower rate of increase was achieved with the addition of P and K alone, and yield depressions occurred when mixtures of fertilizer elements were added (Uriyo et al., 1979).

In Ghana, the application of 125 kg/ha of superphosphate fertilizer was recommended to maintain a high proportion of centro in mixtures with grasses (Thompson cited in Okorie, n.d.).

In Uganda, the application of 250 kg/ha of single superphosphate to a centro-\textit{H. rufa} pasture resulted in higher animal liveweight gains and increased yields of subsequent crops (Stobbs, 1969).

**Seed and seed production**

Few studies have been done in sub-Saharan Africa on seed yields, hard-seededness, and storage. Seed production has been confined to small plots, except in Ghana where larger areas were planted in the early 1970s.

In Ghana, production of centro seed acquired from Singapore was undertaken at the Pokoase Research Station for the northern savanna region. About 450 kg of seeds were harvested and distributed to farmers in 1973-74. As there was great demand for the seed, a further 40 ha of centro was then established for seed production (CSIR, 1973, 1974, and 1977; Tetteh et al., 1974).

Centro produced considerably lower seed yields in irrigated seed production in Burkina Faso than \textit{Stylosanthes hamata} cv. Verano and \textit{S. guianensis} cv. Schofield, but more than \textit{S. guianensis} cv. Cook. Seed was distributed to Togo, Benin, and Ghana (Sikora, n.d.). Senegal has also reported seed multiplication with yields of 2.9 t/ha (Jacquot cited in Diatta, n.d.).

The hard-seededness of centro has received attention in Ghana (Larbi, 1979) where sandpaper, sulfuric acid for 10 and 20 minutes, and 100 °C hot water for 1 minute all increased the percentage of germination. In Zaire, where centro was found to contain 30% hard seeds, hot water at 55 to 60 °C, and 90 °C dry heat were found to have no effect on the percentage of germination. However, a concentrated \textit{H}_2\textit{SO}_4:\textit{H}_2\textit{O} solution (2:1) for 10 to 15 minutes eliminated hard-seededness (Behaeghe and Blouard, 1962; Risopoulous, 1966).
Centro seeds were found to dry very slowly. In one trial, viability (for 19 months) was maintained best by storage in tubes after 7 days in the seed drier, which reduced their moisture content to 14.2%. Storage in cloth bags after drying in the shade (20% moisture content) gave 12 months of storage with good viability (Behaeghe and Blouard, 1962).

**Fallow cropping**

Centro has been found to be useful as a cover crop, green manure, and living mulch in studies in West Africa where it had positive effects on soil characteristics and yields of succeeding crops.

Centro was tested as a green manure in Zaire where the centro crop was either burned or ploughed in. Ploughing produced superior results in the succeeding crops (N. Lugindula, personal communication).

At Ibadan, Nigeria, centro, three other legumes, and four grasses were grown on an Alfisol as cover crops for 2 years in order to study effects on soil properties and zero tillage for succeeding crops. Centro, as had *Melinis minutiflora*, *Neonotonia wightii*, and *Pueraria phaseoloides*, had significant, positive effects on the levels of organic carbon, total N, and cation-exchange capacity in the soils, compared with the control. Yields of succeeding crops were higher in plots with centro, *P. phaseoloides*, *S. guianensis*, and *B. ruiziiensis* than in the control plots (Lal et al., 1978). In a further trial, using strip tillage on an Alfisol, a centro fallow increased yields in the succeeding maize and cowpea crops and was easy to suppress. Only slight improvements were noted in the soil organic matter, total N, and water retention and transmission. The effect of such improvements was brief (Wilson et al., 1982). Centro was one of the most promising legumes tested as a living mulch with maize. It effectively suppressed weeds and resulted in sustained high maize yields with only small additions of N fertilizer being necessary (Mulongoy and Kang, 1986).

In Côte d’Ivoire, two grasses (*P. maximum* and *C. plectostachyus*) and two legumes (centro and *S. guianensis*) were tested in pure swards as fallow cover crops in a multilocational trial on ferrallitic soils (pH 5-6). Slight improvements were noted in aggregate stability and soil organic-matter content. In some cases, soil aggregates and drainage were increased under the legumes. Variations in chemical analyses depended largely on management and fertilizer applied. There were large increases in N under the cover crops which affected the succeeding crops, but only briefly (Talineau et al., 1976).
Palatability and intake

African studies have found the palatability of centro to be intermediate in relation to other pasture plants, independent of the crude-protein (CP) level, and to vary with the season. The dry-matter (DM) intake was found, in one study, to be related to DM solubility.

In Ghana, yearling rams were found to prefer centro to \textit{P. phaseoloides}, although it was less palatable than \textit{Asystasia gangetica}, a native herb. The physical condition of the plant was noted to affect its palatability, while the CP content did not appear to have any effect. Intake of digestible DM was higher for a centro-\textit{Brachiaria lata} mixture than for pure \textit{P. phaseoloides} or a \textit{P. phaseoloides-B. lata} mixture (Asiedu et al., 1978).

Although centro was the herbage with highest CP content (23\%) in pastures under tree crops in Ghana, the grass \textit{B. lata} (11\% CP) and the herbs \textit{A. gangetica} and \textit{Euphorbia heterophylla} were apparently more palatable. Many other plants which were not selected had higher crude protein levels than \textit{B. lata} (Wilson and Lansbury, 1958). When centro silage was fed to 2-year-old Nungua black-headed wethers, the DM and digestible-energy intake were highly correlated to DM solubility, CP, crude fiber (CF), and pH (Abbey, 1976).

In Zambia, centro and \textit{D. intortum} had higher percentages consumed than \textit{M. atropurpureum} and \textit{S. guianensis} (80\% and 84\%, respectively) (van Rensburg, 1967).

Centro has been reported to be more palatable in the late growing season in Tanzania (Kapinga, 1986) and in the dry season in Uganda (Stobbs 1966; Stobbs and Joblin, 1966).

Nutritive value

Centro has been found to be a high-quality fodder in in vitro and in vivo studies conducted with centro alone and in mixtures with grasses. Sheep and goats, including West African dwarf goats, have been mainly used in the in vivo trials.

Analysis of centro for nutritive value has been done frequently (for example in Nigeria by FMEST (1984), Miller and Blair-Rains (1963), and Oyenuga (1957). Centro-\textit{C. plectostachyus} mixtures from a grazed trial were analyzed over 2 years (Okorie et al., 1965) and had their in vitro and in vivo organic-matter digestibility determined at various ages,
using sheep and goats. The digestibility values did not differ between the 
two animal species while the in vivo and in vitro results were similar for 
6-week-old herbage (51.7% and 52.3%, respectively). The older herbage 
(12 weeks) was poorly assessed by the in vitro method (43.4% and 
34.9%, respectively). The metabolizable energy content increased with 
the age of the forage (Mba et al., 1974).

The concentrations of acetic, propionic, and butyric acids produced 
in the rumens of West African dwarf goats receiving diets of C. 
plectostachyus-centro and P. purpureum-centro mixtures, with and 
without groundnut cake as a supplement, were determined. Animals 
were found to have higher propionic-to-acetic acid ratios when fed the 
concentrate. The higher ratio was recommended for enhancing milk and 
meat production (Mba and Olatunji, 1972).

Other studies on the nutritive value of centro were performed in 
Nigeria. One study examined the intake, digestibility, and N metabolism 
of C. nlemfuensis-centro hay and concentrate supplements in West 
African dwarf sheep (Adegbola, 1974). The energy use of such mixtures 
was also investigated (Olatunji et al., 1976). Grass-legume mixtures 
involving C. nlemfuensis var. robusta, P. purpureum, P. maximum, 
centro, and S. guianensis in a grazing trial were analyzed for nutritive 
value, intake, and digestibility (Oyenuga and Olubajo, 1975a and 
1975b). Mixtures of C. nlemfuensis var. robusta and centro were studied 
to determine the proportion of plants in the plots and their crude fiber 
and leafiness. The results were found to vary with the environment and 
the age of the plants (Aboaba and Govinden, 1975). Mixtures of C. 
plectostachyus and D. decumbens with centro and S. guianensis were 
used to assess the value of the chromic-acid method of determining 
digestibility (Olubajo and Oyenuga, 1970).

Nutritive values of centro have also been reported from Ghana 
(Asare, 1975; Asiedu and Karikari, 1985; Skerman, 1977; Wilson and 
Lansbury, 1958) and Burkina Faso (Sikora, n.d.). The nutritive values 
of centro-grass pasture mixtures have been determined with D. 
decumbens and C. plectostachyus (Antwi, 1976a). The effect of the 
plant’s age (60- to 120-day-old leaves and stems) on nutritive value has 
been reported (Asiedu, 1980): CF and nitrogen-free extract increased 
with age, while CP, ether extract, ash, Ca, and P decreased. The results 
were compared with a number of other legumes. The 40- and 60-day 
CP contents of centro were found to be similar to those of alfalfa 
(Adamu, 1971). When centro silage was fed to Nungua black-headed 
wethers (2 years old), in vitro studies were not closely related to
voluntary intake parameters. Among the forages studied, it had higher DM, higher CP, and better digestibility than either maize or sorghum silage (Abbey, 1976).

