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Special Issue IGC 2013
Part 2

This issue of *Tropical Grasslands−Forrajes Tropicales* is the second "Special Issue IGC 2013" and comprises papers presented at the 22nd International Grassland Congress, Sydney 15-19 September 2013. It complements the first Special Issue IGC 2013 (which was composed of all papers presented at the IGC 2013 Session 1.2.1 − "Development and Impact of Sown Tropical Species") and comprises 18 papers on R&D topics, all related to the tropics and subtropics and selected from sessions other than 1.2.1: One plenary paper, 4 invited keynote papers and 13 oral presentation papers.

The issue is the result of an agreement with the International Grassland Congress Continuing Committee (www.internationalgrasslands.org), giving permission to co-publish the papers. The content of papers is essentially the same as that published in the Conference Proceedings. Any changes are the result of additional reviewing and adapting to the journal style.

A third "Special Issue IGC 2013" will include a wide range of selected poster papers, again all related to the tropics and subtropics and selected from IGC 2013 sessions other than 1.2.1. It is scheduled for publication in February 2014.

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Feeding the World in 2050: Trade-offs, synergies and tough choices for the livestock sector

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Keywords: Agriculture, food security, livestock, food systems, misconceptions, trade-offs.

Abstract

Feeding the World in 2050 is a major challenge at the forefront of the global development agenda. The importance of agriculture in addressing this challenge has re-emerged in recent years as food security issues are considered in a more holistic manner. The role of livestock as part of the solution is, however, often not considered. This article presents a brief overview of the global food security challenge, and considers the increased focus on holistic food systems. It contends that animal agriculture is relevant to this complex, multifaceted and dynamic global challenge. However, if livestock-based solutions are to become a reality, a number of partial truths and trade-offs often associated with livestock and food need to be addressed. The role of livestock systems in future food security is considered in relation to different potential development trajectories of the sector, highlighting opportunities to ensure that livestock's contribution to global food security is a positive one, which also addresses concerns of environment, equity and human health.

Resumen

Para el 2050, la alimentación de la población mundial es el mayor desafío dentro de la agenda global. En los años recientes, ha surgido nuevamente la importancia de la agricultura para hacer frente a este reto, ya que los temas de seguridad alimentaria se consideran de una manera más holística que antes. No obstante, el papel de la ganadería como parte de la solución a menudo no es tomado en cuenta. En este artículo se presenta una breve revisión del reto de la seguridad alimentaria global y se considera el mayor enfoque holístico en los sistemas alimentarios. Se sostiene que la ganadería es relevante para este reto global el cual es complejo, multifacético y dinámico. Sin embargo, para que las soluciones basadas en la producción pecuaria lleguen a ser una realidad, es necesario considerar una serie de verdades parciales y compensaciones recíprocas, asociadas a menudo con la ganadería y la producción de alimentos. El papel de los sistemas de producción animal en el futuro de la seguridad alimentaria se discute en relación con las diferentes posibilidades de desarrollo del sector. Se destacan las oportunidades para asegurar que la contribución de la producción pecuaria a la seguridad alimentaria global sea positiva y que aborde los temas relacionados con el medio ambiente, la equidad y la salud humana.

Introduction

By 2050 most of the World's population (10 billion or so inhabitants) will be living in towns and cities. Feeding these people will require a 70–100% increase in the amount of food produced today (Burney et al. 2010). Not only will the quantity of food that is needed increase, but also quality requirements will be more exacting, driven by both consumers and regulators. People who live in the rapidly emerging economies, and even those in countries currently categorized as poor, will demand better and more varied diets that contain far more meat, milk and eggs, the animal-source foods, than today. Increasingly food will be purchased in supermarkets, pre-packed and processed.

Against a background of growing water scarcity, rising energy prices, the best land already being in production and impacts of climate change, which are often detrimental, producing sufficient quantity and quality of food for nearly 10 billion people represents a huge challenge.

It is estimated that by 2050 at least an additional 1 Gt (1 billion tonnes) of cereals (IAASTD 2009), 1 Gt of

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dairy and 460 Mt of meat (FAO 2011a) will be needed annually (based on consumption estimates). With the drivers of increased population, urbanization and higher incomes, value of and demand for animal-source products will increase faster than those from other agricultural sectors (Herrero et al. 2013a). Much of this increased production will have to come from the same land base which is currently producing food of both animal and plant origin.

