



THE IMPACT OF THE INTERNATIONAL LIVESTOCK RESEARCH INSTITUTE

EDITED BY JOHN MCINTIRE AND DELIA GRACE



CABI is a trading name of CAB International

CABI
Nosworthy Way
Wallingford
Oxfordshire OX10 8DE
UK

CABI
745 Atlantic Avenue
8th Floor
Boston, MA 02111
USA

Tel: +44 (0)1491 832111
Fax: +44 (0)1491 833508
E-mail: info@cabi.org
Website: www.cabi.org

Tel: +1 (617)682-9015
E-mail: cabi-nao@cabi.org

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Co-published by CABI and the International Livestock Research Institute 2020.

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ISBN-13: 978 1 78924 185 3 (hardback)
ILRI ISBN: 92-9146-586-3 (hardback)

CABI Commissioning editor: Alexandra Lainsbury
CABI Editorial assistant: Lauren Davies
CABI Production editor: James Bishop

Typeset by SPi, Pondicherry, India
Printed and bound in the UK by Bell and Bain Ltd, Glasgow

13 The Impact of CGIAR Centre Research on Use of Planted Forages by Tropical Smallholders

Alan J. Duncan¹, Michael Peters², Rainer Schultze-Kraft³, Philip K. Thornton⁴, Nils Teufel⁵, Jean Hanson⁶ and John McIntire⁷

¹International Livestock Research Institute, Addis Ababa, Ethiopia and Global Academy of Agriculture and Food Security, University of Edinburgh, UK; ²Alliance of Bioversity and CIAT, Nairobi, Kenya; ³Alliance of Bioversity and CIAT, Cali, Colombia; ⁴CGIAR Research Programme on Climate Change, Agriculture and Food Security (CCAFS), International Livestock Research Institute, Nairobi, Kenya; ⁵International Livestock Research Institute, Nairobi, Kenya; ⁶International Livestock Research Institute, Addis Ababa, Ethiopia; ⁷Santa Barbara, CA, USA

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Executive Summary

The problem

Livestock are an integral component of the smallholder mixed systems that dominate sub-Saharan Africa and South Asia. Availability of sufficient high-quality feed is a major constraint to productivity; livestock are often fed opportunistically and on poor-quality feed resources. A decline in grazing resources in response to the expansion of cultivated land and poor control over grazing rights means ever-increasing proportions of variable-quality cereal and legume crop residues in ruminant livestock diets. Cultivation of green forages specifically for feeding livestock is an important potential means of addressing the feed gap. The prominence of planted forages in smallholder farming systems varies hugely, and the extent of their cultivation in sub-Saharan Africa and to some extent Asia is lower than would be expected given their potential to alleviate the chronic feed gap. This chapter explores the potential and actual impact of planted forages and reviews success cases emerging from CGIAR research.

Potential of planted forages

Planted forages offer a range of benefits, which is at odds with their apparent underuse in many smallholder farming systems. Well-managed cultivated forages provide substantial yields of nutrient-rich biomass. Grasses provide large amounts of moderate-quality feed. Legumes generally yield less, but the vegetative material is of exceptionally high quality and provides an excellent high-quality feed to complement the basal resource of cereal crop residues that often dominate livestock diets across the tropics.

Planted forages have several potential impacts. Use of forages can deliver social benefits

including reducing the labour burden associated with feed sourcing, especially on women. Forages can also deliver economic benefits through improved livestock productivity, which often exceeds the opportunity costs of utilizing land for staple crops. Finally, forages can play a strong role in delivering environmental impact through soil stabilization, carbon sequestration and maintenance of habitats which support biodiversity.

Information on the use of planted forages in the tropics is scanty, although there have been recent attempts to synthesize available information. These reviews point to large areas of improved planted forages in Latin America with a few documented successes in high-potential sites in China, India, South-east Asia and East Africa.

Research spending at ILRI

The International Livestock Research Institute (ILRI) and its predecessor, the International Livestock Centre for Africa (ILCA), have made major investments in livestock feed research. ILCA scientists (1974–1994) working on feed research of all types – range ecology, forage diversity, planted forages, multi-dimensional crops and the nutritional quality of feeds – were about 18.8% of the 1974–1994 number of ILCA staff. These figures imply real spending on various aspects of livestock feeding of some US\$70 million (in 2015 US\$) in the 20 years of ILCA's existence. ILRI (1995–2017) spending was some US\$105 million, for a 1975–2018 commitment of US\$175 million, or roughly 10% of the total. Planted forages accounted for the majority of ILRI spending in the area of livestock feeding. We have not been able to estimate research spending on forages at the International Centre for Agricultural Research in Dryland Areas (ICARDA) or at the Centro Internacional de Agricultura Tropical (CIAT, or International Center for Tropical Agriculture now part of the Alliance of Bioversity International and CIAT).

Impacts

Research by the various CGIAR centres with interests in planted forages has yielded a range of success cases where research has led to widespread uptake of specific interventions involving planted forages. For example, the World Agroforestry Centre (ICRAF) has been working on the use of multi-purpose trees as livestock fodder in East Africa for the past three decades. This research effort led to the development of feeding practices especially in support of dairy production. In partnership with a range of development partners, multi-purpose trees were adopted by up to 230,000 farmers according to some estimates. Similar experiences apply to other forage-based technologies including the push–pull system, intensive small-scale grass production for beef fattening in South-east Asia and recent uptake of planted forages – often based on selections by CIAT and ILRI – in South-east Asia and eastern Africa. In Latin America and the Caribbean, planted forages, by spontaneous adoption and selection by the private sector, national agricultural research systems and CIAT have transformed livestock production over the last 60 years and are the main source of animal feed albeit mostly on large farms. More recently, increased attention has been given to bred grass cultivars, with early uptake estimated by extrapolating from seed sales of more than 900,000 ha of CIAT bred hybrids.

Despite these successes, the uptake of planted forages has been much less in sub-Saharan Africa and Asia than, for example, in Latin America. There are different analyses on the basis for this lack of uptake ranging from those who point to lack of awareness of the potential merits of planted forages among farmers through to those who attribute lack of uptake to inherent system characteristics that make them uncompetitive with alternative use of land and labour.

Scientific impacts

Several scientific impacts are clear from CGIAR research on planted forages over the past four decades. First, CGIAR centres and national and international partners have been successful in developing intervention strategies involving planted forages. Examples include the use of multi-purpose trees in East Africa in support of dairy production, the push–pull system with its

multiple production benefits including improved livestock production, and the development of intensive grass production on small plots in South-east Asia in support of beef fattening.

Second, the development of improved planted forage cultivars, especially in Latin America, involving the private sector, the national research system and CIAT has clearly led to extensive uptake by relatively large-scale farmers with clear livestock production dividends.

A third area of scientific impact has been the developing of understanding and methods for prioritization of planted forage options for particular localities. Examples of research outputs that codify the extensive knowledge within the global forage/feed network including CGIAR scientists have been the widely used Tropical Forages tool (www.tropicalforages.info/; accessed 27 February 2020) and recently the Feed Assessment Tool (FEAST). Linked to this, CGIAR research has been important in understanding the systemic constraints on planted forage use in smallholder systems across the tropics.

Development impacts

There has been considerable development impact from planted forage cultivars notably *Brachiaria* spp. in Latin America, especially in Brazil. In Brazil the strong private sector and national research system (Brazilian Agricultural Research Corporation or EMBRAPA) have been instrumental along with CIAT. In other countries in Latin America and the Caribbean, the contributions of CIAT have been more central. Other examples noted in this chapter include *Stylosanthes* spp. in China and Thailand and fodder hedgerows in East Africa.

Several other development impacts can be identified from CGIAR research on planted forages. The forage gene banks of ILRI, ICARDA and CIAT have been the principal sources of germplasm for development as described in Chapter 12 (this volume). The same centres have acted as a knowledge repository on planted forages for example through collation of the Tropical Forages tool.

Studies of the economic impact of planted forages related directly to ILRI's work are rare. An impact assessment in the 1990s in 15 West African countries showed some 27,000 adopters of the fodder bank technology on 19,000 ha. The calculated economic internal rate of return to the fodder bank technology was 38%.

Capacity building and partnerships as development impacts

Capacity development impacts of CGIAR research have been mainly through the development of knowledge products on forages, notably the Tropical Forages tool, which is the main global knowledge repository on tropical forages and is widely used. In addition, the development of technical materials and training manuals on forage development, notably in South-east Asia, is an excellent example of the capacity development work of CGIAR centres. Finally, CGIAR centres have had a strong convening function, for example in convening of international networks on forages through the Tropical Forages Newsletter initiative and the African Feed Research Network (AFRNET) convened by ILCA in the 1990s and the RIEPT network in Latin America and the Caribbean convened by CIAT in the 1980s.

Future directions

Future work on planted forages by CGIAR centres must involve renewed effort in breeding to produce lines that are resilient to stress, particularly in the face of climate change and land pressure and responding to emerging and specific market demands. The promising work on prioritization of feed options including planted forages must be extended to allow better targeting of forage options to reduce effort to promote options that have little prospect of success. Finally, CGIAR research needs to continue the process of stronger partnering with private-sector actors at a range of scales in the feed sector. In the case of planted forages, this could involve the incubation of small-scale seed producers through technical training.

Introduction

The purpose of this chapter is to answer the question of what the scientific and economic value of research and development work by CGIAR centres and partners has been in planted forages for smallholders in tropical and subtropical livestock systems in Africa, Asia and the Americas. By planted forages, we mean the whole range of plants used for feeding livestock and specifically cultivated for

livestock nutrition. This includes forage grasses, herbaceous forage legumes and forage shrubs/trees, the latter often legumes; in addition, some non-legumes and non-grasses such as *Tithonia diversifolia*, *Morus alba* and *Trichanthera gigantea* are planted and used for animal feeding.