The in vitro digestibility of 6- to 16-week-old centro herbage has been studied by Reid et al. (1973) and the oxalic acid contents of *Centrosema* by Ndyanabo (1974). The oxalic acid contents are higher than for most grasses and similar to *S. guianensis*—but, in common with *S. guianensis*, centro has a much lower water-soluble fraction than grasses.

Oxycarotenoid studies were carried out on laying hens fed with whole-maize diets mixed with 5% oven- or sun-dried centro, cassava, or Madras thorn. Centro gave the highest yolk scores of any of the additives, and as high as maize for oven-dried fodder. The oven-dried scores were higher than those for sun-dried material (CSIR, 1973).

**Carrying capacity and liveweight productivity**

Grazing trials have been carried out, using sheep, steers, and cows on pure centro swards and grass-legume mixtures. The introduction of centro to grass swards increased liveweight gains to an annual 464 kg/ha with daily gains recorded as high as 10 kg/ha in the wet season and as low as 6.4 kg/ha in the dry season.

The carrying capacities for sheep on pure centro and mixed centro-grass and centro-herb pastures have been determined in Ghana under tree crops. *Pueraria phaseoloides* pastures have been found to be more productive (Asiedu and Karikari, 1985; Asiedu et al., 1978; Wilson and Lansbury, 1958).

Liveweight gains of 347 kg/ha in year 1 and 302 kg/ha in year 2 were achieved in a replicated trial, using N'Dama cattle on mixed *C. plectostachyus*-centro pastures at Ibadan, Nigeria (Okorie et al., 1965). In northern Nigeria, daily gains of N'Dama steers on *C. plectostachyus, P. maximum*, and *P. purpureum* and their mixtures with centro during the rainy season (April-June) were of the order of 2.2 to 3.4 kg/ha. The daily dry-season production ranged between 0.6 and 0.8 kg LWG/ha (Miller and Blair-Rains, 1963).

Milk production of White Fulani cows in Ibadan measured on grass-centro mixtures (Olaloku, 1972) indicated that the nutrients supplied by the mixtures were sufficient for the animals.
In Ghana, a 2-year replicated grazing trial, using 3.1 West African Shorthorn steers/ha on *D. decumbens* and *C. plectostachyus* in pure swards and combined with centro, produced higher beef yields on the mixed pastures. The mean monthly liveweight gains for the pure grass swards over 9 months were 6.12 and 5.44 kg/ha, respectively, and 9.61 and 7.58 kg/ha for the respective mixtures with centro (Antwi, 1977).

In Madagascar (Razakabaona cited in Rasambainarivo et al., 1985), cattle liveweight gains were obtained in a put-and-take trial on a mixed sward of *C. gayana, M. minutiflora*, centro, *N. wightii*, and *S. guianensis*. Four stocking rates were used and LWGs of 286 kg/ha were obtained.

In Uganda, liveweight gains were measured on a *P. maximum*, *C. gayana*, and centro mixture. Boran-East African Zebu crosses produced 629 kg/ha over 429 days (Stobbs and Whitting, 1970). Centro increased the production of a *H. rufa* sward by 11% to 26%, giving annual liveweight gains of 464 kg/ha. Centro was estimated to provide 28% of the dry-season weight gain and 15% of that of the wet season, contributing 10 kg/month and 6.4 kg/month, respectively (Stobbs and Joblin, 1966).

**Other Centrosema Species and Genotypes**

Because a range of promising *Centrosema* species has become available to researchers only in recent years, there is very limited information available on their adaptation, productivity, or persistence. *Centrosema pascuorum*, *C. macrocarpum*, *C. brasilianum*, *C. schottii*, *C. virginianum*, *C. plumieri*, and new genotypes of *C. pubescens* have all been reported as promising in initial trials in various environments in sub-Saharan Africa (Table 1). *Centrosema pascuorum* appears to be of particular interest for intercropping in small-farming systems in subhumid areas.

In 1978, a range of *Centrosema* species from Colombia was planted in Burkina Faso and all showed good initial growth. *Centrosema virginianum* died out after the first growing season, while *C. brasilianum* was promoted to an irrigated yield trial in 1980 and its herbage was analyzed for nutritive value. It did poorly in the trial compared with other legumes tested. In the Sourou Valley, irrigated *Centrosema* hybrids CIAT 442 and CIAT 438 were promising and subsequently planted in a yield trial in which, however, they performed poorly (Sikora, n.d.).

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In Mali, a range of *Centrosema* species is currently under initial evaluation by the International Livestock Centre for Africa (ILCA) in the subhumid zone. It includes lines of *C. brasiliananum*, *C. pascuorum*, and *C. pubescens*. No results are yet available (H. Hulet, personal communication). A range of *Centrosema* species from CSIRO and the National Research Council, Washington, had been tested by ILCA earlier in the arid zone at Niono (400-600 mm rainfall), that is, *C. brasiliananum* (2 lines), *C. schottii* (2 lines), *C. pascuorum* (3 lines), *C. pubescens* (3 lines), and *C. virginianum* (1 line). However, none showed any particular success under the conditions of the trials.

The ILCA Subhumid Zone Programme, based in Kaduna, Nigeria (1100 mm rainfall), has tested lines of *C. pubescens*, *C. macrocarpum*, *C. brasiliananum*, *C. pascuorum*, *C. arenarium*, *C. schottii*, and *C. plumieri*, originating from CIAT, ILCA, CSIRO, and the Institute for Agricultural Research at Shika, Nigeria. Initial evaluation and pure sward replicated trials have been established. The most promising lines were *C. pubescens* ILCA 9051 (CIAT 5189) for more humid areas, and *C. pascuorum* ILCA 9 and ILCA 9858 (CPI 55697 and CSIRO cross 12/4, respectively) for subhumid areas. *Centrosema brasiliananum* (CIAT 5234, CPI 55696) is also promising. *Centrosema macrocarpum* does not produce seed at the two sites tested (Kaduna and Kurmin Biri), but is productive and stays green through the dry season (M. A. M. Saleem, personal communication). *Centrosema pascuorum* has also performed well in multilocational strip trials at six sites in northern Nigeria with rainfall ranging from 650 to 1500 mm (S. Tarawali, personal communication). When *C. pascuorum*, among other forage legumes, was planted with sorghum, the *C. pascuorum* grew as well as most of the other legumes tested (1200 kg DM/ha), except *M. lathyroides* which grew better. There was no reduction in the sorghum yield (Saleem, 1985).

In Côte d'Ivoire, *C. plumieri* (accession no. 39) gave very poor growth and produced few seeds (30 kg/ha) (CRZM, 1981).

Eleven legumes from CIAT, which included five *Centrosema* lines, were tested in Liberia on a fine sandy loam under 2150 mm rainfall and with 143 kg/ha of P added. Dry-matter yields of 8-week harvests in the first wet season indicated that *S. guianensis* CIAT 136 was by far the most productive legume (22 t/ha). The *Centrosema* lines (C. *pubescens* CIAT 5189, C. *acutifolium* CIAT 5112, and C. *macrocarpum* CIAT 5062 and 5065) gave lower yields (7.6 to 8.9 t/ha) which were similar to those of other legume genera tested. *Centrosema brasiliananum* was severely attacked by rhizoctonia foliar blight (Smith, n.d.).
Centrosema acutifolium, C. pubescens, and C. macrocarpum (CIAT 5112, CIAT 5189, and CIAT 5065, respectively) have been suggested as promising for use in crop rotations, as live mulches, and for pastures with improved grasses (E. G. Smith, personal communication).

The Gambia Mixed Farming Project acquired Centrosema germplasm from CIAT and ILCA (C. macrocarpum, C. brasilianum, and C. pubescens) and tested it as nursery swards and in pure sward replicated trials twice at three locations. The lines tested were not sufficiently drought resistant or early seeding to persist under Gambian conditions (S. L. Russo, personal communication).

In Senegal, it has been reported that the genus Centrosema in general, and C. brasilianum in particular, are promising. General screening started in 1982 at Sangalkam (300-500 mm rainfall), using lines acquired from CSIRO. Most lines showed drought resistance, despite the rainfall being considerably below the levels normally required for persistence (Roberge and Diop, 1983; Valenza et al., 1982).

In Zaire, C. plumieri, C. pubescens, and C. arenarium were introduced by the Institut National pour l'Etude et la Recherche Agronomique (INERA). They were considered to hold promise for farming systems in the humid tropics such as the Yangambi vegetation zone in Haut-Zaïre, where C. plumieri and C. pubescens have become naturalized and most research has been done. Three lines of C. pascoorum and one of C. pubescens are currently being tested in a range of environments (J. Gobbe, personal communication).

In Ethiopia, the Forage Agronomy Group (FLAG) of ILCA has tested a number of Centrosema species and lines in the middle area of the Rift Valley (rainfall 700-900 mm, altitude 1500-1900 m, mainly on basic soils derived from tufa deposits). Centrosema species, however, have usually not been promising. Nevertheless, under irrigation at the FLAG seed multiplication site, C. pubescens, C. macrocarpum, and some lines of C. virginianum have performed well compared with C. plumieri and C. schottii. Centrosema pubescens was tested under coffee on acid Nitosols in the Sodo, Wolaita region (1800 m, 1100 mm rainfall), but failed. None of the species tested in introduction or seed multiplication plots (C. pubescens, C. virginianum, and C. brasilianum) in that region performed well.