How will the World be fed? Where and by whom will its food be produced and at what cost to the environment, public health and animal welfare? Who will benefit from the global food system and who will lose out? How will agricultural and food systems be adapted to meet these changes and challenges? The answer to these important questions will depend largely on the policy and institutional framework that nations, regions and the global community develop and the incentives and barriers these create.

All too often livestock are ignored in the global agriculture and food debate; the focus of attention for agriculture is invariably crops, and food usually means staples, mostly cereals. Even when nutrition is considered, an area where the animal-source foods have a real comparative advantage, livestock rarely get a mention.

This paper therefore sets out to position livestock as a key part of the solution to feeding the World in 2050: a source of nutrient-dense animal-source foods that can support normal physical and mental development and good health; an income stream that enables the World's billion poorest people to buy staple foods and other household essentials; and a means of underpinning soil health and fertility and increased yields, thereby enabling more sustainable and profitable crop production. In doing so, however, it acknowledges that: livestock production has the potential to do harm to the environment; the sector is a significant source of greenhouse gases; and it can be detrimental to human health. However, there are real opportunities to mitigate such negative impacts as livestock systems transition in the coming decades.

It will argue that the meat, milk and eggs, and other goods and services that livestock provide, can and must be produced in ways that are less damaging to the environment and with reduced risk to public health, while also supporting sustainable livelihoods for hundreds of millions of the World's poorest citizens, who currently have few other options – at least while they transit to new occupations and livelihoods as economies grow, mature and diversify. In the process, it will address some of the common misconceptions that surround livestock and which all too often cloud the debate.

Feeding the World – what are the challenges?

With less than 2 years remaining to the 2015 deadline for the attainment of the Millennium Development Goals (MDGs), the international community is closely scrutinizing the progress made. Goal number 1 refers to the eradication of poverty and hunger, recognizing that these 2 dimensions are inextricably linked: the poor spend the majority of their income on food.

The 2013 hunger report (Bread for the World Institute 2012) recently proposed a bold new goal, a successor to the MDGs, i.e. 'to eliminate poverty and hunger by 2040'. It further recognized that the highest numbers of people living on less than US$ 1.25 a day are in middle income (not poor) countries. Food prices matter and every country will need different solutions.

The Global Hunger Index (von Grebner et al. 2012) is a measure of progress towards the target of eradicating poverty and hunger. The index combines 3 equally weighted indicators: the proportion of the population with insufficient calorific intake; the proportion of children under 5 years of age, who are underweight; and the mortality rate of children under 5 years. Globally, although the index has fallen steadily since 1990, the overall score for the World is categorized as 'serious'.

The poorest 2 regions of the World are South Asia and sub-Saharan Africa. The hunger index for South Asia fell markedly between 1990 and 1996, but has failed to maintain this rate of improvement. In sub-Saharan Africa, as a result of improvements since 2000, the index score for 2012 was below that for South Asia. Of the top 10 countries which have made the most improvement in the index since 1990, none is in South Asia and only one, Ghana, is in sub-Saharan Africa; of the 6 countries, whose scores have deteriorated most during this period, 5 are in Africa and another, DR Congo, misses the list only due to shortage of data.

It is a shocking indictment of the global food system that, in the 21st century, the majority of the World's population have sub-optimal diets: at least a billion go to bed hungry; 2 billion are vulnerable to food insecurity; a billion have diets which do not meet all their nutritional requirements; and another billion suffer the effects of over-consumption (Smith et al. 2012).

The shift to 'food systems'

Alongside increased attention to how the World will feed itself in the coming decades, there have been 2 other shifts in emphasis. The first is: 'from quantity at all costs, to sustainable quantities at acceptable quality'. It is no longer regarded by many as being acceptable to consider production of ‘enough’ food in isolation; in addition, that food must be produced in ways that are environmentally, socially and economically sustainable. The second is: ‘that defeating hunger by providing enough energy is not enough’; balanced, wholesome nutrition must also be part of the solution.

So, in addition to addressing the overall hunger index, the Global Hunger Index 2012 report stresses that food production must include the sustainable and responsible use of natural resources, food distribution and access, balanced nutrition and access to and management of natural resources (von Grebner et al. 2012). It considers that addressing these aspects demands policy steps to include responsible governance of natural resources, scaling up of technical approaches and addressing the drivers of natural resource scarcity.