Forage-based livestock production is significant in temperate systems. In some cases, planted forages are the main source of nutrition (e.g. Williams *et al.*, 2007, for New Zealand). In the tropics and subtropics, cultivation of forage dominates livestock production in Latin America and the Caribbean (Jank *et al.*, 2014) but is much less prominent in Asia and Africa. In the latter regions, livestock are fed on crop residues and natural forage either grazed *in situ* or cut and carried to confined animals (Renard, 1997). In a recent study of 12 global locations in sub-Saharan Africa and South Asia, forage crops contributed no more than 10% of cattle diets, with crop residues accounting for a much larger share (Valbuena *et al.*, 2015). Research in India has found that crop residues were the single most important feed resource, supplying around 70% of intake, with planted forages contributing 15% (Blummel *et al.*, 2014). There are pockets of intensive forage use; for example, Napier grass (*Pennisetum purpureum*¹) in East Africa is a base feed of choice in dairy systems (Staal *et al.*, 2002). Moreover, recent work and case studies have identified the potential benefits of planted forages in eastern Africa (González *et al.*, 2016; N. Teufel *et al.*, unpublished data) and tropical Asia (Stür *et al.*, 2013) with an increasing – although as yet limited – uptake of tropical forages beyond Latin America and the Caribbean, as shown later in this chapter.

The work of CGIAR on forages commenced in the early 1970s with research in CIAT as part of the Beef Production Systems Program. This programme later shifted its focus entirely to tropical forages and became the Tropical Forages Program in 1979 (Lynam and Byerlee, 2017b). In ILCA (and later ILRI), planted forages research began in the late 1970s with evaluations of grass, forage legume and forage tree species in Nigeria and later in Ethiopia. The work of ICARDA started at a similar time, focusing on testing and disseminating cereal/legume rotations with farmers in several countries in the West Asia and North Africa region, including Algeria, Iraq, Jordan, Lebanon, Morocco, Syria and Tunisia.

The empirical basis of the impact of planted forages on tropical and subtropical livestock production in Africa and Asia is not as strong as it should be. Some argue that there has been little to show for this effort in CGIAR institutions (Squires *et al.*, 1992; Thomas and Sumberg, 1995) beyond Latin America and the Caribbean, where there are documented large-scale impacts (Lynam and Byerlee, 2017b).

In this chapter, we first consider the technical merits of planted forages. We then review what is known about the extent of cultivation of planted forages in selected locations before summarizing various successes in different tropical regions. Last, we reflect on lessons from these experiences and present ideas for future research.

The Role of Planted Forages in Tropical Farming Systems

Livestock are ubiquitous in the mixed crop–livestock systems of the tropics. They are often poorly fed, subsisting on poor-quality crop residues, scavenged grasses and leaves, and a limited ration of agro-industrial by-products. Planted forages have long been promoted as a way of improving feed supply. However, the place of planted forages in smallholder livestock production outside of perhaps East Africa, especially Kenya, is often limited². Planted forages are widely used in Latin America, although the definition of smallholder there does not compare with the much smaller scale in sub-Saharan Africa. Some have argued that they are not used because of systemic and economic constraints (McIntire and Debrah, 1986), although analysis often focuses on forage legumes (Thomas and Sumberg, 1995; Sumberg, 2002). There are, however, recent success reports such as from Asia (Stür *et al.*, 2013) with more than 10,000 farmers adopting intensive grass production, eastern Africa (Maass *et al.*, 2015) with stated adoption of *Brachiaria* hybrids by at least 20,000 farmers, eastern Africa (Franzel and Wambugu, 2007) on the uptake of fodder shrubs (mostly *Calliandra calothyrsus*) by more than 200,000 farmers, the adoption of the push–pull system of the International Centre of Insect Physiology and Ecology (ICIPE) by more than 30,000 farmers (Khan *et al.*, 2011), the recent

work on *Brachiaria* coordinated by ILRI and CIAT in East Africa with scaling of up to 25,000 households adopting *Brachiaria* germplasm selections (S. Ghimire, personal communication) and the adoption of *P. purpureum* in eastern and Central Africa (Negawo *et al.*, 2017; Staal *et al.*, 2002).

The work of Peters *et al.* (2001) is a forceful argument for planted forages as instruments for higher productivity and better natural resource management. They reviewed ‘...the role of forage crops in improving the productivity of smallholder farming systems and breaking the cycle of poverty and resource degradation [by presenting] the contributions of forage crops to increasing farm incomes, intensifying farm production, and contributing to better human nutrition.’

Planted forages offer strong technical benefits in mixed crop–livestock systems. For example, Peters *et al.* (2001) gave the agronomic arguments for planted forages in the tropics: (i) they provide higher crop yields per unit of land compared with alternatives, such as crop residues, natural pastures and browse; (ii) they provide higher forage quality in terms of nutrients per unit of dry matter (DM); (iii) there is improvement of soil quality by fixing nitrogen and retaining water; and (iv) they may fill seasonal feed shortages, in terms of providing feed when alternatives are scarcest (e.g. natural pastures in the dry season). Similar arguments were advanced by Shelton *et al.* (2005). Rao *et al.* (2015) outlined the importance of planted forages for ecosystem services.

White *et al.* (2013) give the technical benefits of forages in three domains. First, planted forages can improve labour productivity given that they can reduce work to collect natural vegetation. Second, forages can allow savings in input use, such as water and fertilizer. Cultivation of forages can lead to improved productivity in terms of biomass yield, energy or protein per unit area. Finally, forages can also have environmental benefits. Such benefits include improved soil cover, reduced erosion and less weed infestation.

Table 13.1 lists the top 15 forage species requested from the ILRI forage gene bank since the early 1980s. Of the top ten grasses, *P. purpureum* (commonly known as Napier or elephant grass) has been reported to produce a DM yield of

Table 13.1. Indicative yield and nutritive value of the forage species most commonly requested from the ILRI gene bank (1984–2016). (Data on number of requests extracted from ILRI gene bank database. Yield and protein data from Cook *et al.*, 2005; nutritive value data from Feedipedia, 2013.)

Forage	Type	Number of requests	Indicative yield (t DM/ha/year)	Crude protein (% DM)	Metabolizable energy (MJ/kg DM)	Observations
<i>Chloris gayana</i>	Grass	833	10–25	3–17	8.5	
<i>Cenchrus ciliaris</i>	Grass	699	2–9	6–16	8.0	
<i>Pennisetum purpureum</i>	Grass	564	10–30	Leaf: 9.5–19.7	8.2	
<i>Lablab purpureus</i>	Legume	1,874	4	Leaf: 21–38; stem: 7–20	9.2	Yield is per season
<i>Vigna unguiculata</i>	Legume	1,412	3–10	Green foliage: 14–21; crop residue: 6–8	9.8	Yields refer to 8–12 weeks
<i>Cajanus cajan</i>	Legume	1,354	~2	Leaf: 10–15	9.6	DM yields can be much higher under optimal conditions
<i>Stylosanthes guianensis</i>	Legume	1,210	5–10	12–20	8.0	
<i>Medicago sativa</i>	Legume	1,078	8–27 ^a	18.3	8.5	No crude protein data in Cook <i>et al.</i> (2005)
<i>Neonotonia wightii</i>	Legume	828	3–8	17.1	9.1	No crude protein data in Cook <i>et al.</i> (2005)
<i>Stylosanthes hamata</i>	Legume	785	1–7	Leaf: 17–24; stem: 6–12	8.8	
<i>Stylosanthes scabra</i>	Legume	763	1–10	Leaf: 10–20	n/a	
<i>Trifolium temense</i>	Legume	590	3–6	10–24	10.9	
<i>Sesbania sesban</i>	Tree	2,581	6–12	25–30	11.5	
<i>Leucaena leucocephala</i>	Tree	780	1–15	19–24	11.0	
<i>Gliricidia sepium</i>	Tree	604	2–20	18–30	11.5	

^aThe yield of *M. sativa* is under irrigation.

between 12 and 90 t/ha/year and crude protein concentrations of between 5 and 16% (Negawo *et al.*, 2017, and references therein). The data overall show the very high yield potential of planted forages, particularly forage grasses, when compared with natural pasture DM yields in, for example, Ethiopia, which range from 1 t/ha/year in the lowlands to 4–6 t/ha/year on seasonally waterlogged fertile areas (Alemayehu, 1998). The data also illustrate the high nutritive value of forages, especially forage legumes, many of which have crude protein concentrations of around 20%. Comparing these with the other major sources of nutrition for livestock in developing-world smallholder systems, crop residues, under normal agronomic practices, cereal straw yields in sub-Saharan Africa would be in the order of 1.5–7.0 t/ha with crude protein concentrations of 5–10% and metabolizable energy concentrations of 6–8 MJ/kg DM (Zaidi *et al.*, 2013).

Forage legumes, through their ability to form a symbiotic relationship with nitrogen-fixing rhizobia hosted in their root nodules, also offer improvements in soil quality and reductions in greenhouse gas (GHG) emissions and nitrogen fertilizer application. After harvesting the aerial portion of the plants, the remains are degraded to produce organic matter and the nitrogen component is mineralized to form ammonia, which is released into the soil and can be utilized by other plants in close proximity or planted subsequently. In addition, unlike in the above-ground portion of the plant where nitrogen concentrations do not vary significantly, nitrogen concentrations in below-ground legume tissues have been shown to vary considerably (Carranca *et al.*, 2015).