An ILCA multilocational replicated trial contained, among other legumes, one line each of C. pubescens, C. pascoorum, C. virginianum,
and *C. brasilianum*. The lines were planted at altitudes ranging from 750 to 1950 m, in soil with pH ranging from 6 to 8.5, available moisture (rainfall and/or irrigation) from 187 to 1322 mm, and a mean annual temperature from 17.4 to 26.3 °C. *Centrosera pubescens* and *C. pascuorum* grew as well as any of the other perennial legumes in the first year but the annual legumes *Lablab purpureus* and *Vigna unguiculata* produced more bulk (A. Russell-Smith, personal communication).

The ILCA Southern Rangelands Programme in southern Ethiopia, with a total of 600 mm bimodal rainfall, has tested a number of *Centrosera* species, but only *C. schottii* and *C. pascuorum* showed any promise after 1 year.

The Australian Centre for International Agricultural Research (ACIAR) Project 8326 in Kenya has screened a number of *Centrosera* species, both in nursery plots and in replicated pure sward yield trials at Katumani (elevation 1600 m, rainfall 700 mm) and at Kiboko (elevation 1000 m, rainfall 550 mm). Preliminary results indicated that *C. pubescens* (CPI 63895) and *C. virginianum* (CQ 2748 and CPI 91142) are promising at Katumani, showing persistence, excellent growth in the cool dry winter season and good seed production. It is thought that *C. plumieri*, *C. schottii*, and possibly *C. virginianum* may prove useful for wetter areas. Research sites are therefore being extended to Kitui (1160 m altitude and 1080 mm bimodal rainfall) (W. M. Beattie, personal communication).

In Tanzania, nine lines of seven species of *Centrosera* were introduced, along with other leguminous germplasm, into the lower coffee-banana zone of the Kilimanjaro-Arusha region (800-1200 m altitude, 800-1600 mm rainfall). *Centrosera brasilianum* performed poorly; *C. pascuorum*, *C. schiedeanum*, *C. schottii*, and *C. macrocarpum* lines had moderate success; and centro and *C. plumieri* were among the most vigorous legumes tested. All lines were affected to some extent by pests and diseases. None were considered to be sufficiently promising to continue development (Laurent, 1986).

In Madagascar, *C. plumieri* was tested in 1962 and was found to be not well adapted (J. H. Rasambainarivo, personal communication).

In Zimbabwe, at the Grasslands Research Station at Marondera (1640 m altitude, 900 mm rainfall, sandy soils), the *Centrosera* hybrid CIAT 438 and *C. virginianum* CPI 39060 performed well initially. However, the hybrid produced no seed and the *C. virginianum* did not
persist under grazing. At the Henderson Research Station (1200 m altitude, 880 mm rainfall, silty crusting soils) the Centrosema hybrid CIAT 438 and a C. virginianum line were initially promising. Centrosema schottii and C. pascuorum lines did poorly at both sites. Although the Centrosema accessions tested did not appear to be vigorous or persistent enough to be used in pastures, they are receiving further attention because of increasing research emphasis for small farms.

In the Transvaal region of South Africa, C. pascuorum CPI 55697 and C. virginianum CPI 40057 were introduced in 1983 and established in nurseries in the Burgershall Research Station (720 m altitude, 970 mm rainfall, 40% soil clay content). The C. pascuorum grew well, had good seed yields, and combined well with sorghum when planted in alternate rows. Centrosema pascuorum cv. Calvalcade was very successful at Towooomba Research Station (1130 m altitude, 630 mm rainfall, 25°54' S and 28°20' E, on a clay soil). Seed of cv. Cavalcade will be multiplied for use in an animal production trial. The C. virginianum CPI 40057 was not promising at Burgershall but grew well at Nelspruit in 1985 (677 m altitude, 803 mm rainfall, 25°27' S, 30°58' E, on sandy soil). Another C. virginianum line (CPI 78360) was also promising. Centrosema virginianum will be tested for shade tolerance with a view to using it as a lower storey crop in subtropical fruit orchards (A. J. Kruger, personal communication).

Recommendations for Research

Because of the recent considerable increase in numbers of available species Centrosema and accessions and because some have demonstrated considerable potential, a screening program to test the adaptation and performance of representative genotypes should be undertaken in sub-Saharan Africa. Particular attention should be paid to testing species which have been persistent and productive in CIAT trials on acid soils at medium and low altitudes, for example, C. acutifolium, C. brasiliannum, and C. macrocarpum, in homologous African environments in East and West Africa.

Of the recently available species, C. pascuorum has been the most widely tested in Africa. Most researchers found it relatively successful as an intercrop which does not compete strongly with crops and yet, because of its potential to fix nitrogen, may be particularly useful in small-farming systems.

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The genetic diversity which is available in *C. virginianum* also should be broadly tested. Germplasm from cooler environments of the New World subtropics and tropics may be successful at lower latitudes or higher altitudes in Africa.

Germplasm representatives of the diversity in these species should be obtained by ILCA from CIAT and CSIRO. ILCA would then be responsible for multiplying seed and distributing it to researchers in Africa, either individually or through such forage research networks as PANESA (The Pasture Network for Eastern and Southern Africa), the national forage networks in Ethiopia, Kenya, and Tanzania, the Southern African Grassland Society of Zimbabwe, and possible new networks.

Researchers should be encouraged to test this germplasm in ways that are relevant to local farming systems such as undersown in annual and perennial crops, intercropped, and as temporary leys. Care should be taken to avoid giving greater emphasis than is relevant to research on permanent pastures.

**Conclusions**

Despite a considerable amount of research having been done throughout the continent on centro in the 1960s it remains of little importance anywhere in sub-Saharan Africa. This is largely because research and extension organizations and infrastructure for developing livestock-based industries are undeveloped, rather than because centro lacks potential.

Some of the *Centrocoma* species, whose screening has begun only recently, appear promising for small farmers in a range of environments at lower elevations. However, their yields are not high and their advantages compared with species of other genera are not marked. The advantages of growing *Centrocoma* species are therefore not readily evident to farmers. The basic constraints to the industry will continue to impede the broad use of adapted *Centrocoma* genotypes or any other forage.

**Acknowledgments**

The authors are indebted to the large number of respondents to their queries on research on *Centrocoma* in sub-Saharan Africa.
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Regional experience with Centrosema: sub-Saharan Africa


Regional experience with Centrosema: sub-Saharan Africa


Chapter 23

FUTURE RESEARCH ON CENTROSEMA

J. M. Toledo*

Abstract

The potential contribution of Centrosema to tropical and subtropical agriculture was highlighted throughout all the presentations and working group sessions of the 1987 Centrosema workshop held at the Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia. This paper is a composite summary of recommendations for continuing research with Centrosema. These recommendations arose from working group discussions held at the workshop.

At the basic research level, the recommendations touch upon a wide range of activities, including taxonomic studies; germplasm collection, maintenance, conservation, and description; physiological and anatomical studies with particular reference to tolerances of various kinds, symbioses with soil microorganisms, and relationships between seed production and environment; reproductive behavior and species compatibility; nutritional quality; and methodological research related to screening breeding, fertilizer requirements, nutrient recycling, evaluation under grazing and in silvopastoral systems, and onfarm research.

Suggestions for applied research emphasize technology transfer to farmers' fields and production systems. They include studies related to the potential of Centrosema for pastures and other uses, inoculation trials, minimum cost establishment techniques, seed multiplication, onfarm validation, and adoption studies.

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Suggestions for international cooperation include strengthening research networks; collaboration regarding germplasm movement to prevent spread of pests and diseases; release of promising material; and publication of information.

Highlighted is the necessity of better matching future research and development objectives, emphases, and strategies to farmers’ needs in each region or country.

Introduction

This paper is based on the contributions of the papers presented at the 1987 *Centrosema* workshop and of the seven working groups that were set up during the workshop to consider research priorities. The seven groups discussed germplasm development and management; agronomy and pasture management; plant health and breeding; mineral nutrition and rhizobiology; seed production; nutritional value and animal production; and onfarm research and technology transfer. The members of the groups are named in the following list:

Group 1: Germplasm development and management
- R. J. Lazier (Chairman)
- N. M. S. Costa
- A. E. Kretschmer, Jr.
- J. Menéndez
- R. Schultz-Kraft
- R. J. Williams

Group 2: Agronomy and pasture management
- E. A. S. Serrão (Chairman)
- Chee Yan Kuan
- A. J. Flores
- B. Grof
- G. Keller-Grein
- E. A. Pizarro
- J. M. Spain
- D. Thomas

Group 3: Plant health and breeding
- J. W. Miles (Chairman)
- R. J. Clements
- S. L. Lapointe
- J. M. Lenné
- M. I. de O. Penteado
- A. Serpa

Group 4: Mineral nutrition and rhizobiology
- Wong Choi Chee (Chairman)
- R. Sylvester-Bradley
- G. Cadisch
- R. A. Date
- J. G. Salinas
- R. M. Schunke
- S. M. Souto
- J. K. Teitzel

1. International workshop on *Centrosema*: Biology, agronomy, and utilization, held February 23-28, 1987, at CIAT (Centro Internacional de Agricultura Tropical), Cali, Colombia.
Future research on Centrosema

Group 5: Seed production
L. R. Humphreys (Chairman)
R. P. de Andrade
P. J. Argel
J. E. Ferguson
M. Fisher
M. A. Moreno R.
A. Peralta M.
R. C. Pérez
C. A. Reyes

Group 6: Nutritive value and animal production
O. Royo Pellarés (Chairman)
L. E. Hoyos
C. E. Lascano
P. E. Mendoza
J. B. da Veiga

Group 7: Onfarm research and technology transfer
R. Vera (Chairman)
E. Böhnert
J. N. Clatworthy
R. T. Paterson
C. Seré
A. Topark-Ngarm

During the workshop, the potential contribution of Centrosema to the agricultural development of the tropics and subtropics was highlighted. This potential is considerable, not only for grass-legume pastures but also for cover crops, nitrogen fixation, and green manure crops. It was pointed out that most of the Centrosema research work and development have been carried out with C. pubescens only. Studies with other species have intensified only during the past 10 years. It was recognized that the adoption of C. pubescens by livestock producers is only minor. However, the abundant experimental information proves that this genus has promise for a range of production systems in different ecosystems of the tropical and subtropical world.