The High Level Task Force on global food security, established by the UN in 2008 as a response to the food price crisis that year, has a similarly broad goal and recognizes the importance of functional links between policy and actions for food, land, water and energy security, environmental sustainability, adaptation and mitigation of climate change and ecosystem services (UN 2008).

A number of studies also recognize that food security in the future needs to include managing risk and ensuring reduced vulnerability of the major food systems of the World. Especially in developing economies, food is produced in systems that are often fragile; for example, increased hunger since 1990 in Burundi, Comoros and Côte d’Ivoire can be attributed to prolonged conflict and political instability, while the devastating earthquake of 2010 pushed Haiti back into the ‘extremely alarming’ category.

The poor spend a disproportionate amount of their income on food. This means they are especially vulnerable both through limited access and by being severely affected when food prices spike. The Montpellier Panel (2012) stresses the need for agricultural growth (especially in Africa) to be underpinned by resilient markets, agriculture and people.

Agriculture back on the agenda

Since 2008, when the fragility of national food systems and their susceptibility to the vagaries of trade and price fluctuations came to the fore, the role of agriculture, including the underpinning research and development efforts, has returned to the agenda as a crucial component of food security at global, regional and national levels.

A recent FAO report (FAO 2012) emphasizes the importance of agricultural investment for growth, reduction in poverty and hunger, and the promotion of environmental sustainability. Countries recognized as the poorest and hungriest are also those with the least agricultural investment. Governments have a crucial role in providing a conducive investment climate and helping farming communities, especially women, in governing large-scale investments and investing in public goods and services that generate high returns. Likewise, a recent report from the World Economic Forum stresses the importance of agriculture as a driver for food security, environmental sustainability and economic opportunities (World Economic Forum 2013).

One of the more recent trends in the global quest for food security is land acquisitions involving significant private and foreign investments. Rulli et al. (2013) report that some 46 Mha of land (and the associated water) has been allocated in this way, with 90% of this distributed over just 24 countries. Efforts are underway to promote more positive development opportunities through such processes. Cotula et al. (2009) point out that such acquisitions are often based on the misconception that land is abundant and ‘unused’, and tend to overlook the complexities of land ownership and rights. In relation to the livestock sector, in many cases land that is apparently ‘unused’ may actually constitute critical dry season grazing resources or migration routes crucial for the management and ecological integrity of pastoralists, their animals and the natural resources of which they are stewards.

Smallholder agriculture – what role?

The role of agriculture in addressing future food needs is unquestioned. What is more contentious is how and in which time frame agricultural systems will evolve in relation to this. Today, a considerable amount of food is produced by smallholders; 500 million smallholders support more than 2 billion people (Conway 2012). This begs the question of whether, or for how long, this can continue.

The roles of smallholders in providing future food, especially those who raise livestock, are complex, multidimensional and at times controversial. Hazell et al. (2007) and Wiggins et al. (2010) evaluated the ‘pros and cons’ of smallholder development, recognizing the combinations of policy, market and institutional innovations that are demanded to make these enterprises viable in the future.

One dimension where there is broad agreement is that, as agricultural systems transition, one of the crucial though hitherto marginalized elements will be to address the role of women, in particular their access to information and inputs (FAO 2011b).

Conway (2012) suggests that, while the World's one billion hungry can be fed, 24 conditions are needed, if that is to happen; one of them is more funding for mixed livestock systems.

In South Asia more than 80% of farms occupy less than 2 ha; in sub-Saharan Africa smallholders contribute more than 80% of livestock production; and globally farms with a few ruminants, such as 2 cattle and half-a-dozen sheep or goats, i.e. 2 tropical livestock units (TLU), and 2 ha of land, contribute 50−75% of the total livestock production. South Asia and sub-Saharan Africa have 45% and 25%, respectively, of the World's 725 million poor livestock keepers (Otte et al. 2012).

Smallholder and extensive livestock keepers produce in fundamentally different ways from large-scale industrial farmers. Industrial systems almost always rely on food that could potentially be eaten by people – mostly grains. Smallholder and extensive systems rely mostly on food that is not available to people (grass, fodder, residues and wastes).

Feeding the World – are livestock part of the solution?

While livestock commodities and systems are rarely mentioned in the context of addressing food security, livestock are, and must be, part of the solution to global food security; significant amounts of the World's food supply, both crop and livestock products, come from systems in which livestock are important. Livestock products play a critical role in nutrition and human health. Amongst agricultural commodities, livestock products are among the most expensive and fastest growing in terms of demand. However, the potentially negative impacts of livestock on human health and the environment must also be addressed, along with equity issues as the sector grows.