Results by Muhr *et al.* (1999) showed the positive effects of nitrogen contribution in the order of 80 kg/ha to the succeeding crop, even when removing the above-ground biomass, of *Stylosanthes guianensis*. Depending on the way in which livestock are managed, some nitrogen from legumes may be deposited on arable land as excreta returns but usually only a fraction (Rufino *et al.*, 2007). Finally, there is the case that some forages provide feed at times of general feed scarcity. For example, some fodder trees provide green feed during the dry season when other feeds are scarce (Franzel *et al.*, 2014). Seasonal livestock enclosures, where livestock are excluded for a time to allow biomass accumulation, can also provide dry-season feed by reserving biomass for

periods of scarcity (Tarawali and Pamo, 1992; Mekuria and Veldkamp, 2012) although practical uptake of such practices has generally been limited (Tarawali *et al.*, 1999).

As well as biological nitrogen fixation by forage legumes, some tropical grass roots have recently been shown to exude chemical inhibitors of biological nitrification, which suppress soil-nitrifying bacteria, reducing the rate of leakage of nitrogen from the system, by blocking the conversion of ammonium to nitrate. Inhibitors have been identified in root exudates from a number of legume and grass species including sorghum and rice, but by far the most intense activity was detected in *Brachiaria humidicola* (Subbarao *et al.*, 2007). Subsequently, the cyclic diterpene 'brachialactone' was demonstrated to contribute between 60% and 90% of the biological nitrification inhibition activity in *Brachiaria* root exudate (Subbarao *et al.*, 2009). A further benefit of these soil-nitrifying bacteria is reductions in emissions of the GHG nitrous oxide.

The paradox is that despite the positive nitrogen-fixing properties of legumes, which offer benefits to plant production and soil health when grown in nitrogen-constrained environments, in general the uptake of forage legumes in smallholder systems has been limited (Sumberg, 2002; Shelton *et al.*, 2005).

The extent of planted forages in tropical farming systems

Global estimates of the area planted to forages are not readily available. There are, however, countries where forage data are readily available. Data from the Indian Council for Agricultural Research (ICAR) indicate the area planted to 'improved' forages in India is around 8 million ha with the dominant species being Egyptian clover (*Trifolium alexandrinum*) and forage sorghum (ICAR, 2011). In Brazil, another hotspot of planted forage production, EMBRAPA estimates that the total area planted to forages is 115 million ha with *Brachiaria* spp. accounting for 80% of the area and *Panicum maximum* accounting for 10% (Sluszz, 2012).

Planted forages have been promoted for many years in eastern Africa (Abate *et al.*, 1985). A survey of areas with commercial dairy

production was carried out in Ethiopia and Kenya in 2015 to determine the levels of forage adoption, production practices and importance as a feed source (N. Teufel *et al.*, unpublished data), in which 180 communities were selected across the major regions in each country. In Ethiopia, 20 woredas were purposively selected from Tigray (three), Amhara (six), Oromiya (seven) and Southern Nations Nationalities and Peoples (four) for intensity of dairy production. Within these woredas, nine kebeles³ were randomly selected. In Kenya, 12 counties were selected from Nyanza (three), western (two), Upper Rift (three), central (three) and coast (one) regions, based on the density of dairy animals and information about forages. Random selection identified 15 sublocations, the lowest formal administrative level, within each selected county and one village within each selected sublocation for the survey. During the survey, focus groups responded to quantitative and qualitative questions on farming characteristics and forage production practices regarding the whole village, such as the total number of farming households and cultivated area, the number of households growing a specific forage and the area of this forage planted. Most forages were differentiated by species only. Because of its importance, Napier grass (*P. purpureum*) was differentiated into four variety types at data collection: 'Kakamega I', 'Kakamega II', 'other improved varieties' and 'local varieties'. The share of households growing forages among farming households and the forage share of cultivated land, where forage extent was expressed in area units, were calculated for comparison.

Results of this study indicate that in Ethiopia, forage grasses are grown by 10–35% of households, while in Kenya 10–85% of households grow grasses. Forage legumes are grown by fewer households overall; in Ethiopia, their occurrence (up to 12% of households) is higher than in Kenya (up to 2% of households). Forage trees occur reasonably widely with up to 40% of households growing trees in Ethiopia and up to 20% in Kenya. The areas devoted to planted forages are small. However, forage trees are often planted singly or in rows, for which area measures were not recorded.

Sesbania was the most common planted forage in Ethiopia, with 34% of households growing it and 0.5% of cultivated area allocated to it. Local

varieties of Napier grass also figure highly. In Kenya, local Napier varieties were the most common forage and were grown by over 90% of households in the surveyed areas, although they accounted for only around 5% of total cultivated area. Improved varieties of Napier grass ranked second in frequency of occurrence. Measuring adoption by area favours crops that are grown on larger farms, such as fodder oats in Ethiopia or Rhodes grass and the Kakamega Napier grass varieties in Kenya. In summary, the area shares of fodder crops are generally low in both countries, with Napier grass in Kenya being the most widespread, grown on around 6% of cultivated land (combining all varieties). Because many of these crops are harvested multiple times per year, their biomass shares are higher than their area shares.

Adoption of planted forages in sub-Saharan Africa

In this and the following sections we review current knowledge on adoption of planted forages related to CGIAR research efforts. We do this by focusing on a series of significant bodies of work in different regions that have led to at least moderate success.

Fodder banks in West Africa

The fodder bank concept was developed by ILCA (now ILRI) and partners in the late 1970s in Nigeria to help crop–livestock farmers in the dry to subhumid zone to: (i) overcome dry-season feed constraints; and (ii) improve soil fertility. It consisted of establishing small (typically 4 ha) fenced paddocks with a prolifically seeding, self-regenerating forage legume (mainly *Stylosanthes hamata*) for strategic supplementation of livestock grazing natural pastures (Mohamed-Saleem and Suleiman, 1986). Such supplementation led to significant increases in livestock productivity under experimental conditions. After 2–3 years, the legume fodder bank was replaced by an unfertilized sorghum or maize crop that provided yields equivalent to fertilization with up to 45 kg nitrogen/ha (Tarawali, 1991). After the crop phase, the area was reconverted to a fodder bank via hard-seeded soil seed reserves. Research and promotional activities related to this technology came to an end in the early 1990s.

An impact assessment, conducted by Elbasha *et al.* (1999) in 15 West African countries showed that, until 1995, there were about 27,000 adopters of the fodder bank technology covering about 19,000 ha. Given the estimated US\$7 million research expenditure to develop this technology, an internal rate of return of 38% was calculated. Elbasha *et al.* (1999) stressed the finding that a considerable time lag (at least 15 years) was necessary for diffusion of the technology. The second part of their statement, '... the impact of adopted fodder banks has paid for the research that went into their development at least three times over, and this will increase substantially in the next few years, given current adoption trends' remains to be confirmed.

Multi-purpose trees

ICRAF and partners have been active in developing multi-purpose trees and shrubs as fodder in East Africa over the past three decades⁴. Multi-purpose trees have been defined as 'all woody perennials that are purposefully grown to provide more than one significant contribution to the production and/or service functions of a land-use system. They are so classified according to the attributes of the plant species as well as to the plant's functional role in the agroforestry technology under consideration' (Huxley, 1984). Functions include livestock feed, construction, fuel, improved soil fertility, erosion control and shelter, among others.

Initial research in the early 1990s estimated the potential of *C. calothyrsus*, *Sesbania sesban* and *Leucaena leucocephala* to provide feed for small-holder dairy cows in the central highlands of Kenya (Franzel and Wambugu, 2007). *C. calothyrsus* proved most suitable, and much of the research effort has focused on understanding how it fits into small farms. Multi-purpose trees and forage trees in general have the advantage that they require minimal inputs and can be planted along field margins and on soil bunds. They have the disadvantage of slow growth (first harvests in much of East Africa are 12 months after transplanting) and the need for stable land tenure to justify investment in a multi-season crop.

ICRAF published a comprehensive review of the impact of multi-purpose trees (Place *et al.*, 2009). This review gave data on the production impact of intake of tree forage by livestock as

well as a synthesis of the various adoption studies. The best estimate was that milk yield increased by 0.6–0.8 kg/kg intake of *Calliandra* leaf. Scaling this production impact up using estimates of adopters in East Africa, the authors estimated the economic impact of forage tree adoption in Kenya in 15 years to be in the order of US\$20–30 million. The report also assembled adoption data from various sources to arrive at a total of 206,000 farmers having adopted multi-purpose trees in East Africa by 2005. By the authors' own admission, the farmer numbers are 'rough guesses', often partly based on data from reports of non-governmental organizations promoting multi-purpose trees with associated uncertainties. Nevertheless, it is clear that the number of farmers growing multi-purpose trees in East Africa is notable.

The 'project focus' of the reported adoption of multi-purpose trees was highlighted in a recent paper by Brockington *et al.* (2016) in which a previous agroforestry intervention was revisited 5 years after the project end. While the primary focus was on fruit trees, multi-purpose trees also formed part of the study, and the issues around 'adoption' are generic. Assessment of fodder tree adoption must be done over several years, whereas conventional project cycles are usually too short to allow this. The result is that most assessments track the very early stages of adoption focusing on counting numbers of farmers receiving extension support and materials while neglecting evaluation of longer-term diffusion of tree technologies. Abandonment of fodder tree interventions following the end of projects is relatively common (Francis and Atta-Krah, 1989; Mekoya *et al.*, 2008). Not all farmers who test fodder trees go on to adopt them (Kiptot *et al.*, 2007). However, there are also cases of spontaneous diffusion of fodder tree technologies without researcher involvement (Kiptot *et al.*, 2006; Wambugu *et al.*, 2011) so the story is not clear. What is needed for this and other planted forage initiatives are some independent evaluations involving medium-term revisits to project sites to assess the extent of sustained use of fodder trees beyond the project life. Further studies like that of Brockington *et al.* (2016) would be welcome.