Research, promotion, and development is more difficult for pasture legumes than for grasses. The contribution of legumes must be weighed against the higher costs, inputs, and management required for their maintenance in the pastures. The challenge for researchers is to develop technologies for Centrosema that are consistent with the availability of natural resources and the socioeconomic situation of the farmer. This is the only way to make local and regional adoption possible and create a positive socioeconomic and environmental impact.
In this paper, the working-group discussions and their resulting recommendations are summarized into suggestions that intend to facilitate scientific progress with *Centrosema*. Priorities for basic methodological and applied research are outlined, to allow a rapid transfer to the farmer of technologies based on *Centrosema* spp.

**Suggestions for Basic Research**

Basic research is essential for the progress of applied research; nevertheless, the direct benefits are less tangible to farmers. This research level usually requires high investments in terms of equipment, highly skilled scientific personnel, operational resources, and time. Thus, the institutions that should carry out this sophisticated research are the academic institutions (universities) and research centers with major resources. A list of priority topics for basic research is as follows:

**Taxonomic review of the *Centrosema* genus**

The taxonomic key presented during the workshop is new and updated. In order to make the necessary adjustments for its practical use, it must now be reviewed and tested by researchers interested in *Centrosema*. Future taxonomic study should include the genetic characterization of material, using electrophoresis and including isozymes and other chemical methods to correctly classify new collections.

**Collection of germplasm**

There are regions where native *Centrosema* germplasm has not yet been collected. Among these, priority should be given to:

Southeast Brazil, in order to increase the variability and complete the collections of *C. acutifolium*, *C. grandiflorum*, and *C. brachypodum*. These collections should provide material with high seed-production potential under short-day conditions.

Subtropical South America, including Paraguay, southern Brazil, and northern Argentina. Collection in this region is particularly important in order to provide alternatives for the subtropics where an important constraint is frost.
The region comprising Mexico, Central America, and the Caribbean. Collections should aim at widening the variability of poorly collected species for this region such as *C. macrocarpum* and *C. schiedeanum*.

**Maintenance and conservation of a base collection**

In discussion, particularly in the germplasm development and management working group, priority was given to the definition of responsibilities for maintenance and conservation of base collections. It was recommended that the Centro Internacional de Agricultura Tropical (CIAT) be responsible for maintaining and preserving a *Centrosema* base collection. In order to avoid confusion and duplication, all germplasm references should include the CIAT accession number as well as the number assigned locally. Consequently, it is suggested that CIAT should produce a world catalog of *Centrosema*.

**Definition of germplasm descriptors**

The initial characterization of the collected material should be done in a consistent manner. For such a purpose, it will be necessary to define a list of descriptors that characterize the germplasm with respect to such features as agronomic potential, and mechanisms of reproduction and survival (phenology, root production at the nodes, rhizomes). The use of quantitative descriptors for the main attributes, together with the use of subjective observations to complement the list of measured variables, is also important.

This quantitative and qualitative information must be incorporated into databases that are cross-referenced to the environmental parameters of the evaluation sites to allow an efficient and global use of the germplasm.

**Physiological and anatomical studies**

These studies are necessary in order to understand the mechanisms of adaptation and tolerance to negative environmental conditions. They will provide a base of knowledge for future breeding projects and definition of utilization possibilities and management strategies for farmers. Priority topics for research are:
Adaptation to acid, low-fertility soils. These soils are defined as having high aluminum and iron concentrations, and being low in phosphorus and cation-exchange capacity. Because they are implicated in adaptation to Al and Fe toxicity, the anatomical characteristics and physiological mechanisms of root membranes and the role of the rhizosphere should be studied. In order to understand the ability of some Centrosema spp. to grow in poor and unbalanced soils, the absorption capacity of deficient nutrients such as P, Ca, K, Mg, and S, should also be studied, as well as the tissue-nutrient level and its interaction with the metabolism.

Tolerance to drought and flooding. Some Centrosema species and accessions are tolerant to both conditions. Nevertheless, the physiological and anatomical responses to these constraints are not clear enough and should be investigated. Emphasis should be given to the reaction of foliage under conditions of water deficiency, and to root functioning under saturated-soil conditions and flooding.

Shade tolerance. Centrosema pubescens is recognized as a shade-tolerant legume in plantations. Nevertheless, the mechanisms of adaptation to low radiation are not well understood and require further study. This is important in order to better select superior materials for plantations and agroforestry systems. Among the mechanisms to be studied are the light-saturation level, and plant reaction in terms of leaf area expansion and stem elongation. The depth of root systems and capacity to use available superficial versus deep soil water, should also be studied.

Resistance to fire. The level of tolerance to fire in Centrosema spp. is unknown, as are the anatomical and physiological mechanisms of survival during fires. Some species appear to survive fire by developing shoots from meristems underneath the soil surface. This is particularly important when selecting Centrosema for savanna environments where burning is common practice.

Symbiotic studies on Centrosema spp. with N₂-fixing bacteria and mycorrhizae

These symbioses are recognized as important mechanisms for adaptation to acid, low-fertility soils. The genotype specificity in the symbioses with mycorrhizae and rhizobia must be analyzed, together with the effect of nutrients on the uptake and assimilation of nitrogen and phosphorus. It is also important to continue to broaden and
characterize the collection of rhizobia and mycorrhizae. Emphasis should be given to the selection of strains of high effectivity and competitiveness in different soils. Research should also be carried out to develop inoculants of low cost and high reliability under farm conditions.

**Physiological studies on seed production and its interaction with the environment**

There is a need for studies of physiological factors affecting the flowering and seed production of promising accessions of *Centrocoma* spp. The photoperiod effect, and its interaction with temperature in relation to critical physiological stages of the plant, should be analyzed. The effect of water availability at different physiological stages should also be studied.

**Studies on genetic and reproductive compatibility**

Studies must be done on *Centrocoma* spp. regarding the biology of flowering, pollination mechanisms, and reproductive compatibility among species; natural-outcrossing rates and identification of gene markers; possibilities of in vitro selection; and gene transfer. It is recommended that these basic studies be undertaken only in research centers highly equipped for such a purpose. These techniques may be used by applied research centers once the routines are established and their comparative advantage in relation to traditional methods has been defined.

**Basic studies on nutritional quality**

Studies should include the separation of quality components such as animal preference, consumption, digestibility, nitrogen degradability, antiquality factors such as polyphenols and organoleptic substances, and anatomic plant characteristics. These quality components should be related to plant physiological stages, and to climate and soil environmental conditions.

**Suggestions for Methodological Research**

Basic research includes the development of methodologies that would measure, in detail, specific phenomena that may elucidate proffered
hypotheses. These methods either already exist and need further development or adjustment, or must be specifically developed by basic research scientists.

In contrast, applied researchers and extension workers are under pressure to achieve rapid results. These pressures, and the lack of time and resources for methodological research, force applied researchers to follow methodologies already established without reexamining them. Consequently, the process of applied research in pastures is often deficient and the results obtained difficult for farmers to accept.

Research on approaches, methods, and techniques for efficient and effective pasture development is necessary. This will help lower the cost and reduce the time required for the development of new Centroserma-based pasture technologies relevant to farmers' needs.

This methodological research must be carried out by larger applied research institutions, with the support of basic research institutions. The objective is to ease the development of a reliable and rapid research process in smaller applied research institutions.

Because this methodological research is not exclusive to the Centroserma genus, a few aspects require development and adjustment. These are:

**Methodologies to screen Centroserma germplasm for adaptation to environmental conditions in different ecosystems**

A methodical approach is necessary to guide breeders and agronomists to a clear analysis of the problems to be solved. The orientation must include the definition of an experimental methodology, measurements, and observations that directly relate to the selection of materials.

The methods of assessing total annual dry matter (DM) productivity must be used only when the region has no contrasting seasons. In regions of contrasting seasons, Centroserma germplasm should be evaluated for its seasonal reactions in terms of DM yield, diseases, and pests. It is particularly important to evaluate stoloniferous development, regrowth from stolons and underground meristems, and leaf-retention capacity during drier periods.
Methodologies to evaluate the resistance of *Centrosema* spp. to pests (chewing insects, suckers, thrips, and mites) and diseases (rhizoctonia, cercospora, bacteriosis, and virus)

New methods should enable the identification of pests and diseases, and to assess potential biological and economic damage when *Centrosema* spp. are exposed to grazing. Such capacity to forecast is particularly important when selecting cultivars for farmers in order to reduce the use of applied-research resources to solve problems that arise once *Centrosema* cultivars become commercially available.

