SOIL ADAPTATION AND NUTRIENT REQUIREMENTS OF VARIOUS Stylosanthes

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It is generally accepted that maximum yields of tropical pastures are obtained with high inputs of nitrogen fertilizers. Such pastures are based on pure stands of grass since legumes do not persist under such conditions. This is due to the low competitive ability of legumes in absorbing soil nitrogen in competition with grasses (Hall, 1974). In general, a detrimental effect on the legume growth and a benefit of the grass growth occurs.

Most productive pure grass livestock production systems are found in developed regions where economic conditions favor intensive land use. In other areas such as tropical America, although beef cattle population is higher than North America, Western Europe, or tropical Africa, beef production per animal and per capita beef consumption are relatively low (CIAT, 1978). The principle constraint to beef production in these regions is the inadequate year-round forage supply caused by low soil fertility and soil water stress. In the vast marginal soil areas of savanna and forest ecosystems of tropical America, commonly with acid infertile soils (Oxisols, Ultisols, and

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acid subgroups of Inceptisols and Entisols), the high inputs of N and other fertilizers are not considered feasible due to unfavorable market conditions. First, because fertilizers and lime are expensive or not available at all, and second, because transportation costs are excessive, or simply because the risks are too high (Sánchez and Salinas, 1981).

The identification and use of forage species better adapted to acid infertile soils and climatic conditions in tropical regions is one means of increasing beef production (CIAT, 1978, 1979). Specifically, any economical improvement in animal productivity in tropical ecosystems appears to be the use of adapted forage legumes in nutrient deficient soils. Hence, emphasis is on the search for legumes, both as a means of increased forage quality of high mineral and protein content, as well as a source of nitrogen for associated grasses in these extensive grassland regions.

Many tropical forage legumes have been identified as tolerant to acid soil constraints and many of them have their center of origin in acid soil regions. This suggests that adaptation to soil constraints is part of the evolutionary process (Sánchez and Salinas, 1981). Among these forage legumes, the genus Stylosanthes occurs throughout in tropical areas of the world, although most numerously in tropical America (Coelho, et al., 1981). This chapter is concerned mainly with ecological adaptation and nutrient requirements of some Stylosanthes species which are considered as promising legumes for tropical pastures.

SOIL AND CLIMATE ADAPTATION

The genus Stylosanthes contains approximately 39 known species which are widely distributed between 40°N and 40°S (Mohlenbrock, 1957; Wilbur, 1963; Burt, et al., 1970; Coelho, et al., 1981). This broad zone includes different climatic regions such as the humid tropics, seasonal rainforests, seasonal rainsubtropics, piedmonts, savannas, deciduous forests and dry tropics (Burt and Reid, 1975). However, most of the Stylosanthes species are distributed in seasonal tropical and subtropical environments of both hemispheres (Ferreira and Sousa Costa, 1979). Some of them have also been introduced into tropical areas for use as cover crops and as pasture legumes (Tuley, 1969). Figure 1 shows collection sites in tropical America of several Stylosanthes species, which are of special interest for tropical regions because they are adapted to a wide range of climatic and soil conditions (CIAT, 1978; Burt and Miller, 1975; Grof et al., 1979).

Most Stylosanthes species grow from sea level to about 2000 meters altitude with a wide range in annual precipitation. For instance, many Stylosanthes species are well established in Madagascar in arid regions with just 350 mm of mean annual rainfall (Dulong, et al., 1967), in Australia from 900 mm to 4000 mm, in Brazil from 1000 to 1700 mm (Skerman, 1977). In Colombia with mean annual rainfalls between 1000 and 2500 mm (CIAT, 1982).

The temperature has been indicated as essential factor for adaptation of most *Stylosanthes* species, since temperature fluctuations can exert a modifying influence through delaying or accelerating inflorescence elongation after floral induction (Cameron, 1967). Significant reductions in plant height, dry matter production, root growth and number of nodules were observed at temperatures of 23°C and above 35°C (Alferez, 1975). In addition, frosts may prevent seed formation in high altitudes ('t Mannetje, 1965; Kretschmer, 1974). An important feature in the adaptation of introduced plants in flowering time and ability of seeding. Photoperiod is considered as the main controlling factor of flowering in *Stylosanthes* species ('t Mannetje, 1965; Cameron, *et al.*, 1977).