Successful use of multi-purpose trees for fodder is 'knowledge intensive', and much of ICRAF's recent work has been around suitable

dissemination pathways to enhance adoption (Kiptot *et al.*, 2006; Lukuyu *et al.*, 2012). At the current stage of smallholder system development, it may therefore be some while before we see spontaneous uptake of multi-purpose trees without project intervention.

Napier grass in East Africa and beyond

Napier grass (*P. purpureum*, sometimes called elephant grass) is a perennial species originating in sub-Saharan Africa that is known for its high biomass production and rapid regeneration capabilities, good palatability and nutritional qualities. These features have made it highly popular, mainly as a 'cut-and-carry' feed in livestock production systems across the tropics and subtropics. The popularity of Napier grass is not attributable to CGIAR research as it was introduced from southern Africa in the colonial, pre-CGIAR era. However, because of its importance, especially in East Africa, it has featured strongly in CGIAR research as outlined below. Napier grass is highly adaptable to a broad range of production systems and environments. Although it is known to grow best in regions where annual rainfall exceeds 750 mm and in locations below 2100 m above sea level, it has been reported to grow at up to 3000 m above sea level in tropical regions and to contain similar concentrations of crude protein to lucerne, and has been used to replace lucerne hay in livestock production systems (Criscioni *et al.*, 2016). It can be chopped and fed directly and can also be grazed or conserved and made into hay, silage or pellets (Figueira *et al.*, 2015; Mapato and Wanapat, 2018). There are approximately 25 Napier grass varieties or cultivars, and an additional 16 sterile hybrids formed with pearl millet (*Pennisetum glaucum*) currently being grown around the world (Cunha *et al.*, 2011). In addition, the species is open pollinated and therefore highly heterozygous with significant variability for both nutritional and agronomic traits, which indicates that there are significant opportunities for the development of new and improved varieties (Negawo *et al.*, 2017). The current varieties come in two main forms: there are the standard 'tall' varieties, which are renowned for their biomass production and are most popular in the cut-and-carry systems and there are the dwarf or 'short' varieties, which do not produce as much biomass but have shorter

internodes (i.e. increased leaf:stem ratio) and are considered to be of higher quality and to have greater resilience to abiotic stresses (Sollenberger *et al.*, 1987).

Napier grass is most prevalent in the cut-and-carry systems that dominate livestock production systems, particularly dairy, in East and Central Africa. It is considered the most popular perennial fodder for the smallholder crop-livestock farming systems in Kenya (Nyambati *et al.*, 2010), and has been reported to represent approximately 80% of planted forages in this country (Staal *et al.*, 1997). Recent estimates by authors of this chapter based on the survey reported in Tables 13.2 and 13.3 indicated that Napier grass is an important feed resource for at least 1.3 million households in Kenya and Ethiopia. The variety Bana is currently the most commonly grown in Kenya, although, as indicated elsewhere in this chapter, other selected varieties are growing in importance. This is mainly because, while considered resilient in the face of many pests and diseases, the impact of some specific diseases (namely head smut and stunt) have had a negative impact on the further growth and distribution of this species. However, new material such as the smut-resistant Kakamega I and Kakamega II, which are accessions from the ILRI gene bank, are alternatives where smut is a threat (Mwendia *et al.*, 2008). More recently, other gene bank accessions have been identified as a source of tolerance, or resistance, to stunt disease (Wamalwa *et al.*, 2017). The potential of Napier grass with respect to yield, disease resistance and ease of harvest has been assessed in Ethiopia (Kebede *et al.*, 2017) and Tanzania (Sikumba *et al.*, 2015).

Napier grass has also had a significant impact in production systems outside Africa and has been readily adopted in South and Southeast Asia. For example, Pakchong 1 (or 'Super Napier'), a tall hybrid cultivar recently developed in Thailand and distributed in other countries including the Philippines, Malaysia and India, is being widely promoted for cultivation in smallholder systems (Halim *et al.*, 2013; Wangchuk *et al.*, 2015). In India, the standard Bajra-Napier hybrid (also known as king grass) variety has been identified as an option for sustained fodder yields, particularly for cattle and buffalo production systems (Kadam *et al.*, 2017). Napier grass is also a popular cut-and-carry forage in the trop-

Table 13.2. Distribution of fodder grasses, legumes and trees in areas with dairy production in Ethiopia and Kenya. (Data from N. Teufel. *et al.*, unpublished survey.)

Country	Region	No. villages	Forage grasses			Forage legumes			Forage trees		
			No. villages ^a	Hh (%) ^b	Area (%) ^c	No. villages ^a	Hh (%) ^b	Area (%) ^c	No. villages ^a	Hh (%) ^b	Area (%) ^c
Ethiopia	Amhara	54	40	10.9	0.6	25	5.6	0.4	53	40.6	2.4
	Oromiya	63	54	12.2	0.6	30	3.3	0.1	40	15.2	3.1
	SNNP	36	34	34.5	1.3	23	12	0.4	21	6.1	0.3
	Tigray	27	25	14.8	1.3	23	8.5	1.1	27	24.3	3.4
Kenya	Central	45	45	82.7	12.9	13	2	0.2	11	0.7	0.1
	Coast	15	6	9.2	0.5				1	0.1	0
	Nyanza	45	39	67.1	6.7	3	0.8	0.1	16	20.3	0.7
	Upper Rift	45	45	42.2	7.6	3	0.3	0.2	11	6.3	0.1
	Western	30	30	68.3	6.8	4	0.8	0	12	4.2	0.1

SNNP, Southern Nations, Nationalities, and Peoples' Region.

^aNumber of villages in which fodder was grown.

^bShare of households (Hh) growing forages among farming households.

^cArea share of cultivated area devoted to forage, considering only forages for which extent of adoption was recorded by area units.

Table 13.3. The most important fodder crops by households in Ethiopia and Kenya. (Data from N. Teufel *et al.*, unpublished survey.)

Country	Rank	Species	No. villages ^a	Hh (%) ^b	Area (%) ^c
Ethiopia	1	Sesbania (<i>Sesbania sesban</i>)	136	34	0.5
	2	Napier, local (<i>Pennisetum purpureum</i>)	141	16	0.3
	3	Rhodes grass (<i>Chloris gayana</i>)	50	7	0.2
	4	Desho grass (<i>Pennisetum pedicellatum</i>)	44	6	0.1
	5	Lucerne (<i>Medicago sativa</i>)	43	5	0.1
Kenya	1	Napier, local (<i>Pennisetum purpureum</i>)	162	93	5.2
	2	Napier, other improved (<i>Pennisetum purpureum</i>)	11	10	0.2
	3	Rhodes grass (<i>Chloris gayana</i>)	41	8	0.8
	4	Calliandra (<i>Calliandra calothyrsus</i>)	43	7	0
	5	Fodder sorghum (<i>Sorghum</i> spp.)	3	6	0

^aNumber of villages in which fodder was grown.^bShare of households (Hh) growing forages among farming households.^cArea share of cultivated area devoted to forage, considering only forages for which extent of adoption was recorded by area units.

ical southern states of China where king grass is also an option. Here, new varieties that have been developed include Guimu and Guimin Yin, which are mainly considered for use as feed for cattle and other livestock (Shilin *et al.*, 2007). In the grazed systems of Japan, the dwarf varieties, commonly grown in combination with Italian ryegrass (*Lolium multiflorum*), are growing in popularity (Ishii *et al.*, 2005; Fukagawa and Ishii, 2018).

In South America, one of the few active breeding programmes for Napier grass exists at EMBRAPA in Brazil (Gomide *et al.*, 2015). There is a history of exchange of material between the ILRI gene bank and EMBRAPA, which enhanced the diversity in each of the collections in support of the development of new cultivars (Negawo *et al.*, 2018). Some of the most recent cultivars from EMBRAPA produced include Pioneiro, a standard variety for cut-and-carry systems (Figueira *et al.*, 2016), and BRS Kurumi, a dwarf variety mainly targeted for grazing but also considered suitable for cut-and-carry systems (Gomide *et al.*, 2015; Pereira *et al.*, 2017).

Push–pull technology

The so-called push–pull system developed by ICIPE and the Rothamsted Research Institute is

a biological intervention to control maize stem borer (Khan *et al.*, 2006, 2008a, 2014; ICIPE, 2015). The basis of the technology is that stem borer moths are repelled by phytochemicals in the legume *Desmodium* spp. (*D. intortum*, *D. uncinatum*) but are attracted by the green biomass provided by Napier grass. Planting patterns for *Desmodium*, Napier grass and maize that take account of these effects can lead to reduced stem borer infestation. The planting pattern usually involves maize intercropped with *Desmodium* as a repelling plant (push) with the intercropped area surrounded by Napier as an attractant for pests (pull). A further benefit is reduced infestation by *Striga* spp. (*S. hermonthica* and *S. asiatica*), an obligate parasitic weed that can greatly reduce host crop yields. The technology has potential environmental and economic benefits in that it does not require expensive and damaging pesticides. The technology also provides feed in the form of Napier grass and *Desmodium* fodder, as well as reducing pests.