By 2050 it is projected that per capita consumption of meat and milk in developing countries will have increased by more than 57% and 77%, respectively, and total consumption of meat and milk in these regions will have increased by 2.4- and 2.6-fold (FAO 2011a). Yet even with this rate of increase, consumption levels of meat and milk will still be less than half those found in developed countries.

More than 60% of all human diseases are shared by animals, and for new and emerging diseases, the number is as high as 75%. Diseases can pass from animals to people in many ways, but one of the most common is through livestock products. Not only can animal-source foods transmit pathogens present in the animal, but also they are often a vehicle for people to transmit pathogens present in the environment or shed. While foods derived from animals are excellent sources of nutrition for people, unsurprisingly, they are also better at supporting growth of pathogens than staple crops (Grace 2012).

Trajectories of livestock systems

The context for livestock development is rapidly evolving, driven by the continued rising demand for livestock products, particularly in Asia, and a greater recognition that the on-going transformation needs to be nuanced in relation to the roles of smallholders, their diverse economic situations and the different livestock commodities they produce.

Higher demand means that the private sector in developing countries has become much more dynamic, creating new types of opportunities for smallholder livestock production and marketing systems, and means for market development. Accompanying these, however, are rapid structural changes in scales and quality of production, marketing and consumption of livestock commodities. As with all aspects of food production, there is a need to consider the diversity of livestock production systems and scales in developing country food systems and how they can evolve to improve food security, while reducing poverty in a way that is environmentally sound and has positive human health outcomes.

With the objective to position better research and development efforts in order to encompass the diversity of livestock systems, 3 potential livestock growth scenarios have been identified recently, which capture the dynamics of the sector better than the conventional pastoral, mixed crop-livestock and industrial categorization. These emerged from a High-Level Consultation for a Global Livestock Agenda to 2020, co-convened by the International Livestock Research Institute (ILRI) and The World Bank (AU-IBAR et al. 2012), and were developed further in ILRI's strategy 2013−2022 (ILRI 2013). These trajectories also resonate with the categorization of livestock systems used in a recent FAO study of the role of livestock in food security (FAO 2011a): livestock-dependent societies, small-scale mixed farmers and city populations.

The 3 trajectories are:

Strong growth systems

These address the need to develop sustainable food systems that deliver key animal-source nutrients to the poor, while facilitating a structural transition in the livestock sector of developing countries. This will entail a transition from most smallholders keeping livestock in lowly productive systems to eventually fewer households raising more productive animals in more efficient, intensive and market-linked systems. These mostly mixed smallholder systems already provide significant livestock and crop products in the developing World and are likely to grow the most in aggregate. In some instances, strong growth will occur in rangeland systems, where appropriate market connections and productivity increases can be facilitated. In many parts of Africa and Asia, the transition is happening slowly, with smallholder marketing systems still largely informal, although there are pockets of more rapid change in systems with higher potential and good market access.

These rapidly changing scenarios provide real opportunities to apply approaches such as sustainable intensification (Pretty et al. 2011), which describes 7 key components to sustainable intensification summarized as: *"….producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services"*.

Fragile growth systems

Rapid, market-focused growth will, however, not be the trajectory for all poor livestock keepers. In areas where growth in productivity is severely limited by remoteness, harsh climates or environments, or by poor institutions, infrastructure and market access, the emphasis will need to be on enhancing the important role livestock play in increasing the resilience of people and communities to variability in weather, markets or resource demands. Livestock-based livelihoods will continue to be important for feeding families and communities, supported by protection of assets and conservation of natural resources. Payment for ecosystem services is also likely to become increasingly important, although so far these schemes are still rare (Silvestri et al. 2012).

High growth with externalities

Where dynamic markets and increasingly skilled human resources are already driving strong growth in livestock production, fast-changing small-scale livestock systems might damage the environment and expose their communities to increased public health risks. Furthermore, in these scenarios participation of the poorest livestock keepers and other value chain actors is limited. This demands an understanding and anticipation of all possible negative impacts of small-scale livestock intensification. Incentives, technologies, product and organizational innovations that mitigate health and environment risks, while supporting the poorest people to comply with increasingly stringent livestock market standards, are important approaches.