Methodologies to determine the appropriate time to start breeding projects

The high costs and large amount of time required by breeding projects, and the tendency of scientists, even in small applied-research institutions, to prematurely undertake such projects, should be analyzed. A systematic procedure should be developed to analyze the convenience and potential payoff of a breeding project versus the likelihood of solving problems through selection from natural variability within the species or through the use of other species.

Methodologies to determine fertilizer requirements for establishment under diverse soil conditions

Emphasis should be given to the definition of methodologies for greenhouse and field experiments that will rapidly, simply, and reliably identify critical elements and determine applicable levels. These methodologies should provide for the study of more than one element in simple experimental designs.

Methodologies to evaluate nutrient recycling

The dynamics of the different nutrient pools in the pasture system (soil-detritus-plant biomass-animals) need to be studied when undertaking nutrient recycling experiments to determine maintenance fertilizer requirements. Emphasis should be given to the development of methodologies that quantify the dynamics of macronutrients such as nitrogen, potassium, magnesium, calcium, and sulfur. Phosphorus, as a
slow-moving element, should, however, be studied in terms of its status in time to allow normal plant growth. It is therefore important to improve the sensitivity of analytical methods for determining low P levels in the soil. In general, soil-P determinations need to be standardized to improve reliability between laboratories. Similarly, analytical methods for the determination and study of P in plant tissue can also be improved. For example, recent works suggest that a technique comparing active with total phosphorus may be a better guide to the availability of P.

Methodologies to evaluate *Centroisma*-grass mixtures under grazing

In the development of new pasture options, it is more important to select and promote mixtures that will tolerate a range of options in management and use than to simply study the specific management required for the use of a particular mixture. A reliable, systematic approach to exposing new *Centroisma*-based pastures to relevant but differing managements, and to measure their effects on animal productivity and stability, is important for the development of those *Centroisma* pasture technologies that will be adopted by farmers.

Methodologies to evaluate *Centroisma* spp. in silvopastoral systems

Silvopastoral integrated production systems are particularly important for humid and subhumid conditions. Research methodologies for studying plants, animals, and trees require evaluation and further development. Similarly, screening methods to select accessions of *Centroisma* spp. for adaptation (competition for light, soil, water, and nutrients) to specific plantation systems should also be further developed.

Methodologies of early onfarm exposure of promising *Centroisma* spp. pastures

There is a need to develop analytical modeling and research steps that will allow the rapid transfer of new technological options from the research station to the farmers’ fields. At the same time, feedback on farmers’ needs and opinions must be efficiently obtained.
Depending on the objectives and promise of the new technology, different approaches must be developed for onfarm experiments and evaluation. These should consider different levels of intervention by researchers and/or extension workers in relation to farmers’ management with respect to the present situation and to future evaluation of the farming system. The development of methodologies for an effective incorporation of the farmers’ perspective and input is particularly important to the whole applied research process.

**Organization and methods to transfer and promote the new Centrosoema-based technologies to different “sets” of anthropological, socioeconomic, and political conditions**

The process of releasing new plants, catalyzing commercial seed production, promoting adoption by farmers, and defining responsibilities of institutions in this total process is particularly important, considering the lack of significant adoption of Centrosoema pastures in the past.

**Suggestions for Applied Research**

Applied research addresses the development of improved production economy through efficient use of Centrosoema germplasm and natural and socioeconomic resources available to farmers. In order to attain this, the researcher and/or extension worker must be permanently conscious of the farmers’ problems, and of the relative potential impact of new technology, given the varying availability of different resources at the farm level.

Applied research on pastures requires a wide coverage in space and time. Scientists and extension workers of relevant institutions must participate at many locations to cover the respective target areas. To date, through basic research, the genetic variability of the Centrosoema genus has been broadened and characterized. Furthermore, through applied research at multiple locations, promising accessions have been evaluated. Because of this combination of efforts, there is today a significant body of knowledge on the range of adaptation of promising accessions and cultivars of many Centrosoema species. In addition, there is considerable information on their potential contribution to animal production, and their sustainability in pastures. Nevertheless, these potentials have not yet flowed through to the farmers.
Some suggestions for applied research are listed below, emphasizing the transfer of technology to the farmers' fields and production systems.

**Potential of Centrosera-based pastures**

The best selections, adapted to soil, climate, and biotic factors, should be rapidly established in mixtures with different grasses for evaluation under a range of grazing managements. The role of the legume should be evaluated and documented in terms of its contribution to animal productivity and pasture persistence. These studies should allow for economic analysis. Some of these trials may be used by multidisciplinary teams for evaluation of nutrient cycling with emphasis on nitrogen.

**Other potential uses**

Other potential uses of promising Centrosera accessions should be explored. Green manure, cover crop, protein bank, and cut-and-carry options should be considered. These will allow promising accessions to be used in diverse ways.

**Need for Rhizobium inoculation**

Through simple trials, the capacity of promising Centrosera accessions to establish effective symbiosis with the native Rhizobium should be determined. The objective is to ascertain the necessity of inoculation in order to optimize the N₂-fixing capacity of the legume. This should be done under a wide range of soil conditions, representing the region where the material is to be used. If necessary, emphasis should be given to the selection of competitive, effective Rhizobium strains.

**Minimum-cost, low-risk, pasture-establishment techniques**

Research directed to the reduction of costs and risks in the establishment of pastures with promising Centrosera species should be undertaken as a major task. Common causes of establishment failure are poor initial vigor and lack of aggressiveness of selected materials at seedling stage, poor weed control, inadequate fertilizer application, and
poor physical conditioning of the soil. Farmer adoption would be greatly enhanced through the development of cheap and reliable pasture-establishment techniques.

**Seed multiplication**

Experience shows that the development of commercial seed production of new legumes by private enterprises is often difficult. Also, the lack of experimental seed often creates a bottleneck to the rapid movement of new *Centrosema* selections to grazing trials and onfarm research. In order to demonstrate new *Centrosema* spp. on a large enough scale (at least 10 ha of pasture per farm), research programs must include experimental and basic seed multiplication. These actions should be backed by appropriate organizations and financing within the respective pasture programs.

At the same time, these seed multiplication units should be responsible for the development and adjustment of efficient and economic technologies for commercial seed-production systems. The definition of quality standards with respect to viability, purity, and hardness of commercial seed will also be their responsibility. Standards must be relevant to production conditions and farmers' need in those areas where the cultivar is to be adopted.

**Onfarm validation**

Onfarm trials with *Centrosema* accessions that experimentally have proven the most promising and/or have reached cultivar status should be established and followed carefully. The aim is to expose new technology to real use conditions, and to obtain valuable feedback on farmers' opinions and needs. This work requires the joint participation of researchers, extension workers, and farmers.

**Adoption studies of *Centrosema* spp.**

Regional studies to document adoption and success of *Centrosema* cultivars in mixed pastures, or in any other form of use, are recommended. The adoption of *C. pubescens* in mixed pastures in Australia, the Brazilian Amazon, and in Malaysian plantations should be documented and studied.
Suggestions for International Cooperation

International cooperation mechanisms for pasture research and development already exist. Nevertheless, cooperation on *Centrosem* a has to be strengthened. In order to achieve this, the following steps are recommended:

**Strengthening and consolidating research networks on pastures**

Regional evaluation of germplasm by RIEPT (Red Internacional de Evaluación de Pastos Tropicales) in tropical America, PANESA (The Pasture Network for Eastern and Southern Africa) in Africa, and the Pasture Network of Southeast Asia coordinated by CSIRO (Commonwealth Scientific and Industrial Research Organisation) and financed by ACIAR (Australian Centre for International Agricultural Research), should be strengthened and expanded. In addition, these networks must establish clear and solid cooperative connections among themselves, as well as with centers of advanced research in other regions.

CIAT, ILCA (International Livestock Centre for Africa), and CSIRO must continue the responsibility for preselecting material adapted to major ecosystems, and for the initial multiplication and distribution of experimental seed. This includes the responsibility of interchanging results and maintaining close communication with the network participants who make the final selections. The institutions that coordinate these networks should also undertake fundamental and methodological research to support their collaborators.

Emphasis should be given to methodological research that supports applied research which addresses farmers’ problems. In this way, duplication of effort will be avoided, resulting in more efficient and effective pasture research and development with *Centrosem* a.

**Reduced movement of pests and diseases**

Genetic resource scientists and pathologists should collaborate to avoid transfer of seed-borne diseases. This is particularly important, because the interchange of germplasm will continue to be essential in the future. It is vital that diseases and pests not be spread if possible.
Release of promising materials

Certain *Centrosema* species and accessions that have not yet been released commercially have high potential. This potential should be documented, and release for the appropriate environments should be expedited. Seed of these accessions should be available to the international cooperation networks.

Publishing information

Effort should be made to publish all research and development experiences with *Centrosema*. It is particularly important to share information at present “hidden” in personal records. In fact, a particularly valuable feature of the 1987 *Centrosema* workshop was the effort made by participants to glean and summarize previously unpublished data.