Stylosanthes varies widely among and within species due to the adaptation to quite different ecological environments. For instance, *S. humilis* in an annual, well adapted to areas with short summer growing seasons, whereas *S. guianensis* is highly valued because it is perennial. Within *S. guianensis*, there are ecotypes which vary in their frosts resistance, date of flowering and growth habit (Burt, *et al.*, 1980; Whiteman, 1980). Ecotypes of *S. capitata* differ in many morphological characters including size and stage of inflorescence, growth habit and flowering time (Grof *et al.*, 1979). There are other *Stylosanthes* species and ecotypes within species with similar characteristics (Burt *et al.*, 1980; Flores, 1982).

Because of such morphological characteristics associated with physiological variability, the introduction of many Stylosanthes species into diverse environment has often been successful. Most Stylosanthes species have a reputation as a forage legumes that grow well under adverse soil conditions which are mainly characterized by low base status, low phosphorus availability and strong acidity.

The latter results in high levels of exchangeable aluminum which are toxic to most cultivated crops. However, there are also several Stylosanthes species that require fertile soils without Al toxicity (CIAT, 1979, 1980). In general, soil adaptation of Stylosanthes species and ecotypes is closely related to center of origin and collection sites (CIAT, 1981). In addition, some morphological and physiological characteristics of the plants of Stylosanthes may explain the broad adaptation to different soil conditions. Among these characteristics are the mechanism of adaptation to soil water stress which involves a deep root system, stomatal closing, shadding of leaves, and leaf movement to avoid excessive evapotranspiration ('t Mannetje et al., 1980; Whiteman, 1980; Humphreys, 1981).

In general, most Stylosanthes species grow on well drained sandy, sandy loam and clay loam soils (Ferreira and Sousa, 1979). However, some of the Stylo species such as S. capitata are more common in infertile sandy soils (Grof et al., 1979).

In spite of the adaptation of Stylosanthes species to a wide range of climatic and soil condition, anthracnose, caused by Colletotrichum *gloeosporioides* (Penz.) Sacc., is responsible for loss of vigor, defoliation and often death of susceptible species of *Stylosanthes* over a wide latitudinal range of tropical America (Lenné *et al.*, 1982) as well as in Africa, Australia, Thailand and Florida (Clatworthy, 1975; Irwin and Cameron, 1978; Sonoda *et al.*, 1974; Grof *et al.*, 1979). It is believed that plant resistance is the best mean of control in the tropics (Sonoda and Brolman, 1980) and therefore emphasizes the need for disease-resistant species. At the present, the *Stylosanthes* evaluation project of CIAT deals with identifying anthracnose resistant species which are also adapted to acid soils. For instance, some 2000 accessions of *Stylosanthes* spp. have been tested in Carimagua, Colombia, and *S. capitata* has shown high resistance to anthracnose than any other species of the genus in Colombia (Grof *et al.*, 1979; Lenné *et al.*, 1983). In addition, recent comparisons among different *Stylosanthes* species have shown that *S. macrocephala* has high resistance to anthracnose in both Colombia and Brazil, and is thus considered as worthy of further collection and evaluation (CIAT, 1982).

DIAGNOSIS OF MINERAL DISORDERS

In general, determination of which minerals are deficient or toxic for any leguminous pasture can be made by soil analysis, plant tissue analysis and, by observing foliar symptoms of mineral disorders. Diagnosis of mineral disorders in *Stylosanthes* species are not always clear due to their wide range of adaptability to tropical ecosystems.

In addition, the diagnosis of mineral disorders in legumes is somewhat more complex than for non-leguminous species because of the symbiotic relationship existing with associated rhizobial bacteria. Consequently, diagnoses of mineral disorders will depend largely on pooling information from soil tests, plant tissue analysis and/or visual symptoms of mineral disorders.