Livestock partial truths explored

Given the importance of livestock systems for food security, as well as their potential to impact on poverty, livelihoods, health and nutrition and the environment, the limited attention paid to the sector is puzzling. This might, perhaps, be related to a number of misconceptions. Although true in some circumstances, none of them is globally true, and there are invariably various trade-offs, synergies and tough choices that need to be addressed in developing livestock-based solutions to the global food security challenge. These often differ according to the most likely livestock growth trajectory. Below a series of livestock partial truths are explored and opportunities to address these in relation to different livestock trajectories are suggested.

Livestock contribute to food security both directly and indirectly, and play a crucial role in the livelihoods of almost one billion of the World's poorest people. At the same time, animal production, marketing and consumption can have negative impacts on human health, the environment and climate change. Understanding and making appropriate choices amongst trade-offs is essential if the positive attributes are to be realized and the negative ones minimized. In this context, a number of perceptions about the livestock sector are explored in relation to: food security; animal-source foods and human health; how and where food is produced; and the environment.

Food security

Food security is about staple cereals – animal-source foods are a luxury

It is true that the direct contribution made by livestock products to World food supply may appear modest: globally, 17% of the energy and 33% of the protein come from livestock commodities (FAO 2009). However, the contribution of livestock to the World's food supply is often under-appreciated. Mixed crop-livestock systems contribute significantly to the global supply of animal products and also supply almost half of global cereal; in the developing World, these systems supply 41% of maize, 74% of millet, 66% of sorghum and 86% of rice (Herrero et al. 2009). Developing countries now produce 50% of the World's beef, 41% of milk, 72% of lamb, 59% of pork and 53% of poultry (FAO 2011a).

In these mixed systems, livestock also play an important role in the production of crops. Livestock provide manure, a valuable soil nutrient, plus traction for land preparation and transport, and generate income that can be used to purchase seeds of improved varieties, fertilizer, labor and other inputs. Manure provides 12% of the nitrogen used for crop production globally, rising to 23% in mixed crop-livestock systems (Liu et al. 2010). In many of these systems, livestock consume and use crop by-products as major feed resources (Blümmel 2010). Livestock therefore have and will continue to have a major role in food security, especially for the poor in developing countries, and approaches such as sustainable intensification continue to play an important role (Pretty et al. 2011).

In addition, it has been estimated that 1.3 billion people are employed in livestock value chains globally (Herrero et al 2013a); the incomes they gain therefore make a major contribution to their food security.

Livestock compete with human food

It is often argued that livestock consume feedstuffs that people could benefit from directly, such as grains and legumes, and thus, impact negatively on the total amount of food available. It is true that today, about half the World's annual production of grain is fed to animals, especially monogastrics (IAASTD 2009), and 77 Mt of plant protein are fed to livestock to produce 58 Mt of animal protein (Steinfeld et al. 2006). Feed crops occupy an estimated half a billion hectares of land; including grazing land, livestock account for four-fifths of all agricultural land (Steinfeld et al. 2010).

Extrapolating from current trends, by 2050 an additional 1 Gt of grain will be needed world-wide, about 40% of which will be required for feeding livestock, mostly pigs and chickens (IAASTD 2009).

It is often overlooked that raising fewer livestock and consuming less animal products is unlikely to make more grain available for human consumption; for the billion undernourished people in the World, releasing grain by not feeding it to animals would not make it available for their consumption; fundamental challenges would remain related to affordability and access to food (FAO 2011a). Msangi and Rosegrant (2011) explored the implications of 'healthier diets' with less meat in developed countries on improving nutrition in developing countries, and found little, if any, positive results. Importantly, it is not the livestock of the poor, which compete for their food, it is the livestock of the rich.

For livestock systems based on grazing, which constitute 40% of the earth's surface and support some 120 million people (FAO 2011a; 2012b), livestock are not consuming food that could be directly consumed by people; rather, they are converting materials humans cannot eat into milk, meat and eggs, that they can eat. Herrero et al. (2009) estimate that 7% of the milk and 37% of global beef and lamb production is from such systems. FAO (2011a) estimates that such grassland-based systems provide 12% of the milk and 9% of the meat annually. Differences in these estimates are most likely due to the system boundaries used for such estimations. In some of these systems, there is potential for strong growth, if appropriate market arrangements coupled with productivity increases can be aligned. For other regions, these will be systems with fragile growth prospects, where a focus on safety nets, insurance function of assets and environmental stewardship must come to the fore.