Assessments by the originating institutions suggest that tens of thousands of farmers have adopted the practice in East Africa. For example, a 2011 study put the number of adopters at 30,000 in East Africa, with the technology covering 15,000 ha (Khan *et al.*, 2011). More recent promotional materials estimate the number of

adopters to be closer to 100,000 (ICIPE, 2015). In common with fodder trees, push–pull is a knowledge-intensive technology that has been heavily promoted by the originating institutions. Definitions of ‘adoption’ in the literature around push–pull tend to be vague and often relate to the numbers of farmers ‘reached’ with the technology rather than those accepting and adopting the practice over the long term. Adoption estimates are usually presented without a clear definition of adoption and without supporting evidence against which to judge their reliability. As with fodder trees, there is a need for independent evaluations to assess the true extent of adoption of the push–pull technology.

The assumed strength of push–pull is its multiple benefits, which include reduced pest damage, fewer weeds, more feed and improved soil fertility using legumes (*Desmodium* spp.). However, in the context of assessing forage successes, push–pull is not necessarily the strongest example because the potential benefits accrue from both improved cereal yields and improved forage production. In some economic assessments of the benefits of push–pull, the extra milk from improved livestock feeding does not feature in cost–benefit calculations (Khan *et al.*, 2008b). Other studies have factored in economic benefits from forages based on prevailing market prices for forages and found them to be important in the overall profitability of the technology (de Groote *et al.*, 2010).

Adoption of planted forages in Asia

CIAT has stimulated adoption of intensive grass production linked to beef cattle fattening and cow–calf breeding systems in South-east Asia (Stür *et al.*, 2007). The technology involves cut-and-carry grass plots with the species being mainly *Panicum maximum*, *B. humidicola* and *Brachiaria* hybrids. The areas planted to grasses are small, averaging around 0.25 ha, but plots as small as 0.1 ha are viable because production is intensive and grass yields can be very high. The success of the planted forages initiative depended on the participatory nature of the intervention coupled with improved planting materials (Ayele *et al.*, 2012).

The planted forage initiative in South-east Asia evolved over two decades through multiple projects with estimated numbers of farmers adopting it in excess of 10,000 in Vietnam alone among those directly involved in project areas (Stür *et al.*, 2013). Although assessments of the extent of adoption are conducted by the originating institutions and are thus not independent, the counts are based on surveys of random samples of households in the study districts and thus have some credibility. The technology has now been taken up by local government structures (Millar and Connell, 2010), and the reach is likely to be much larger although, again, independent assessments are needed.

Other examples are the adoption of the legume *Stylosanthes guianensis*, based on accession CIAT 184, as a cover crop and for leaf meal production in tropical China, reaching about 300,000 farmers to feed poultry and pigs (Guodao and Chakraborty, 2005) and the use of various *Stylosanthes* spp. in India by 250,000 farmers (Shelton *et al.*, 2005).

Adoption of planted forages in Latin America and the Caribbean

In terms of area, adoption of tropical forages in Latin America and the Caribbean is widespread and the role of the CGIAR centres has been important (Lynam and Byerlee, 2017a) although the beneficiaries have generally been larger farmers.

In 2002, a *Brachiaria decumbens* × *brizantha* × *ruziziensis* cultivar coming out of CIAT’s breeding programme (Miles, 2001, 2007) was released (Lynam and Byerlee, 2017b) as the first bred *Brachiaria* cultivar to be documented. *Brachiaria* hybrids have since been commercialized through interaction with the private sector, namely the Papalotla Group and Dow AgroSciences. Uptake based on documented commercial seed sales to the end of 2018 was estimated to be some 960,000 ha mostly sown in the past decade. According to CGIAR reports, more than 100,000 ha are planted on an annual basis, with numbers still below the potential as seed production and commercialization channels are still evolving (CGIAR, 2018). Most adopters appear to be small and medium-sized livestock producers (Papalotla, personal communication),

although not equivalent to 'smallholders' as used in the African context. Recently, Papalotla registered advanced cultivars in Kenya and is commercializing these through licensing agreements (Government of Kenya, 2016). The original cultivar Mulato had limited commercial success due to low seed production and was quickly replaced by Mulato 2 when higher seed production was included as an additional breeding objective. In subsequent years, a series of *Brachiaria decumbens* × *brizantha* × *ruziziensis* hybrid cultivars and a synthetic mixture were released, namely Cayman (tolerant to water logging), Cobra (more erect growth habit), Camello (better drought tolerance), Mestizo (synthetic mixture of three hybrids for better establishment and pasture utilization) (Papalotla: www.grupo-papalotla.com/productos.html and Tropical Seeds: www.tropseeds.com/varieties/, both accessed 27 March 2020) and Converse (Dow Agrosciences). Additional materials for increased tolerance to drought and shade (e.g. for silvopastoral systems) and additional synthetic mixtures are to be commercialized in the next 2–4 years (Papalotla, personal communication). CIAT is also advancing the development and commercialization of *B. humidicola* and *Panicum maximum* breeding lines.

Some of the most widespread adoption of planted forages is in Brazil where it is estimated that about 120 million ha have been planted, of which 99 million are *Brachiaria* spp. and about 17 million ha are *P. maximum* (Jank *et al.*, 2014). This has largely been driven by the private sector and EMBRAPA, which are valuable partners, and involves large farms that are only peripherally within the mandate of the CGIAR system.

Similar production increases have been achieved in the Eastern Plains of Colombia as part of the collaboration of the Corporacion Colombiana de Investigacion Agropecuaria (CORPOICA) and CIAT, with inclusion of *Brachiaria* spp. in crop/pasture rotations leading to a doubling of carrying capacity compared with degraded pasture and a tenfold increase over native savannah (Rincón and Ligarreto, 2008; Rincón *et al.*, 2010).

Better documented is the uptake of *Brachiaria* grasses in Mexico and Central America where by the early 2000s over 3 million ha were reported based on extrapolation from seed sales

(Holmann *et al.*, 2004). Surveys in Colombia's Eastern Plains carried out in 2017 suggested that about one-third (about 3 million ha) of improved pastures are sown using *Brachiaria* cultivars selected by CORPOICA and CIAT or bred by CIAT; across a set of five countries, an estimated 59.2% of all pastures were found to be planted with *Brachiaria* grasses, with about half being CIAT-selected *Brachiaria* (ISPC, 2018). Through the work of EMBRAPA, with contributions from CIAT, Rivas (2002) estimated that 1.5 million ha had been sown to *Andropogon gayanus* by 2000.

The documented success of forage legumes so far is less visible. However, for *Arachis pintoi*, cv. Amarillo developed in Australia and selected by EMBRAPA and CIAT for tropical America, around 65,000 ha have been reported to be adopted in Acre in Brazil (Valentim and de Andrade, 2005). A *Stylosanthes* spp. mixture ('Estilosantes Campo Grande'), co-developed by B. Grof (EMBRAPA, ex-CIAT), has been sown on 150,000 ha in the southern Cerrados of Brazil (Fernandes *et al.*, 2005).

These South American examples point to possible future growth in use of planted forages in Africa once livestock production becomes more commercial, farm sizes increase, private-sector actors have stronger engagement and the institutional environment is more conducive to growth of the forage sector.

Knowledge products on planted forages

As well as research on planted forages, CGIAR centres have generated a range of 'knowledge products', which collect internal and published knowledge and present it in a form that is useful for scientists and the wider livestock development community. Examples of such knowledge products are the Tropical Forages tool, the *Tropical Grasslands-Forrajes Tropicales* journal and the Feed Assessment Tool (FEAST).

Tropical Forages tool

A wide array of plant species is used as feed for livestock and these differ in both their suitability as livestock feed and in the biophysical conditions

that support their growth. In 2005, the international planted forages community initiated the Tropical Forages tool to collate the tacit knowledge of forage experts as well as published data on forage characteristics to develop an online tool to support selection of appropriate forages for specific purposes and locations. The Tropical Forages tool (www.tropicalforages.info; accessed 28 February 2020) has been available since 2005 and is currently receiving approximately 500,000 annual hits with visitors coming from universities, development agencies, seed companies and (informed) farmers. It is open access and easy to use, providing detailed information on more than 170 major forage species and the environments they are adapted to. The tool was developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Queensland Department of Agriculture and Fisheries, CIAT and ILRI, and capitalized on the inputs on more than 50 forage experts, with widespread knowledge and experience in tropical and subtropical forages. An updated version of the tool was launched in 2021.

Tropical Grasslands-Forrajes Tropicales

The online journal *Tropical Grasslands-Forrajes Tropicales* was established in 2012 as a successor to the former journals, *Tropical Grasslands*, published during 1967–2010 by the Tropical Grassland Society of Australia, and *Pasturas Tropicales*, published during 1979–2007 by CIAT.

The main features of *Tropical Grasslands-Forrajes Tropicales* are that the journal is international, published online only, open access (no charges for subscription or publication fees), bilingual (English and Spanish), peer reviewed and guided by a 23-member Editorial Board, which is composed of the world's leading tropical pasture scientists. Further information on the journal is available at its website (www.tropicalgrasslands.info; accessed 28 February 2020). Back issues of the predecessor journals, *Tropical Grasslands* and *Pasturas Tropicales*, can also be accessed at this site. The journal is indexed in the major abstract and citation databases of peer-reviewed literature and is widely used; as of December 2019, there had been more than 492,000 abstract views and more than 669,000 PDF/eBook downloads; currently the journal receives 229,000 annual visits.

Feed Assessment Tool (FEAST)

FEAST (Duncan *et al.*, 2012) is a systematic, participatory approach to supporting design of livestock feed interventions at the village/community level. It was originally developed in 2008 by ILRI in collaboration with CIAT. FEAST involves a structured conversation with farmers at the village level to characterize the local farming system, the role of livestock in the farming system and the way in which livestock are currently fed. This is followed by application of a short household survey among selected farmers. Data from the survey are used to develop a series of standardized graphical outputs, which support decision making on appropriate feed interventions. A further feature is an intervention-ranking module, which generates a prioritized list of candidate interventions derived from automatic analysis of survey data. The FEAST data application itself has been downloaded by 1400 individuals and has been applied in over a dozen countries. Over 70 FEAST reports have been published online. Published outputs in the FEAST collection in the CGIAR publication repository have had over 15,000 views and downloads per year in the past 5 years.