Final Comments

The 22 preceding chapters of this volume document the large amount and high quality of research already done with *Centrosema*, particularly *C. pubescens*. In conclusion, *Centrosema* offers multiple options to improve agricultural production, but adoption by pasture growers is so far limited in most countries. The extent to which past research has been sufficiently development-oriented is debatable. An important goal, therefore, is to better match future research and development objectives, emphases, and strategies to farmers’ needs in each region or country.
Appendix I

COLOR PLATES

The *Centroserma* species recognized by Williams and Clements (*see* Chapter 1) and the symptomatology of important *Centroserma* diseases described by Lenné et al. (*see* Chapter 7) are illustrated in color on plates I to IX, and X to XI, respectively. The *Centroserma* species are presented in alphabetical order, but exclude *C. dasyanthum*, *C. heptaphyllum*, and *C. tapirapoanense* because no photographs of living plants are available. The photographs were provided by Drs. R. Schultze-Kraft and R. J. Clements (*Centroserma* species) and Dr. J. M. Lenné (diseases of *Centroserma*).
Color plates

Color plate I

Figure 1. *C. acutifolium*.

Figure 2. *C. acutifolium* (seed-production plot).

Figure 3. *C. angustifolium*.

Figure 4. *C. arenarium*.
Color plate II

Figure 5. *C. arenicola*.

Figure 6. *C. bifidum*.

Figure 7. *C. brachypodum*.

Figure 8. *C. bracteosum* (at collection site).
Color plate III

Figure 9. *C. brasilianum.*

Figure 10. *C. brasilianum* (seed-production plot).

Figure 11. *C. capitatum.*

Figure 12. *C. carajasense.*
Figure 13. C. coriaceum.

Figure 14. C. fasciculatum.

Figure 15. C. grandiflorum.

Figure 16. C. grazielae.
Figure 17. *C. jaraguaense* (non-flowering plant at collection site).

Figure 18. *C. latidens*.

Figure 19. *C. macrocarpum*.

Figure 20. *C. macrocarpum* (seed-production plot).
Color plate VI

Figure 21. *C. pascuorum* (close-up of flower).

Figure 22. *C. pascuorum*.

Figure 23. *C. platycarpum*.

Figure 24. *C. plumieri*. 

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Color plate VII

Figure 25. *C. pubescens*.

Figure 26. *C. rotundifolium* (at collection site; with underground pods exposed).

Figure 27. *C. sagittatum*.

Figure 28. *C. schiedeanum*.  

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Color plate VIII

Figure 29. *C. schottii*.

Figure 30. *C. "tetragonolobum."*

Figure 31. *C. triquetrum*.

Figure 32. *C. venosum* (at collection site).
Color plate IX

Figure 33. *C. vetulum*.

Figure 34. *C. vexillatum*.

Figure 35. *C. virginianum*.

Figure 36. *Centrosema* new sp. No. 4.
Color plate X

Figure 37. Cercospora leaf spot symptoms on *Centrosema pubescens* leaflets.

Figure 38. Anthracnose pod lesions on a *Centrosema pubescens* pod.

Figure 39. Rhizoctonia/phoma/phomopsis leaf-spot complex symptoms on a *Centrosema acutifolium* leaf.

Figure 40. Cylindrocladium leaf spot symptoms on *Centrosema acutifolium* leaflets.
Color plate XI

Figure 41. Rhizoctonia foliar blight (RFB) symptoms on *Centrosema brasilianum* plants.

Figure 42. Damage caused by RFB to a *Centrosema brasilianum* plot.

Figure 43. Pseudomonas leaf spot and dieback symptoms on *Centrosema acutifolium* plants.

Figure 44. Centrosema mosaic virus symptoms on a *Centrosema macrocarpum* plant.
Appendix II

SUMMARIES OF POSTER PRESENTATIONS AT THE 1987 CENTROSEMA WORKSHOP

During the workshop, opportunity was given to delegates to present posters on relevant Centrosema work. Four posters were presented, and their summaries are included in this appendix.
Studies on the Floral Biology and Reproductive System of *Centrocoma macrocarpum* Benth.

G. Escobar and R. Schultze-Kraft*

During plant introduction work in Colombia, it was observed that *Centrocoma macrocarpum* flowers and sets seed in the field, but despite profuse flowering, fails to set seed under greenhouse conditions. This contrasts with the behavior of all other *Centrocoma* species studied so far, for which no major seed-setting differences have been observed between field and greenhouse. Mechanisms of pollination and reproduction of *C. macrocarpum* were therefore studied. These studies were conducted between January 1984 and August 1985 on experiment stations of the Centro Internacional de Agricultura Tropical (CIAT) at Palmira, Valle del Cauca, and Santander de Quilichao, Cauca, Colombia. The tests for pollination and reproduction modes were carried out through isolation and/or protection of plants or inflorescences from insects, and by manual pollination. Analysis of pollen dispersion by insects was done through marking pollen with fluorescent powder.

*Centrocoma macrocarpum* has bisexual, conspicuous, papilionate flowers, cream in color with purple lines or blotches along a yellowish central stripe on the vexillum. Flower development takes 8-10 weeks from anthesis to ripe pod.

The tests for reproduction mode indicate that pollination occurs naturally only when flowers are visited by large insects such as bumblebees. Pollination by wind does not occur. Tripping by hand usually leads to pollination; plants are, therefore, self-compatible. However, successful hand-pollination of emasculated flowers with pollen from other flowers showed that there are no cross-pollination barriers. Only in one accession (CIAT 15233), out of a collection of

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several dozen accessions tested, was seed-setting of an isolated, untripped plant observed. This case of a spontaneous self-pollination may be genotype-determined and/or a response of the plant to a particular, unknown environmental stress. It suggests that *C. macrocarpum* is facultatively autogamic.

In the field, abundant visits by pollinating insects of the Xilocopidae and Anthophoridae families were observed. The analysis of pollen dispersion showed a high degree of efficiency of pollen transportation and a large percentage of fertilization by pollinating insects. The floral structures involved and the mechanism of pollination by insects suggest that a high degree of cross-pollination (allogamy) occurs in *C. macrocarpum*.

Some indication of self-sterility was also found in plants that were protected from insect-pollination: both the percentage of pod-setting from flowers and the number of developed seeds per pod were remarkably lower when flowers were hand-tripped than when they were insect-pollinated. In the facultatively self-pollinating accession, CIAT 15233, the number of unfertilized ovules was particularly high.

These preliminary studies suggest that, in the evolution of its floral biology, *C. macrocarpum* has developed several pollination strategies. However, at present, the species can be considered as obligately insect-pollinated. Flower morphology and pollination mechanism favor cross-pollination (allogamy) but do not exclude self-pollination.
Poster Presentation 2

Biogeography of *Centrosema* in Cuba

J. Menéndez V.*

Annual rainfall in Cuba is 1375 mm, 80% of which occurs during a 6-month wet season from May to October. Rainfall is higher in the mountainous zones and in the north, becoming lower toward the south and extreme east. A vegetation survey, using the “microfrontier” sampling method, aimed at describing the natural distribution of native forage legumes in Cuba. For this purpose the country was divided into five natural regions: the western region; Isla de Pinos, with the Isla de la Juventud as the main component; central region; Camagüey-Maniabón region; and eastern region.

Four *Centrosema* species (*C. plumieri, C. pubescens, C. schottii, and C. virginianum*) were recorded in the western region and on the Isla de Pinos. Of these, the most common, most widely distributed, and most attractive species as a forage plant was *C. pubescens*. All four species were also represented in the central region and in part of the Camagüey-Maniabón region where *C. pubescens* was, again, the outstanding species. In these regions, *C. pubescens* occurred in association with *Hyparrhenia rufa, Dichanthium annulatum*, and savanna vegetation where *Sporobolus indicus* and *Andropogon bicorns* were predominating grasses. Soils varied, but *C. pubescens* was not found on very acid nor on poorly drained soils. *Centrosema schottii* occurred mainly on sandy soils.

In addition to two unidentified species, *C. plumieri, C. pubescens, C. schottii, and C. virginianum* were also recorded in the eastern region and in the northeast Camagüey-Maniabón region. Here again, *Centrosema pubescens* was the most frequent species. It was found on a wide range of soils, particularly in marginal lands with native pastures and scrub vegetation. In north Holguín Province and northwest from Guantánamo, where one of the unidentified species was found, *C.*

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Centrosema: biology, agronomy, and utilization

*pubescens* also occurred, associated with pangola grass (*Digitaria decumbens*), or with crops such as sugarcane and coffee. The other unidentified species has a creeping habit, and was found in Pinares de Mayari, Holguín Province, growing among sparse vegetation, at an altitude of 1000 m.a.s.l., and on a red-brown fersiallitic soil. *Centrosema plumieri* was abundant in southwest Las Tunas Province where it was represented by two distinct types. In the remaining zones of this region, neither *C. plumieri* nor *C. schottii* was frequent.

In conclusion, *C. pubescens* is the most widespread *Centrosema* species throughout Cuba, occurring extensively in a wide range of crop and pasture lands. Except for a few samples from the eastern region, *C. pubescens* always showed symptoms of a mosaic virus disease. These symptoms, however, were not detected in the other species. All recorded *Centrosema* species, particularly *C. pubescens* and *C. plumieri*, showed morphological variation.
Poster Presentation 3

Centrosema in Minas Gerais, Brazil

N. M. Sousa Costa*

The State of Minas Gerais is variable in terms of total annual rainfall, rainfall distribution, soils, and vegetation. According to the literature, many Centrosema species are native to this state. In particular, the agriculturally less developed northern region, where total annual rainfall is less than 1000 mm, falling in only 5 months, is rich in Centrosema diversity. However, only very limited collection and evaluation of germplasm have taken place.