Overall in the mixed crop-livestock systems, livestock mostly do not compete directly with people for food and mainly convert inedible materials into milk and meat. The major feed resource for animals in these systems (notably ruminants) is crop residues; as much as 70% of animal diets is composed of such materials, which are essentially a by-product of food production and therefore not in competition with human food (Blümmel 2010). However, increasingly trade-offs between the use of crop residues for animal feed, maintaining soil fertility and biofuels are being highlighted as important issues to consider as crop-livestock systems evolve (Valbuena et al. 2012). A major challenge for the future is to address the looming biomass shortage and how livestock systems may be intensified in sustainable ways (Duncan et al. 2013).

There are significant opportunities to improve animal productivity without introducing high grain-based diets (Tarawali et al. 2011), thereby achieving win-win efficiency and greenhouse gas mitigation, especially in those systems that have the potential for strong growth.

Animal-source foods and human health

Poor people don't care what they eat

It is true that poor consumers are sensitive to prices, but contrary to common belief, developing country consumers, who shop in informal markets, do care about quality attributes of food; they are even willing to pay a 5−15% premium for safer foods (Jabbar et al. 2010). Studies in Ethiopia have shown that, while the poorer sectors of society have less concern than the rich, they take food safety seriously.

Food scares, whether bird flu in poultry or horsemeat in burgers, offer 'natural experiments' in which peoples' attitudes towards food safety and quality can be tested. Even in poor countries, dramatic changes in consumption patterns have been observed in response to food scares. ILRI's work in Vietnam showed that when 'blue ear' (porcine reproductive and respiratory syndrome virus) made the news, the vast majority of consumers stopped eating pork, shifted to chicken or went to outlets perceived as safer (ILRI 2010). Assessments conducted in the context of Rift Valley fever outbreaks in Kenya showed consumers demanding to see butchers' certificates and a drop in demand for ruminant meat as consumers switched to poultry (ILRI 2007).

All 3 growth scenarios require solutions to the challenges of food-borne diseases and zoonoses, especially in the higher growth scenarios. The use of risk-based approaches and complex institutional arrangements will be important in addressing such challenges (Randolph et al. 2007).

Animal-source foods are bad for your health

It is true that over a billion people suffer from the effects of over-consumption, including of animal-source foods, increasing their risk of non-communicable diseases such as cancers, cardiovascular disease and diabetes (McMichael et al. 2007). Understandably animal-source foods are often considered a threat to health. However, it is often not appreciated how important foods derived from animals can be for the several billion who are undernourished, for whom consumption of too little animal-source food may have even worse consequences.

Children are particularly vulnerable to nutritional deficiencies during the first 1000 days from conception and chronic under-nutrition of young girls means that: *"….a vicious cycle of under-nutrition repeats itself, generation after generation*" (UNICEF 2008).

Several forms of malnutrition (protein-energy malnutrition, iron-deficiency anaemia and vitamin A deficiency) can be prevented if sufficient animal-source foods are included in the diet. Even small amounts of these foods can result in better cognitive development, growth and physical activity of children (Neumann et al. 2002; Sadler et al. 2012). Animal-source foods are a concentrated source of energy, protein and various essential micronutrients, including those absent or scarce in plant-based foods. They also match well with human dietary requirements (Young and Pellett 1994; Allen 2005). It has been estimated that, to combat undernutrition effectively, 20 g of animal protein per person per day is needed – the equivalent of an annual per capita consumption of 33 kg lean meat, 230 kg milk or 45 kg fish (FAO 2009).

As people get wealthier, an important question to address is: how much animal-source food should they eat? This is the subject of considerable debate, from the perspectives of the quantity as well as the practicalities of limiting the increased consumption of milk, meat and eggs; as people become less poor, the first manifestation is often an increase in consumption of animal-source foods. A range of figures has been proposed, ranging from 58 to 90 g of meat per person per day (McMichael et al. 2007; FAO 2011a; Westhoek et al. 2011). Livestock products themselves are not major contributors to the increasing problem of obesity in poor countries, but are often fried or otherwise processed in ways that make them unhealthy choices (Ziraba et al. 2009).

As livestock systems evolve in strong and high growth scenarios, paying attention to an appropriate level of animal consumption will be a challenge. Meanwhile for fragile growth scenarios, ensuring that enough animal-source food is available and accessible will remain paramount.