Soil Analyses

Although the main purposes of soil tests are in relation to the availability of nutrients, the analytical techniques are empirical in nature and it is necessary to calibrate soil test values against actual plant responses before they can be used to predict soil nutrient status or to define a soil as having low native fertility. The actual technique used in soil analyses vary greatly among laboratories in tropical America, but details of the more commonly needed procedures for tropical soils can be found in the handbook "Analytical methods for acid soils and tropical plants" (Salinas and García, 1979).

Based on the analytical procedures, data on tentative critical levels of soil parameters for *Stylosanthes* species are summarized in Table 1. These values are not absolute but they can be used as a general guide in the interpretation of tropical soil tests data. It is important to realize that calibrations may vary with soil type and *Stylosanthes* species. Consequently, the unique use of soil test values to predict the amount of fertilizer should not be applied to correct nutrient deficiencies. In addition when considering low rates of fertilizer additions, the conventional soil test extraction procedures often do not reflect the amount of fertilizer added (CIAT, 1980). This causes difficulties in making fertilizer recommendations based only on soil tests. Because of this, some studies have been started to improve the sensitivity of the existing soils tests (CIAT, 1981) and also to incorporate plant tissue analysis and/or foliar symptoms of mineral disorders to ensure fertilizer recommendations.

Plant Tissue Analysis

Critical concentrations for nutrient deficiencies in the plant tissue for several Stylosanthes species have been determined in several studies, and were presented elsewhere in this paper. The level of nutrients in Stylosanthes plants is being more frequently used as a diagnostic index due to certain limitations on the soil tests for tropical acid soils under a low input soil management (Sánchez and Salinas, 1981; CIAT, 1982). In addition, one of the reasons for a great deal of emphasis on plant tissue analysis is that a critical concentration may be used over a wide range of soil types and environmental conditions (Smith, 1978). In this review, "critical level" and/or "critical concentration" in both soil and plant are considered as those obtaining in most cases 80% of the maximum yield (dry matter production at 8 weeks of plant growth). In general, the critical values shown in Tables 3, 4, and 5 indicates that plant tissues of the *Stylosanthes* species are quite low in most nutrients and this may also indicate a lower internal and external nutrient requirements as compared with other tropical legume pastures.

Foliar Symptoms of Mineral Disorders

Symptoms of nutrient deficiencies in many *Stylosanthes* species are not always very clear since production of deficiency symptoms varies among species, soil fertility, and environmental conditions (Salinas and Sanz, 1981). However, foliar symptoms of mineral disorders in several *Stylosanthes* species have been obtained in nutrient solution cultures and many of the mineral deficiency symptoms have been observed under field conditions in different tropical ecosystems. Detailed descriptions and color photographs of mineral deficiency and toxicities were published by CIAT (1982). A brief summary of them can be described as follows:

Deficiencies: N – Uniform chlorosis in the whole plant from the beginning: under severe conditions lower leaves with red pigmentation and border necrosis.

P – Reduced plant growth, dark bluish green leaf colour, thick leaves, and defoliation of lower leaves.

K – Reduced plant growth, small and chlorotic upper leaves, marginal yellowing and border necrosis of lower leaves.

Ca - Apical chlorosis and marginal yellowing of younger leaves, malformation of newly expanded leaflets, abundance of new regrowths which turn quickly brown, dark green colour of lower leaves.

Mg - Marked interveinal chlorosis on the lower and mid-positioned leaves, under severe conditions yellowing of young leaves and border necrosis on lower leaves.

S - General yellowing of upper leaves, which soon spreads throughout the plant; similar to N-deficiency; under severe condition, lower leaves develop marginal necrosis, becomes yellow in colour, and fall off.

Zn - Interveinal chlorosis in top leaves associated with a slight degree of bronzing of the young emerging leaves; under severe conditions leaflets curved epinastically.

Cu - Plants have an erect growth habit, shoot tip becomes necrotic and upper leaves show marginal necrosis; during mid-day and early afternoon upper parts of the plants tend to wilt.