Collection of native germplasm. Germplasm of the following species has been collected in Minas Gerais:

Centrosema acutifolium — near Ipiassú in the Triângulo Mineiro.

C. brachypodum — near Itamonte, João Felício, and Pocos de Caldas, with 1500-1700 mm annual rainfall and 4-5 dry months.

C. brasilianum — near Jacinto, Janaúba, and Januária, with 700-950 mm annual rainfall and 5-7 dry months.

C. coriaceum — near Serro, at 900 m.a.s.l., on a sandy, acid soil, in “campo rupestre” vegetation, with 1620 mm annual rainfall and 5 dry months.

C. grazielae — near Diamantina at 1300 m.a.s.l., an amphicarpic accession from a very sandy, poor soil, in campo rupestre vegetation, with 1550 mm annual rainfall and 5 dry months.

C. plumieri — in the Unai-Buritis region; on the very fertile, alluvial soil of a river bank.

C. pubescens — a widespread species; accessions were collected near Bom Jardim de Minas, Governador Valadares, Nanuque, and

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Teófilo Otoni on soils of intermediate to high fertility, and with 1200-1400 mm annual rainfall and 2-5 dry months.

*C. sagittatum* — near Janaúba, 700 mm annual rainfall, on a fertile soil.

*C. schottii* — in dry environments in northern Minas Gerais such as near Montes Claros.

*C. venosum* — an amphicarpic species from extremely sandy, poor soils, near Novo Cruzeiro, in “cerrado” vegetation, and near Diamantina in campo rupestre vegetation.

*C. virginianum* — also a widespread species with collections known from Andrelândia, Jaíba, Montes Claros, Padre Paraiso, and São João del Rei with 750-1500 mm annual rainfall and 4-7 dry months.

Further collection activities in Minas Gerais are urgently needed, particularly in view of the rapid and extensive genetic erosion.

**Evaluation.** *Centrocoma* evaluation in Minas Gerais has been virtually restricted to work in plant introduction nurseries with native and introduced germplasm. The following summary is based on observations with a small number of accessions at a variable number of testing sites.

*Centrocoma pubescens*: Most widely tested species; variable adaptation; main biotic constraints are rhizoctonia foliar blight (RFB) and leaf-eating insect *Diabrotica*.

*C. acutifolium*: Good adaptation to cerrados conditions; tolerant to pests and diseases; good seed production.

*C. brasilianum*: Susceptible to RFB and sucking insect *Cyrtocapsus*.

*C. macrocarpum*: Slow establishment; susceptible to *Cyrtocapsus*; poor seed production.

*C. sagittatum*: Performs as an annual; requires high soil fertility.

*C. schottii*: Performs as an annual; requires high soil fertility; tolerates pests and diseases; intermediate seed production.

In conclusion, *C. acutifolium* seems to be a particularly promising species for Minas Gerais, especially under cerrados conditions. More accessions of this species should be evaluated. Systematic evaluation of a wider germplasm range should, however, also be extended to other *Centrocoma* species in order to identify material adapted to low-fertility soils and tolerant to pests and diseases.
Characterization of *Centrosema acutifolium* CIAT 5277 in the Llanos Orientales of Colombia

L. E. Hoyos and D. Thomas*

The information summarized here was collected by members of the Tropical Pastures Program of the Centro Internacional de Agricultura Tropical (CIAT), in collaboration with the Instituto Colombiano Agropecuario (ICA), from trials conducted between 1982 and 1985 at the ICA Carimagua Research Station in the Eastern Plains (Llanos Orientales) of Colombia. The station lies at latitude 4°3' north, longitude 71°30' west, and altitude 150-175 m.a.s.l. Precipitation is 2100 mm per year, distributed from April to November, with a mean annual temperature of 26 °C. The soils are classified as Oxisols.

*Centrosema acutifolium* CIAT 5277 is native to the Colombian Llanos. The plant is a trailing-twinning perennial and its stolons have a high capacity to root at the nodes. CIAT 5277 grows well in tropical climates where precipitation ranges from 1000-2500 mm per year and at altitudes from sea level to 1400 m. It is well adapted to soils of low pH, high aluminum saturation and relatively low nutrient status.

In Carimagua, soil preparation by minimum tillage methods has been used successfully to establish *C. acutifolium* CIAT 5277. Such methods reduce erosion risk and establishment costs. Sowing early in the wet season is recommended to ensure vigorous growth and good seed production in the first year. Seed, scarified with concentrated sulfuric acid for 5-10 minutes, can be sown at a rate of 3-4 kg/ha. Inoculation of seed is recommended. In a greenhouse trial, using cores of Carimagua soil, the most effective of eight tested *Bradyrhizobium* strains was CIAT 3101. Seed may be broadcast or sown with a grass in alternate rows 60-90 cm apart and at a depth of 12-15 mm. Grass and legume should be sown simultaneously. In Carimagua, fertilizer

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* Universidad de Córdoba, Facultad de Medicina Veterinaria y Zootecnia, Montería, Colombia; and Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia, respectively.
recommendations for establishment are 22 kg P/ha, 30 kg K/ha, 20 kg Mg/ha, and 20 kg S/ha. For maintenance of production, it is recommended that half the establishment fertilization rates be applied every 2 years.

In preliminary agronomic trials, *C. acutifolium* CIAT 5277 showed excellent vegetative vigor and, in subsequent cutting experiments, it outyielded eight other promising *Centrosema* accessions. *Centrosema acutifolium* CIAT 5277 is resistant to pests such as leaf-eating and leaf-cutting insects, and to diseases such as rhizoctonia foliar blight, cercospora leaf spot, and bacteriosis. On the Carimagua Oxisol, the plant has shown no symptoms of nutrient deficiency or nutrient toxicity when grown with minimal fertilizer inputs. In large grazing trials, daily liveweight gains as high as 1000 g/animal have been obtained for short periods in the wet season, in associations containing *Andropogon gayanus* cv. Carimagua 1. In the dry season, animals have gained 115 g/day. Under flexible grazing management systems, legume contents in mixed pastures have varied, but levels of 25%-26% have been maintained under a regime of 7 days grazing followed by 7 days rest. Pure seed yields of 112 kg/ha have been hand-collected from the accession.

The Instituto Colombiano Agropecuario is at present, considering the release of *C. acutifolium* CIAT 5277.1

---

1. Editor's note: CIAT 5277 was released as cultivar Vichada on 9 October 1987 by ICA.
Appendix III

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### Appendix IV

**LIST OF ACRONYMS AND ABBREVIATIONS USED IN TEXT**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Institution</th>
<th>Country</th>
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<tbody>
<tr>
<td>ACIAR</td>
<td>Australian Centre for International Agricultural Research</td>
<td>Australia</td>
</tr>
<tr>
<td>ARECFP</td>
<td>Agricultural Research and Education Center Fort Pierce (of the University of Florida’s IFAS)</td>
<td>USA</td>
</tr>
<tr>
<td>CARDI</td>
<td>Caribbean Agricultural Research and Development Institute</td>
<td>Caribbean region</td>
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<tr>
<td>CENARGEN</td>
<td>Centro Nacional de Recursos Genéticos (of EMBRAPA)</td>
<td>Brazil</td>
</tr>
<tr>
<td>CEPEC</td>
<td>Centro de Pesquisas do Cacau (of CEPLAC)</td>
<td>Brazil</td>
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<td>CEPLAC</td>
<td>Comissão Executiva do Plano da Lavoura Cacaueira</td>
<td>Brazil</td>
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<td>CIAT</td>
<td>Centro Internacional de Agricultura Tropical</td>
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<td>Centro Nacional de Pesquisa de Gado de Corte (of EMBRAPA)</td>
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<td>Centro de Pesquisa Agropecuária dos Cerrados (of EMBRAPA)</td>
<td>Brazil</td>
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<td>CPATU</td>
<td>Centro de Pesquisa Agropecuária do Trópico Úmido (of EMBRAPA)</td>
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<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation</td>
<td>Australia</td>
</tr>
<tr>
<td>EMBRAPA</td>
<td>Empresa Brasileira de Pesquisa Agropecuária</td>
<td>Brazil</td>
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<tr>
<td>EPAMIG</td>
<td>Empresa de Pesquisa Agropecuária de Minas Gerais</td>
<td>Brazil</td>
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<td>FAO</td>
<td>Food and Agriculture Organization of the United Nations</td>
<td>Italy</td>
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<td>Acronym</td>
<td>Institution</td>
<td>Country</td>
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<td>----------</td>
<td>-----------------------------------------------------------------------------</td>
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<tr>
<td>FLAG</td>
<td>Forage Agronomy Group (of ILCA)</td>
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<tr>
<td>FONAIAP</td>
<td>Fondo Nacional de Investigaciones Agropecuarias</td>
<td>Venezuela</td>
</tr>
<tr>
<td>IBPGR</td>
<td>International Board for Plant Genetic Resources</td>
<td>Italy</td>
</tr>
<tr>
<td>ICA</td>
<td>Instituto Colombiano Agropecuario</td>
<td>Colombia</td>
</tr>
<tr>
<td>IDIAP</td>
<td>Instituto de Investigación Agropecuaria de Panamá</td>
<td>Panamá</td>
</tr>
<tr>
<td>IFAS</td>
<td>Institute of Food and Agricultural Sciences (of the University of Florida)</td>
<td>USA</td>
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<tr>
<td>ILCA</td>
<td>International Livestock Centre for Africa</td>
<td>Ethiopia</td>
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<tr>
<td>INERA</td>
<td>Institut National pour l'Étude et la Recherche Agronomique</td>
<td>Zaire</td>
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<td>INIFAP</td>
<td>Instituto Nacional de Investigaciones Forestales y Agropecuarias</td>
<td>Mexico</td>
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<td>INIPA</td>
<td>Instituto Nacional de Investigación y Promoción Agropecuaria</td>
<td>Peru</td>
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<tr>
<td>INTA</td>
<td>Instituto Nacional de Tecnología Agropecuaria</td>
<td>Argentina</td>
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<td>IVITA</td>
<td>Instituto Veterinario de Investigaciones Tropicales y de Altura</td>
<td>Peru</td>
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<tr>
<td>MARDI</td>
<td>Malaysian Agricultural Research and Development Institute</td>
<td>Malaysia</td>
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<tr>
<td>NifTAL</td>
<td>Nitrogen Fixation for Tropical Agricultural Legumes (Project at the University of Hawaii)</td>
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<td>NTDPP</td>
<td>Northern Territory Department of Primary Production</td>
<td>Australia</td>
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<td>PANESA</td>
<td>Pasture Network for Eastern and Southern Africa</td>
<td>Ethiopia</td>
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<tr>
<td>PESAGRO-RIO</td>
<td>Empresa de Pesquisa Agropecuária do Estado do Rio de Janeiro</td>
<td>Brazil</td>
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<tr>
<td>PRONIEGA</td>
<td>Programa Nacional de Investigación y Extensión Ganadera</td>
<td>Paraguay</td>
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</table>
### List of acronyms and abbreviations...