How food is produced

Large industrial livestock farms are the only answer

Smallholder livestock farms are often inefficient, producing at low levels and often with a high level of greenhouse gas emissions per unit of product (FAO 2010). Capper et al. (2009) assessed dairy production in the USA and noted that, compared with 1944, in 2007 just 21% of the animals, 23% of the feedstuffs, 35% of the water and only 10% of the land were being used to produce one billion kilograms of milk. This period was characterized by significant increases in average herd and farm size, a phenomenon not yet observed to a significant extent in developing countries, where it may be anticipated that a similar trajectory is likely over coming decades.

More than 70% of the dairy products in India, the World's largest dairy producer, come from small-scale production enterprises and considerable amounts of livestock products are sold in informal markets (Costales et al. 2010). While smallholders may continue to be competitive in the dairy sector, a more rapid switch to industrial systems is likely for pig and poultry production (Tarawali et al. 2011).

Standards of disease management and biosecurity are also considered poor in smallholder systems. Hence, many recommend that future livestock farming must be based on large-scale industrial systems. Not all agree, however. Industrialization of livestock systems may facilitate disease transmission, for example through high density populations and the challenge of managing large volumes of waste, and promote the use of antimicrobials and thus emergence of antibiotic resistance. It may also lead to reduced levels of genetic diversity, which may promote evolution of pathogens and reduce options for an uncertain future (Jones et al. 2013).

Livestock and the environment

Livestock are responsible for climate change

There is no doubt that livestock production contributes to greenhouse gas emissions. How much has been a matter of some debate; estimates range between 8 and 51% of total greenhouse gas emissions emanating from the sector (Herrero et al. 2011a), although most estimates fall in the range of 12−18%. Within agriculture as a whole, the livestock sector provides the greatest opportunities for mitigating the greenhouse gas emissions, both today and in the future. Herrero et al. (2013b) estimate that up to half of the global greenhouse gas mitigation potential of agriculture, forests and land use combined is in the livestock sector. Thornton and Herrero (2010) estimated that the mitigation potential from feeding improvements alone in tropical systems was around 7% of the global mitigation potential of agriculture.

Emissions per unit of production of milk at the farm gate in sub-Saharan Africa are more than twice the global average (FAO 2010) and similar inefficiencies are reported for beef (Capper 2011). In the USA dairy sector, a 4-fold increase in the efficiency of production, attributed to better feeding, breeding and animal health, took place over a 6-decade period (Capper et al. 2009). Real opportunities exist in many mixed systems for similar efficiency gains, even without moving fully to industrial style production systems (McDermott et al. 2010; Tarawali et al. 2011; FAO 2011a, 2012b), especially for ruminant production in agrarian economies. There are also opportunities to improve efficiencies in all livestock production systems, given the wide range in the current values (de Vries and de Boer 2009). Developing country livestock systems, especially those on a strong growth trajectory, also present significant greenhouse gas mitigation potential and opportunities for carbon offsets. For fragile growth trajectories, carbon sequestration from rangelands and the associated co-benefits can be explored (see below).

Livestock systems are significantly impacted by climate change and sound adaptation strategies are required. This is especially critical in the grassland systems, which are often undergoing fragile growth and where some of the World's poorest people rely entirely on livestock for their livelihoods. Recent crises in the Horn of Africa and Sahel bear witness to this and have resulted in major humanitarian and food security disasters. In many such cases, livestock are the only asset remaining on which to rebuild, and attention needs to be paid to insuring the asset and mitigating loss. Innovative arrangements, such as weather-index-based livestock insurance schemes, which are triggered by remotely sensed thresholds, are showing considerable promise in this regard (Carter and Janzen 2012).

Water scarcity is a result of livestock production

Until recently, livestock and water were considered almost exclusively from the perspective of the impact of livestock on water pollution (Steinfeld et al. 2006). Yet, almost one-third of total agricultural water is used by the livestock sector: feed from cropland uses 37% of the water used for crop production and biomass grazed by livestock represents 32% of the evapotranspiration from grazed lands; direct consumption for drinking is relatively insignificant, representing 10% of total usage (Herrero et al. 2013a).