B - Fast necrosis of young leaves, short petioles, irregular growth of young leaves, lateral leaflets show unequal size and are malformed; root growth restricted, dark in color and suppressed lateral root development.

Fe - Uniform chlorosis of upper leaves, which become white under severe deficiency; at this stage marginal necrosis in young leaves.

Toxicities:

Al - Reduced root growth, root tips inhibited, necrosis and severe stunting and thickening of lateral roots; yellowing of older leaves under severe toxicity.

Mn - Reduced top growth and chlorosis on newly expanded leaves similar to Fe-deficiency symptoms, irregular chlorosis on intermediate and lower leaves; under severe conditions, irregular brown spots near the main veins in lower leaves.

MINERAL NUTRIENT REQUIREMENTS

During recent years in many tropical areas attention has been focused on a low-input management technology which has been recently reviewed by Sánchez and Salinas (1981). This technology is based on three main principles: (1) adaptation of plants to the soil constraints, rather than elimination of all soil constraints; (2) maximization of production through an efficient use of the existing resources; and (3) advantageous use of favorable attributes of acid, infertile soils. Hence, the genus Stylosanthes has received particular attention in tropical areas because of the adaptability of several species and ecotypes to acid soils with low native soil fertility (CIAT, 1978-1982).

However, It is important to realize that soil fertility is relative and depends on the scale used to measure it. Using corn as a standard, most of the acid soils would be classified as infertile, but measuring fertility with adapted species such as Stylosanthes capitata, these acid soils look quite fertile (Spain, 1981). Consequently the nutrient requirements of Stylosanthes species will largely depend on the soil-plant relationships existing in a specific ecosystem. For instance, the more acid the soil and the more limiting the availability of plant nutrients, the more restricted the range of plant adaptation to the ecosystem. Nutrient requirements for tropical pastures generally involve two stages: establishment and maintenance. This paper refers to nutritional requirements during the first stage which in most cases covers the first year of plant growth. Knowledge of the nutrient requirements for Stylosanthes species during the maintenance period is very minimal and still needs substantial investigation.

Lime, Calcium and Magnesium

Aluminum is often the predominant cation in the exchange complex in extremely acid soils, and maybe a growth limiting factor for some species. Most species of the genus Stylosanthe are generally considered tolerant to acid infertile soils and, specifically to aluminum toxicity (Spain *et al.*, 1975); Carvalho, 1978; CIAT, 1980). Recently obtained results are particularly relevant to liming of acid soils in that 80% maximum yield was obtained on a range of 150 to 600 kg $CaCO_3$ equiv./ha with several ecotypes of Stylosanthes capitata (CIAT, 1982). These observations indicate that lime need to be applied in only small amounts, primarily to supply Ca as a nutrient.

Small amounts of lime also gave maximum response with Stylosanthes spp. in the work of Andrew and Norris (1961) and Munns and Fox (1977). The importance of Ca in legume growth and soil fertility in temperate regions is well known, but evidence from research in tropical areas indicates that adequate legume growth may be obtained under conditions of low Ca status in the soils. This is the case of many Stylosanthes species which appear to be quite efficient in extracting Ca from the soil (Norris and Date, 1976). Table 2 summarizes some of the experience about external requirements of Ca and lime applications for species and ecotypes within the genus Stylosanthes during the first year of establishment.

Basic slag or rock phosphate application may also meet the low external Ca requirements, this avoiding the use of lime. On the other hand, yield depression has been observed in several Stylosanthes species at lime rates over 1 ton/ha (CIAT, 1980). In these cases, yield decrease is probably related to some nutritional imbalance, or simply, these species are not adapted to this modified soil condition.

Despite the low Mg content of many acid tropical soils, few field responses to this element have been observed in pasture legumes including Stylosanthes species (Kerridge, 1978). Similarly to the Ca requirements, which imply small amounts of lime, the absence of responses may be due to the presence of Mg in many limestone materials such as dolomitic lime from which the plans are also using Mg efficiently. Under circumstances of not using dolomitic lime, a recommended rate for many Stylosanthes species growing in acid tropical soils is about 12 kg Mg/ha (CIAT, 1982).