Forage seed technical support and distribution

CGIAR has been active in the provision of advice and technical training in forage production as well as production and sale of seeds for establishment of tropical forages to address these constraints. The seed production units of CIAT and ILRI provide a source of tropical forage seeds and planting material of selected best-bet species at cost for use in establishing national forage seed production. CIAT provides seeds of 25 herbaceous legumes, nine grasses and seven fodder trees. ILRI currently can supply seeds of 33 species of herbaceous legumes, ten species of grass and five species of fodder trees. Provision of seeds from the two sources is complementary, mostly handling different species and distributing in different regions, primarily within the regions where the centres are located (Table 13.4). CIAT has shipped seeds of over 20,000 samples to 88 different countries, while ILRI has provided over 8500 samples in response to over 1500 orders

since the establishment of their forage seed activities. Seed distribution has supported the forage evaluation networks of CIAT and ILRI in Asia, Latin America and the Caribbean, and sub-Saharan Africa, and has strengthened forage research and development activities globally.

Tropical forage seed production is a specialist market because many species are perennial and annual reseeding is not required. This leads to uncertain demand, which causes a high degree of risk to both seed producers and sellers and has reduced investment in a more formal distribution seed system for forage seeds in many developing countries (Hanson and Peters, 2003). This has also contributed to fewer new varieties and species being released in recent years and promotion of an informal integrated community-based seed supply system to fill the gap. A recent survey in Ethiopia showed that many smallholders are willing to pay for forage seeds and to use land for planted forages where alternative feed is scarce and where market opportunities for milk and meat exist (Negassa *et al.*, 2016).

Both centres have supported alternative suppliers in the tropical forage seed agribusiness. CIAT has partnered with the Papalotla Group from the private sector to achieve a wide dissemination of hybrid pasture seeds developed

by CIAT that will be distributed by Papalotla. Both CIAT and ILRI have supported entrepreneur or farmer-led seed supply systems to complement large-scale private seed production. Collaboration with government institutions and non-governmental organizations has ensured training of farmers in seed production, seed quality control and certification. A farmer-led seed enterprise, PRASEFOR (Artisanal Forage Seed Production), was formed in Honduras as an association of 12 smallholder farmers to produce grass seeds. In contrast to many other farmer-led seed enterprises, this was business oriented and formed with very limited financial support, making the approach easily replicable (Hanson and Peters, 2003). Farmers were able to obtain a return of more than US\$600/ha on forage seed production compared with an estimated US\$60/ha for maize production. A similar approach was recently piloted in Ethiopia through the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ)-funded FeedSeed project by mentoring individuals and forage seed businesses representing smallholder farmers, cooperatives and commercial seed companies, thereby helping to stimulate the availability of more and better-quality forage seed and forage use by smallholder livestock producers. The pilot project

Table 13.4. Major countries of recipients of forage seeds from CIAT and ILRI. (Data from ILRI and CIAT databases, February 2019.)

CGIAR centre	Country	Number of seed samples	Amount distributed (kg)
CIAT	Bolivia	492	306
	Brazil	837	535
	Colombia	16,202	55,912
	Costa Rica	570	993
	Ecuador	618	189
	Honduras	476	95
	Mexico	597	110
	Nicaragua	522	162
	Peru	1,024	1,295
	Venezuela	605	1,723
ILRI	Burundi	42	54
	Cameroon	98	74
	Ethiopia	6,989	34,591
	Ghana	81	33
	Kenya	159	199
	Pakistan	51	44
	Rwanda	47	29
	Tanzania	130	136
	Uganda	69	77
	Zambia	58	43

incubated 30 profitable private companies whose annual seed sales reportedly started at US\$20,000 and increased to US\$400,000 by the end of the 2-year project. With seed prices at US\$5–20/kg in early 2019, forage seed production does seem to be economically attractive.

Environmental benefits of planted forages

The potential impact of tropical forages on GHG emissions has been well documented. Mitigation approaches include direct reduction of emissions, enhancing of carbon sequestration, higher productivity per land area and/or livestock unit and of feed efficiency (Peters *et al.*, 2013; Searchinger *et al.*, 2013; Rao *et al.*, 2015) and avoiding detrimental land conversion. By applying suitable practices, land can be freed for reforestation or for landscape restoration while livestock output grows. Genetic solutions to curb nitrous gas emissions and nitrate leaching – while reducing the amount of nitrogen fertilizers in crop–livestock rotations – have been demonstrated as a proof of concept for biological nitrification inhibition (Subbarao *et al.*, 2017). The environmental role of symbiotic nitrogen fixation by tropical legumes is recognized, as is the potential of tannin-rich legumes for reduction of methane emissions by livestock (Schultze-Kraft *et al.*, 2018). Less information is currently available on the water footprint of forage-based feed production, with fodder production being a major driver of water use in livestock systems (Herrero *et al.*, 2012).

The main potential environmental impact of tropical and subtropical planted forages will be through intensification of livestock production and accompanying reductions in emissions assuming livestock numbers decrease as production intensifies. The situation may change when the role of tropical forages in providing ecosystem services is further recognized and economic incentives for increased adoption of planted forages are in place (such as Payment for Ecosystem Services schemes). Because pasture-based systems, which are the largest single land-use category globally (Erb *et al.*, 2007), are changing from extensive grasslands to more intensive mixed crop–livestock farming, there is the opportunity that this transition could reduce GHG emissions without negative effects on food security (Havlik *et al.*,

2013). Moreover, the high-risk sites, or ‘hotspots’, for GHG emissions are located in areas of low livestock productivity – extensively managed areas in eastern Africa, Latin America and the Caribbean, and South Asia (Gerber *et al.*, 2013; Herrero *et al.*, 2013). These are also the areas with the greatest potential for increased forage use, although as argued elsewhere in this chapter increased forage use would depend heavily on the economics of land and labour use.

As examples of the potential importance of forages in climate-change scenarios, the governments of Brazil and Colombia have identified the intensification of livestock production, using planted forages and proper management, as key strategies to mitigate GHG emissions in agriculture. The strategies are outlined in the Plano ABC (Ministério da Agricultura, Pecuária e Abastecimento, 2012) and the NINO (Ministerio de Ambiente y Desarrollo Sostenible, 2015) for Brazil and Colombia, respectively, as a combination of increased productivity per livestock unit and land area and favouring environmentally sound land-use changes. Thornton and Herrero (2010) has illustrated the possibility of specific technologies such as improved *Brachiaria* and *Leucaena* spp. to reduce GHG emissions through increased per-animal productivity and assumed reductions in livestock numbers. Lal (2010) has stated that 29% of the overall carbon mitigation potential will be from pastureland. The biggest potentials for carbon sequestration (i.e. through restoring degraded grasslands) are in South America and Africa (Conant, 2002; Conant *et al.*, 2011).

In a review of the potential of forages to mitigate emissions, Peters *et al.* (2013) concluded that forage-based systems have a lower ecological footprint than feedlots. Better management of crops and grasslands, and restoration of degraded lands, can result in a mitigation potential as high as 3.5 billion t CO₂-eq/year or 75% of the biophysical mitigation potential stated by Smith *et al.* (2008). Thornton and Herrero (2010) calculated that a modest 30% adoption rate of improved deep-rooted *Brachiaria* pastures could yield a mitigation potential of 29.8 million t CO₂-eq/year in the Cerrados of Brazil alone, an amount equivalent to 2% of the total mitigation potential of agriculture. According to Fisher *et al.* (2007) and Blanfort *et al.* (2012), the mitigation potential of planted forages to accumulate carbon under adequate pasture and animal

management is second only to forests. To refine these estimates, further research in a variety of contexts is required.

What has limited the impact of planted forages in tropical Africa and Asia?

Despite the technical potential of planted forages, a common research finding is that they are rarely adopted beyond project-led initiatives in Africa and Asia. Evidence for spontaneous widespread adoption is rare, except, for example, Australia and Brazil where the context is very different and smallholders are not the main beneficiary. The reasons for lack of adoption are complex. Promoters of planted forages are convinced of their technical merits and advocate greater 'promotion and dissemination' to convince smallholders of their advantages. In the terminology of Sumberg (2002) forage legumes have taken on a 'mantle of absolute goodness'. The realists view lack of adoption as being related to inherent system properties, which make them unattractive for farmers given the prevailing economic environment. To quote Sumberg (2002): 'Particular attention is placed on the idea that the biophysical and socio-economic factors that have previously been constraints to legume adoption should now be viewed as system properties and incorporated into the design specification of technology.'

This idea that system properties are what constrain the uptake of planted legumes and planted forages in general is compelling and was also proposed by McIntire and Debrah (1986) as long ago as the mid-1980s. McIntire and Debrah (1986) laid out a series of propositions regarding the suitability of forage legumes for smallholder systems. Among their propositions were that at different population densities competition for land and labour will tend to disadvantage forage legumes as a viable part of the farm enterprise. At low population densities (e.g. pastoral systems), competition for labour is an issue. In such systems, crops and animals are managed as separate enterprises, as mobility of livestock is a necessary property of the system. Devoting labour to tending of forage crops becomes impractical. At high population densities (e.g. mixed intensive systems), competition for land becomes the

issue. In such systems, land is scarce and use of land for production of staple and cash crops takes priority over the production of livestock feeds for reasons of economics.