<table>
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<th>Acronym</th>
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<td>PROPASTO</td>
<td>Projeto Melhoramento de Pastagem da Amazônia (of CPATU)</td>
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<td>QDPI</td>
<td>Queensland Department of Primary Industries</td>
<td>Australia</td>
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<tr>
<td>RIEPT</td>
<td>Red Internacional de Evaluación de Pastos Tropicales <em>(also known as International Tropical Pastures Evaluation Network)</em></td>
<td>Colombia</td>
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<tr>
<td>RRIM</td>
<td>The Rubber Research Institute of Malaysia</td>
<td>Malaysia</td>
</tr>
<tr>
<td>UAPNPBS</td>
<td>Unidade de Apoio ao Programa Nacional de Pesquisa de Biologia do Solo (of EMBRAPA)</td>
<td>Brazil</td>
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### Abbreviations Description

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>Af, Afi</td>
<td>Tropical, wet, rain-forest climates with no dry season (based on Köeppen’s classification)</td>
</tr>
<tr>
<td>Am, Ami</td>
<td>Tropical, monsoon, rain-forest climates with limited dry season (based on Köeppen’s classification)</td>
</tr>
<tr>
<td>an.</td>
<td>Animal</td>
</tr>
<tr>
<td>Aw, Awi</td>
<td>Tropical wet-and-dry climates with well-defined dry season (based on Köeppen’s classification)</td>
</tr>
<tr>
<td>BA</td>
<td>Bahia, state in Brazil</td>
</tr>
<tr>
<td>BNR</td>
<td>Binucleate <em>Rhizoctonia</em>-like fungi</td>
</tr>
<tr>
<td>CaMV</td>
<td>Centrosema mosaic virus (a potexvirus, also known as CenMV)</td>
</tr>
<tr>
<td>CEC</td>
<td>Cation-exchange capacity</td>
</tr>
<tr>
<td>CeMV</td>
<td>Centrosema mosaic virus (a potyvirus)</td>
</tr>
<tr>
<td>CenMV</td>
<td>Centrosema mosaic virus (a potexvirus, also known as CaMV)</td>
</tr>
<tr>
<td>CF</td>
<td>Crude fiber</td>
</tr>
<tr>
<td>Cfa</td>
<td>Humid mesothermal climates with no dry season (based on Köeppen’s classification)</td>
</tr>
<tr>
<td>CP</td>
<td>Crude protein</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Cwa</td>
<td>Humid mesothermal climates with dry winter (based on Köeppen's classification)</td>
</tr>
<tr>
<td>DDM</td>
<td>Digestible dry matter</td>
</tr>
<tr>
<td>DF</td>
<td>Distrito Federal, Brazil</td>
</tr>
<tr>
<td>DM</td>
<td>Dry matter</td>
</tr>
<tr>
<td>ELISA</td>
<td>Enzyme-linked immunosorbent assay</td>
</tr>
<tr>
<td>FFB</td>
<td>Fresh fruit bunches (of oil palm)</td>
</tr>
<tr>
<td>FL</td>
<td>Florida, state in USA</td>
</tr>
<tr>
<td>GM</td>
<td>Green matter</td>
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<tr>
<td>HI</td>
<td>Hawaii, state in USA</td>
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<tr>
<td>IVDMD</td>
<td>In vitro dry-matter digestibility</td>
</tr>
<tr>
<td>IVOMD</td>
<td>In vitro organic-matter digestibility</td>
</tr>
<tr>
<td>LWG</td>
<td>Liveweight gain (of livestock)</td>
</tr>
<tr>
<td>M</td>
<td>Mole per liter solution or molar solution</td>
</tr>
<tr>
<td>m.a.s.l.</td>
<td>Meters above sea level</td>
</tr>
<tr>
<td>meq</td>
<td>Milliequivalent</td>
</tr>
<tr>
<td>MG</td>
<td>Minas Gerais, state in Brazil</td>
</tr>
<tr>
<td>MLOs</td>
<td>Mycoplasma-like microorganisms</td>
</tr>
<tr>
<td>MPa</td>
<td>Megapascal, a measure of pressure or stress</td>
</tr>
<tr>
<td>MS</td>
<td>Mato Grosso do Sul, state in Brazil</td>
</tr>
<tr>
<td>n.d.</td>
<td>Not dated</td>
</tr>
<tr>
<td>N.T.</td>
<td>Northern Territory, Australia</td>
</tr>
<tr>
<td>NVI</td>
<td>Nutritive value index (of forage)</td>
</tr>
<tr>
<td>OM</td>
<td>Organic matter</td>
</tr>
<tr>
<td>ppm</td>
<td>Parts per million</td>
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<tr>
<td>PWV</td>
<td>Passionfruit woodiness virus</td>
</tr>
<tr>
<td>Qld.</td>
<td>Queensland, state in Australia</td>
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<tr>
<td>r.h.</td>
<td>Relative humidity</td>
</tr>
<tr>
<td>640</td>
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</tbody>
</table>
### Abbreviations Description

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>RFB</td>
<td>Rhizoctonia foliar blight</td>
</tr>
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<td>RJ</td>
<td>Rio de Janeiro, state in Brazil</td>
</tr>
<tr>
<td>RTA</td>
<td>RIEPT Regional Trial type A</td>
</tr>
<tr>
<td>RTB</td>
<td>RIEPT Regional Trial type B</td>
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<tr>
<td>SP</td>
<td>São Paulo, state in Brazil</td>
</tr>
<tr>
<td>TDF</td>
<td>Tropical dry forest</td>
</tr>
<tr>
<td>TRF</td>
<td>Tropical rain forest</td>
</tr>
<tr>
<td>TRF-DS</td>
<td>Tropical rain forest-derived savanna</td>
</tr>
<tr>
<td>TSSF</td>
<td>Tropical semievergreen seasonal forest</td>
</tr>
<tr>
<td>VA</td>
<td>Vesicular-arbuscular (used with “mycorrhizae”)</td>
</tr>
<tr>
<td>VI</td>
<td>Voluntary intake (of livestock consuming forage)</td>
</tr>
<tr>
<td>YMA</td>
<td>Yeast-mannitol-agar medium</td>
</tr>
</tbody>
</table>
INDEX

The following index is based on two topics: individual *Centrosema* species, subdivided by major themes discussed in the first twelve chapters; and country or region, subdivided by *Centrosema* species. Other major themes can be readily found by consulting the “Contents.”

A minor point to note is that, because of differing classifications, the subentry “Nematodes” does not fall easily under the more general entries “Diseases” or “Pests.” Consequently, it was classified separately under “Nematodes.”

Italicized numbers refer to figures or maps; boldfaced numbers refer to color plates; and “fn” is the abbreviation for “footnote.”

Adaptation, see under Name of *Centrosema* species, adaptation
Adoption by farmers, see under Name of *C*. sp., adoption by farmers
Africa, see Sub-Saharan Africa
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Agronomic evaluation, see under Name of *C*. sp., germplasm evaluation
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Andros Island, see Bahama islands
Animal production, see under Name of *C*. sp., animal production
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    Lesser Antilles
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    *C*. *plumierii*, 349, 353
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    *C*. *virginianum*, 349, 350, 358, 359
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