Critical concentrations for calcium and magnesium in plant tissue have been determined for several Stylosanthes species, and are summarized in Table 3. These values are not absolute but are merely a guide in the interpretation of plant tissue analysis. In addition, the critical levels are considered as a range of values rather than single values, since they can fluctuate with species and/or ecotypes used, soil texture and moisture, time of sampling, soil fertility, and interaction with other nutrients.

Nitrogen, Phosphorus and Potassium

Nitrogen values reported for tropical legumes vary between 0.9% and 6.0% with a mean nitrogen percentage of 2.8 for all legumes (Minson, 1977). Values presented in Table 4 for *Stylosanthes* species fluctuate around this mean value but are considered as high in terms of forage quality. This explains the primary efforts on the use of this legume, both as a means of increased forage quality and as source of nitrogen for associated grasses in the vast tropical savannas (Grof *et al.*, 1979).

Table 4 also shows ranges of critical P and K concentrations in plant tissue of *Stylosanthes* species. Although differences in P response within the genus *Stylosanthes* exist, many *Stylosanthes* species have often been observed to grow in soil with low available P (3-5 ppm P-Bray II). This has been attributed in part to their low internal P requirement (Andrew and Robins, 1969). In addition, it was suggested that *Stylosanthes* species present inherent characteristics of low P uptake which combined with their low initial growth rate enables these species to survive and produce under conditions of low P supply (Jones, 1975; Grof *et al.*, 1979; CIAT, 1982).

The P required for 80% maximum dry matter yield of several *Stylosanthes* species growing on acid soils in tropical America, with available P of 1 to 4 ppm (Bray II extraction) ranged between 20-40 kg P/ha (Grof et al., 1979; Sánchez and Salinas, 1981; CIAT, 1982). Phosphorus is generally applied as single or triple superphosphate, basic slag or ground phosphate rock. There has been considerable interest in the use of the last two P sources on tropical soils because of the low cost and the possibility of using local sources of phosphates (Fenster and León, 1979; CIAT, 1982).

Critical K concentrations in plant tissue of Stylosanthes species show a mean value of 0.85% ± 0.07. This value may be considered as the low internal requirement since symptoms of K deficiency were not observed within this range of K concentrations among Stylosanthes species (Coelho and Blue, 1979; CIAT, 1982). However, when these Stylosanthes species are grown in grass-legume mixtures it appears that external K requirements increase in order to maintain the internal K content around the critical value. This was attributed to: (a) the poorer competitive ability of this legume than grasses for soil K (Hall, 1974), (2) the advantage of grasses in K uptake in competition with the legume (Asher and Ozanne, 1961), and (3) the higher cation exchange capacity of the legume roots as compared with that of grasses (Ramos et al., 1977).

Potassium requirement for adequate establishment of Stylosanthes species in tropical soils with exchangeable K of 0.05 to 0.1 meq/100 g range from 20-30 kg K/ha (Coelho and Blue, 1979; CIAT, 1981, 1982). When land is cleared by slash and burn in forest ecosystems, K applications may be omitted initially (Kerridge, 1978).

Sulfur and Micronutrients

Table 5 shows ranges of S, Zn and Cu concentrations in plant tissue of *Stylosanthes* species. These critical concentrations represent values obtained for plant tops harvested at 8 weeks of plant growth and are to be accepted for pasture establishment. Definitively these concentrations have to be subjected to further checking under the presence of grazing animals for pasture maintenance.

Sulfur rates required to meet the critical concentrations of *Stylosanthes* species on tropical soils with available S less than 10 ppm (calcium phosphate extraction) are about 20 kg S/ha. The common fertilizer sources of S are pure sulfur and gypsum but simple superphosphate, ammonium sulphate, sulfur coated urea, and rock phosphates with partial acidulation with H_2SO_4, are also used as source of S in addition to N, P, and Ca.

Zinc sulphate and copper sulphate has been the most commonly used sources of Zn and Cu. Recommended rates are 3 kg/ha Zn and 2 kg/ha Cu (Cook 1978; Kerridge, 1978). The residual effect of Cu and Zn in tropical soils appears to be considerable and recommendations for reapplying these micronutrients are about each 4 years (Teitzel *et al.*, 1978). However more research is required to compare a range of soils and particularly acid sandy soils.