The barrier of system properties is also apparent in the arguments of Ruthenberg (1980) in his consideration of the scarcity of medium- to long-term grass cultivation in the tropics ('ley farming'). Ruthenberg pointed out various characteristics of tropical farming systems that make ley farming unattractive. Among the reasons offered by Ruthenberg were the poor nutritive quality of tropical grasses, the advanced animal husbandry needed to make such systems work and the relative (un)profitability of use of land for livestock production compared with arable options such as maize, sorghum and cassava.

A more recent line of argument in the debate about adoption success of planted forages frames the problem as one of 'innovation capacity failure' (Hall *et al.*, 2007). The application of innovation systems theory to the question of feed development follows a trend across the CGIAR system to think about technical change in the context of innovation systems – the network of agents and their interactions that are necessary to foster change. In ILRI and CIAT, projects around the time, including the Fodder Adoption Project and Fodder Innovation Project, attempted to move beyond technical feed research to investigate institutional barriers to technical change in the feed sector (Ayele *et al.*, 2012; Reddy *et al.*, 2013). In the logic of these projects, there was a recognition that Sumberg's (2002) 'system properties' were indeed impediments to progress but that focusing on the institutional issues could overcome some of these barriers including difficulties of seed supply, access to markets and the need to deal with policy constraints to bring about improvements in livestock feeding. While these projects did not fully achieve their ambitions, they did bring in new thinking about innovation in the livestock feed sector and helped to broaden research perspectives beyond a narrow focus on forage management. In South-east Asia in particular, application of such thinking did lead to adoption of forages at a reasonable scale (Stür *et al.*, 2013). Such innovation systems thinking is now routinely embedded in CGIAR-led projects and programmes focused on feed and forage

improvement in the CGIAR Research Programme on Livestock and Fish (Puskur *et al.*, 2011).

Global impacts from planted tropical forages

Early research on tropical planted forages focused on collection and characterization of forage species with economic potential to improve livestock productivity. This involved collections in sub-Saharan Africa organized mainly from Australia. Promising accessions are now stored in the various gene banks of CGIAR, notably those at ILRI, CIAT and ICARDA. Despite extensive forage research activity in the CGIAR and other centres, forage adoption among smallholders has generally been disappointing. Pengelly *et al.* (2003) concluded that 'despite 50 years of investment in forage research in the tropics, forage adoption has been relatively poor across all tropical farming systems'. Sumberg (2002) argued that forage legumes had not achieved their potential in sub-Saharan Africa, despite 70 years of research to promote them. Shelton *et al.* (2005) in their review of forage legume successes found that none of the 14 legume cultivars released in Latin America and the Caribbean between 1980 and 2000 was well adopted.

In reaction to these disappointing findings about the impact of tropical forages research, there have been attempts to re-evaluate the impact. The most recent example is the meta-analysis of White *et al.* (2013), which built upon the study by Shelton *et al.* (2005). The Shelton study presented 19 case studies and estimated areas planted to various tropical legumes around the world, along with numbers of farmers and gross economic benefits. Notable successes were cowpea in West Africa accounting for 1.4 million ha (*ex ante* impact estimate), fodder trees in East Africa totalling 4 million m of hedgerows, *Stylosanthes* spp. in southern China (more than 200,000 ha), Thailand (more than 300,000 ha) and India (less than 250,000 ha), *Pueraria phaseoloides* as grazed pastures in Brazil (480,000 ha) and *A. pintoi* also in Brazil (more than 65,000 ha). The authors identified factors favouring adoption as meeting the needs of farmers, building partnerships, understanding the resources and skills of farmers, engagement with

rural communities, and long-term involvement of champions (Shelton *et al.*, 2005).

The study by White *et al.* (2013) sought to quantify the impact of planted tropical forages in general (and not just legumes, as in the study by Shelton *et al.*, 2005). They defined the impacts in three main domains: economic, social and environmental. Positive impacts can include improved soil cover and hence reduced erosion, nitrogen fixation by legumes leading to improved soil health, and deeper rooting leading to improved water-use efficiency and soil carbon storage. Negative impacts can include the introduction of invasive characteristics and loss of local biodiversity.

The authors set out a series of nine methodological shortcomings of the studies reviewed as a caution to the conclusions about economic impact. Despite shortcomings in the methods and data in the evidence reviewed, the analysis yielded some interesting insights. White *et al.* (2013) identified a total of 118 million ha planted to 'improved' tropical forages from the studies they compiled. They estimated that Brazil accounted for 86% of the known planted area of improved forages. The area under *Brachiaria* spp. dominated. The farm-size characteristics of this adoption were not fully defined and included large commercial operations.

Emphasizing the methodological shortcomings of the sample studies, fewer than 20% of the studies directly attempted to quantify economic impacts. Furthermore, the lack of a common methodology to quantify economic impacts (mixture of net present value approaches and annual estimates) meant that it was difficult to come up with an estimate of total economic benefit. Environmental and social impacts were even less frequently quantified, with 7% and 2% of the studies quoting environment and social impacts, respectively. The authors recognized a trend for greater emphasis on longer-term impacts in later studies, suggesting that the research for development community is increasingly aware of the need to quantify large-scale impacts. Of all the studies analysed, fewer than 15% were conducted independently of the personnel affiliated with the programme or project. This may have led to exaggeration bias, as those closely involved would be under pressure to justify their research through impact. As previously noted,

this lack of independent assessment is also an issue with the various success cases outlined earlier in this chapter.

New adoption potential

Given the advances in the quality and coverage of databases, scientists can target forage research to sites of highest probable adoption. Several factors affect adoption potential. One is population density. Forage cultivation can be expected to occur at intermediate population densities where there is sufficient land but where labour does not become a limiting constraint, or in areas of high population density that are highly productive. A second factor is profitability in the situations where high demand and prices can provide the incentive to invest in forages (e.g. instead of or as well as vegetable production). A third factor is rainfall distribution: given that forage is a year-round enterprise especially for dairy production, forages are more likely to succeed where rainfall is well distributed. If this is not the case, forages can work but the capacity to conserve, especially through hay-making, may be crucial for adoption.

We outline an example for Napier grass (*P. purpureum*) and its potential as a cut-and-carry forage. We utilized the model EcoCrop as implemented in DIVA-GIS (Hijmans *et al.*, 2012). To generate suitability surfaces for Napier grass, EcoCrop estimates a suitability index from 0 to 100 for a crop, based on monthly precipitation and temperature surfaces and on a small number of crop-specific parameters. We evaluated Napier grass suitability for current climatic conditions using the WorldClim dataset (distributed as part of DIVA-GIS). For possible future climatic conditions, we downscaled spatially coarse output from

several climate models in relation to a high GHG emissions scenario for periods centred on 2050 and 2090 (Jones and Thornton, 2015). Aggregate differences in both projected temperature and rainfall for the climate models selected are shown in [Table 13.5](#).

To identify areas with ‘moderate’ population densities, following Kruska *et al.* (2003) we used a lower limit of 20 people/km², above which increasing proportions of land are cultivated (Reid *et al.*, 1995, 2000). Goddard *et al.* (1975) and McIntire *et al.* (1992) showed that fallowing disappears (and agricultural fields coalesce) at densities above 85 people/km² across the semi-arid to humid zones in Africa. We thus set the moderate population density to be between 20 and 85 people/km², and we used the dataset GPW v4 (CIESIN, 2016).

As a proxy for market pull, we used the accessibility dataset of Nelson (2008), which gives the travel time in minutes to the nearest city with a population in excess of 50,000, based on the estimated travel time to cross each pixel in relation to land cover, slope, elevation, the roads network, and any railways, rivers and water bodies. As a threshold, following Jones and Thornton (2009), we selected a value of 200 min, allowing the possibility for a smallholder to take produce to market and return home on the same day.

The results are shown in [Table 13.6](#) and [Fig. 13.1](#). These ‘high-potential’ sites are defined as the areas having at least moderate suitability for Napier grass and having a moderate human population density (20–85 people/km²) and are within 200 min travel time of large population centres. In all regions, suitability increases to the 2050s but then declines to the 2090s, presumably in response to ever-higher temperatures and increased plant

Table 13.5. General Circulation Model (GCM) responses for the land areas between latitudes 30°N and 30°S. Values shown are for ‘future minus current’. (From Jones and Thornton, 2015.)

GCM	2050s		2090s	
	Annual rainfall (mm)	Average annual temperature (°C)	Annual rainfall (mm)	Average annual temperature (°C)
GISS-E2-R (NASA Goddard Institute for Space Studies)	–53	+1.96	–56	+3.63
Ensemble mean (17 GCMs)	+12	+2.36	+32	+4.68
HadGEM2-ES (UK Met Office, Hadley Centre)	–2	+2.93	–10	+5.83

Table 13.6. High-potential sites for Napier grass as a cut-and-carry forage by region, period and climate model (km²). (Unpublished data from K. Kekae, G. Brychkova, P.C. Mckeown, J. Hanson, C.S. Jones, P.K. Thornton and C. Spillane, 2018.)