In the search for better pasture legumes adapted to the climate, soils, diseases and pests in different ecosystems, *Stylosanthes* has been the genus most intensively collected (CIAT, 1981, 1982). Although the variability of genetic material seems to be wide enough to justify efforts in plant breeding at this time, the emphasis should be on quantitative characterization and evaluation of germplasm collected during the last 3 years and then to consider the need for further collection.

Figure 1. Collection sites of *Stylosanthes* species in tropical America (Adapted from the Catalog of Tropical Forage Species, CIAT, 1980).

Table 1. Tentative levels of soil parameters for Stylosanthes species adapted to tropical acid soils.

Soil Parameter	Level			Method of Analysis*	Reference
	Low	Critical	High		
pH	< 4.5	4.5-5.5	> 5.5	1:1 water-soil ratio	Salinas & García, 1979
Al-Saturation (Al toxicity) (%)	<70	70-90	>90	(Al/Al+Ca+Mg) x 100	CIAT, 1980
Ca-Saturation (%)	<10	10-30	>30	(Ca/Al+Ca+Mg) x 100	CIAT, 1980
Mg-Saturation (%)	5	5-15	>15	(Mg/Al+Ca+Mg) x 100	CIAT, 1980
P (ppm)	< 3	3-5	> 5	Bray-II-extract	CIAT, 1981
K (meq/100g soil)	< 0.05	0.05-0.10	> 0.10	Bray-II-extract	Salinas & García, 1979
S (ppm)	<10	10-15	>15	0.008M Calcium Phosph.	CIAT, 1981
Zn (ppm)	< 0.5	0.5-0.8	> 0.8	Mehlich- 2extract	Salinas & García, 1979
Cu (ppm)	< 0.1	0.1-0.4	> 0.4	DTPA Extract	Bruce, 1978
B (ppm)	< 0.3	0.3-0.5	> 0.5	Hot water-Extract	Salinas & García, 1979
Mn-Toxicity (ppm)	<20	20-50	>50	1 N KCl	Salinas & Sanz, 1979

* 1N KCl extractant for Al, Ca and Mg.

Bray-II = 0.1N HCl + 0.03 N NH_4F

Mehlich-2 = 0.05 N HCl + 0.025N H_2SO_4

DTPA = 0.005M DIPA + 0.01 M $CaCl_2$ + 0.1 M Triethanolamine

Table 2. Estimated calcium and lime requirements for several *Stylosanthes* species and ecotypes.

Species	Ecotype	Calcium Rate	Lime Rate ($CaCO_3$ equiv.)	Source
		------- kg/ha -------		
S. guianensis	La Libertad	50	150	Spain *et al.*, 1975
S. guianensis	-	250	800	Carvalho, 1978
S. capitata	CIAT-1315	50	150	CIAT, 1982
S. capitata	CIAT-1318	100	300	CIAT, 1982
S. capitata	CIAT-1405	200	600	CIAT, 1982
S. capitata	CIAT-1419	300	1000	CIAT, 1982
S. capitata	CIAT-1899	300	1000	CIAT, 1982
S. macrocephala	CIAT-1643	200	600	CIAT, 1982
S. humilis	CIAT-118	150	500	CIAT, 1980
S. hamata	CIAT-174	1200*	4000	Grof *et al.*, 1979

* Ca rate also associated with a decrease of Al toxicity in the soil.