Region	Current conditions (2000)		Ensemble mean (17 GCMs) (2050s)		Ensemble mean (17 GCMs) (2090s)	
	Moderate suitability	Excellent suitability	Moderate suitability	Excellent suitability	Moderate suitability	Excellent suitability
Global	600,847	1,355,312	516,552	2,169,758	652,472	1,668,437
Latin America	174,039	363,101	97,149	560,998	162,458	394,257
Sub-Saharan Africa	201,548	712,057	109,829	920,105	186,875	725,251
Asia	149,343	257,897	89,741	436,231	125,500	304,854
Region	Current conditions (2000)		GIS2 GCM, 2050s		GIS2 GCM, 2090s	
	Moderate suitability	Excellent suitability	Moderate suitability	Excellent suitability	Moderate suitability	Excellent suitability
Global	600,847	1,355,312	546,007	1,981,659	524,104	2,044,916
Latin America	174,039	363,101	115,716	522,540	88,633	504,335
Sub-Saharan Africa	201,548	712,057	117,360	766,692	120,844	689,778
Asia	149,343	257,897	94,726	467,864	82,912	483,741
Region	Current conditions (2000)		HADG GCM (2050s)		HADG GCM (2090s)	
	Moderate suitability	Excellent suitability	Moderate suitability	Excellent suitability	Moderate suitability	Excellent suitability
Global	600,847	1,355,312	557,462	2,212,979	571,497	2,365,266
Latin America	174,039	363,101	114,498	557,242	131,724	491,588
Sub-Saharan Africa	201,548	712,057	116,960	876,141	109,760	848,881
Asia	149,343	257,897	87,816	446,145	94,043	441,943

Top, mean of 17 General Circulation Models (GCMs); middle, a 'cool' GCM (GISS-E2-R, see [Table 13.5](#)); bottom, a 'warm' GCM (HadGEM2-ES, see [Table 13.5](#)).

evapotranspiration. Nevertheless, the proportion of area that is of high suitability increases over time compared with the area of moderate suitability, and the proportion of highly suitable hotspot land outside the tropics is increasing over time. The trends for the cooler General Circulation Model (GCM; [Table 13.6](#), middle panel) are similar, although Asia sees an increasing area of highly suitable high-potential sites up to the 2090s. The hotter GCM results ([Table 13.6](#), lower panel) indicate that the tropics are in general becoming rather warm for Napier grass, and there are large areas in the northern temperate zones that are projected to be highly suitable high-potential sites.

Changing human population dynamics in the coming decades can be expected to affect suitability by increasing pressure on land,

particularly in peri-urban areas. These effects are difficult to estimate, however. For example, increasing population densities to the middle of the current century are likely to decrease the range of tsetse-transmitted trypanosomiasis in parts of Africa through habitat destruction (McDermott *et al.*, 2002). However, evaluating possible future changes in land use and land competition due to population growth and urban migration is more challenging, mostly because of the difficulty in projecting future development of road and other transport infrastructure, which is often the forerunner of highly localized increases in population density.

This simple illustrative analysis suggests that the potential high-potential sites for Napier grass adoption as a cut-and-carry forage are relatively

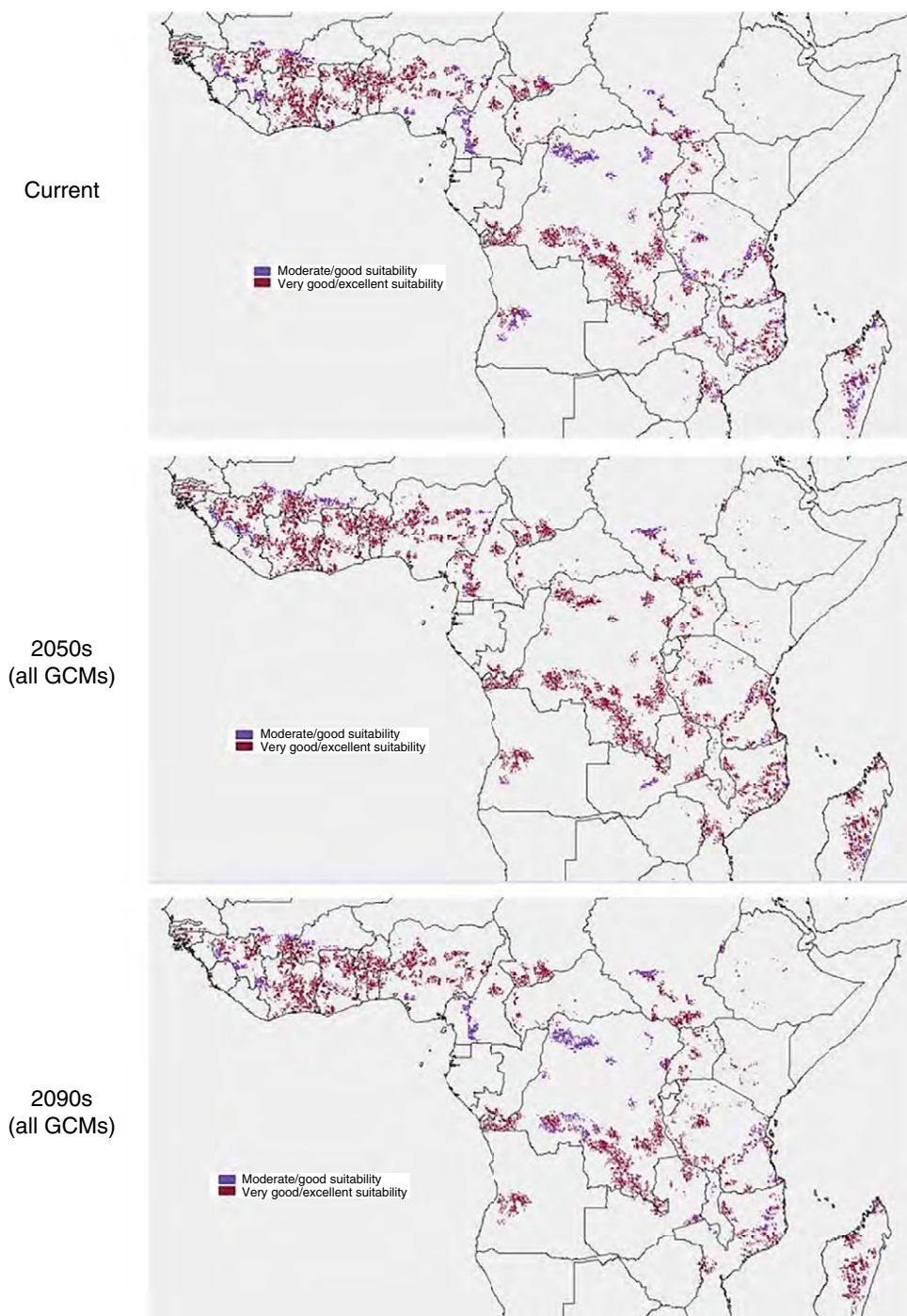


Fig. 13.1. High-potential Napier adoption sites in sub-Saharan Africa.

limited in the global tropics. A more robust analysis could be done that takes rainfall distribution into account, as well as by using a more sophisticated niche and suitability model than EcoCrop, such as MaxEnt (Warren and Seifert, 2011). Another missing element is information on possible changes in forage quality under a changing climate. Nevertheless, there is considerable potential to exploit new datasets for more appropriate targeting. Local evaluation, coupled with information on where particular forages are actually being utilized, has considerable potential to guide future forage targeting and adoption.

The Future

Planted forages have the potential to fuel growth in the smallholder crop and livestock sector in Africa and Asia by providing high-quality feed and by filling seasonal gaps. In addition to productivity benefits, planted forages can reduce the environmental footprint of livestock.

Adoption of planted forages has been below its potential in nearly all of sub-Saharan Africa and South Asia. Adoption in Latin America has been better, notably in Brazil and in parts of Central America. Such success is rare in Asia and sub-Saharan Africa (with the possible exception of Napier grass in East Africa), but as mixed crop–livestock systems continue to expand, so will planted forage use.

To conclude, we offer some lessons for the future:

- Apply lessons from Latin America and the Caribbean to sub-Saharan Africa and South-

east Asia about the systemic conditions needed for successful planted forage development among smallholders. These South American examples point to possible future growth in use of planted forages in Africa once livestock production becomes more commercial, farm sizes increase, private-sector actors have stronger engagement and the institutional environment is more conducive to growth of the forage sector.

- To exploit the full potential of environmental benefits, it is evident that work on forages (and other feeds) needs to be integrated with animal health and animal genetics.
- We need to better define system constraints to forage use and to target solutions for system constraints along with a continuing focus on farm-level experimentation and on forage breeding. Understanding system constraints will facilitate better forage targeting using spatial forecasting of global high-potential sites.
- Create markets for public and private agents by: (i) building germplasm supply arrangements (public or private, depending on location); and (ii) identifying value chain constraints and resolving them through novel business arrangements.

Acknowledgements

Thanks to Werner Stür Chris Jones and Bruce Pengelly for commenting on a draft of this chapter, and to Steve Franzel and Jim Sumberg for critical reviews.

Notes

¹ The nomenclature of several tropical forage species has changed recently. Because this review considers past research, we use the earlier accepted names throughout. It should be noted, however, that according to the taxonomy proposed by the USDA Germplasm Resources Information Network (GRIN), *Brachiaria brizantha*, *B. decumbens* and *B. humidicola* are now accepted as *Urochloa brizantha*, *U. decumbens* and *U. humidicola*, respectively; *Pennisetum glaucum*, *P. pedicellatum* and *P. purpureum* as *Cenchrus americanus*, *C. pedicellatus* and *C. purpureus*, respectively; and *Panicum maximum* as *Megathyrsus maximus* and *Pueraria phaseoloides* as *Neustanthus phaseoloides*.

² Older accounts from East Africa show Napier grass in the early 20th century (Boonman, 1993).

³ A kebele is the smallest administrative unit in Ethiopia. A 'woreda' is the second smallest administrative unit in Ethiopia.

⁴ Fodder tree research has been pursued in East Africa for decades, as shown in the archives of the *East African Agricultural and Forest Journal*: (www.tandfonline.com/toc/teaf20/current).

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