Table 3. Ranges of critical Calcium and Magnesium concentrations in the plant tissue of *Stylosanthes* species

Element	Species	Plant Tissue	Range of Critical Element Concentration (%)	Reference
Calcium	*S. capitata*	plant tops	1.00 ± 0.30[1]	CIAT, 1982
	S. macrocephala	plant tops	0.70 ± 0.15[1]	CIAT, 1982
	S. guianensis	plant tops	0.85 ± 0.20	CIAT, 1981
	S. humilis	plant tops	2.00 ± 0.4	Andrew and Hegarty, 1969
	Mean		1.10 ± 0.3	
Magnesium	*S. capitata*	plant tops	0.25 ± 0.04	CIAT, 1982
	S. guianensis	plant tops	0.30 ± 0.03	CIAT, 1981
	S. macrocephala	plant tops	0.18 ± 0.02	Florez, 1982
	S. humilis	plant tops	0.35 ± 0.06	Andrew and Robins, 1969
	Mean		0.27 ± 0.04	

[1] Ranges correspond to values obtained with different ecotypes and associated with 80% of maximum yield at 8 weeks of plant growth.

Table 4. Ranges of critical N, P, and K concentrations in plant tissue of *Stylosanthes* species.

Element	Species	Plant Tissue	Range of Critical Element Concentration (%)	Reference
Nitrogen	*S. capitata*	leaves	2.4 ± .5	CIAT, 1982
	S. guianensis	plant tops	1.9 ± .3	Blunt & Humphreys, 1970
	S. hamata	plant tops	2.6 ± .3	Aitken, 1979
	S. humilis	plant tops	3.4 ± .6	Andrew & Robins, 1969
	Mean		2.6 ± .5	
Phosphorus	*S. capitata*	plant tops	0.14 ± 0.04[1]	CIAT, 1982
	S. macrocephala	plant tops	0.12 ± 0.03[1]	CIAT, 1982
	S. guianensis	plant tops	0.25 ± 0.05[2]	Jones, 1974
	S. hamata	Apical tissue	0.27 ± 0.03[2]	Wailapon et al., 1979
	S. humilis	plant tops	0.27 ± 0.03[2]	Jones, 1974
	Mean		0.21 ± 0.04	
Potassium	*S. capitata*	plant tops	1.08 ± 0.13[1]	CIAT, 1982
	S. macrocephala	plant tops	1.05 ± 0.15[1]	CIAT, 1982
	S. guianensis	plant tops	0.82 ± 0.03[2]	Brolman and Sonoda, 1975
	S. hamata	Apical tissue	0.70 ± 0.02[2]	Aitken, 1979
	S. humilis	plant tops	0.60 ± 0.02[3]	Andrew & Robbins, 1969
	Mean		0.85 ± 0.07	

[1]Ranges correspond to values obtained with different ecotypes and associated with 80% of maximum yield at 8 weeks of plant growth.

[2]Ranges associated with 90% of maximum yield at 8 weeks of plant growth.

[3]Preflowering stage.

Table 5. Ranges of critical S, Zn and Cu concentrations in plant tissue of *Stylosanthes* species

Element	Species	Plant Tissue	Range of Critical Element Concentration (%)	Reference
Sulfur	*S. capitata*	plant tops	0.16 ± 0.02[1]	CIAT (1981)
	S. guianensis	plant tops	0.13 ± 0.04	Miller and Jones, 1974
	S. hamata	plant tissue	0.11 ± 0.02[2]	Aitken, 1979
	S. humilis	plant tops	0.14 ± 0.02[2]	Andrew, 1977
	Mean		0.13 ± 0.02	
			(ppm)	
Zinc	*S. capitata*	plant tops	25 ± 5	CIAT, 1982
	S. guianensis	plant tops	20 ± 5	Winter & Jones, 1977
	S. hamata	plant tops	15 ± 5	Bruce, 1978
	S. humilis	plant tops	21 ± 2	Crack, 1971
	Mean		20 ± 4	
Copper	*S. capitata*	plant tops	8.0 ± 2.0[1]	CIAT, 1982
	S. guianensis	plant tops	3.5 ± 0.5	Winter & Jones, 1977
	S. hamata	plant tops	4.5 ± 0.5	Bruce, 1978
	S. humilis	plant tops	4.0 ± 1.0	Webb, 1975
	Mean		5.0 ± 1.0	

[1] Ranges correspond to values obtained with different ecotypes and associated with 80% of maximum yield at 8 weeks of plant growth.

[2] Ranges associated with 90% of maximum yield at 8 weeks of plant growth.

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