For mixed crop-livestock systems that are on a strong growth trajectory, there are significant opportunities to increase productivity of milk and meat per unit of water used through feed, water and animal management strategies (Peden et al. 2007). If such approaches are combined, they could improve livestock water productivity at least 3-fold (Descheemaeker et al. 2010a; 2010b). For rangelands, there are opportunities to improve water productivity by 45% through better rangeland management practices (Rockstrom et al. 2007).

Water use estimates for livestock production have been a hotly contested issue; highly diverse estimates of up to 4.6 m^3 (Singh et al. 2004) and a global average of 0.77 m^3 water per liter of milk produced (Chapagain and Hoekstra 2003) and a range of 10–100 m^3 water per kg of beef (Descheemaeker et al. 2009) suggest there is significant potential for improvement.

Livestock production causes land degradation

Headlines often tell a grim story of land degradation due to livestock; extensive cattle raising in the Amazon accounts for at least 65% of the deforestation and up to 600 000 hectares per annum are reported to be cleared for crop production to produce feed for pigs, poultry and intensive dairy (Herrero et al. 2011b). However, with rangelands occupying 40% of the earth's surface, these resources, largely managed by livestock-dependent people, are a potentially huge carbon sink similar in magnitude to forests.

Carbon sequestration through rangelands, which is optimum under conditions of moderate livestock grazing (Conant and Paustian 2002), has the potential to sequester up to 8.6 Mt of carbon per year in Africa (compared with 1.9 with light grazing and 6.1 with heavy grazing). Supporting such schemes and implementing them in practice, however, are areas that require new research and development efforts to address the complexities of institutional and certification mechanisms, benefit sharing and co-benefits (Silvestri et al. 2012; The World Bank 2012). These areas could have significant dividends for livestock systems undergoing fragile growth.

Conclusion

With the global population approaching 10 billion by 2050, the World is understandably concerned about how it will feed itself in the future. Increasingly, the solution to this challenge is being considered in relation to holistic 'food systems', in which producing food is considered in relation to environmental, health and sometimes equity issues.

Responding to rising food demand and uncertainty of supply and prices in recent years put agriculture firmly back on the development agenda. Yet, it is only very recently that smallholder agriculture has been recognized as part of the food security equation.

The role of livestock is seldom articulated in relation to global food issues, and yet it presents opportunities for important contributions to solutions that relate to food security and sustainable livelihoods, as well as health and environmental dimensions.

Livestock are undoubtedly part of the solutions to feeding the World in 2050, but this will require a nuanced approach that takes cognizance of the different development trajectories of the livestock sector and encompasses solutions that combine a range of biophysical, institutional, market, infrastructure and policy issues.

In all these situations, better information about the true impacts of livestock and a balanced assessment of the benefits and dis-benefits of the sector will enable the livestock sector's role in global food security to be more appreciated, valued and addressed.

The complexities of the livestock sector, plus the varied trade-offs and balances, demand that research and development efforts to address food security must consider both biophysical and institutional solutions in relation to the potential transition of today's diverse livestock sector.

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Harry Stobbs Memorial Lecture: Can grazing behavior support innovations in grassland management?

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Keywords: Grazing management, pasture structure, grazing systems, forage intake, bite mass.

Abstract

Grazing is a fundamental process affecting grassland ecosystem dynamics and functioning. Its behavioral components comprise how animals search for feed, and gather and process plant tissues in different spatio-temporal scales of the grazing process. Nowadays, there is an increasing emphasis on grazing management and the role of the grazing animal on ecosystem services, concomitantly with a decreasing emphasis on grazing management generating animal production outputs. Grazing behavior incorporates both approaches, which are not necessarily dichotomist. It would provide the basis to support innovation in grazing systems. However, it is unclear how the significant knowledge, developed in this research area since the disciplines of Agronomy and Ecology began to interact, have supported creativity in grazing science. It seems there is a current gap in this context, which was a major concern of researcher leaders like Harry Stobbs. This paper pays tribute to him, reviewing recent grazing behavior research and prioritizing those studies originating in the favorable tropics and subtropics. New evidence on how pasture structure limits forage intake in homogeneous and heterogeneous pastures is presented. Pasture management strategies designed to maximize bite mass and forage intake per unit grazing time are assumed to promote both animal production and landscape value. To conclude, a Brazilian case study (PISA) is briefly described to illustrate how grazing behavior research can reach farmers and change their lives by using simple management strategies ("take the best and leave the rest" rule) supported by reductionist approaches applied in holistic frameworks.

Resumen

El pastoreo es un proceso fundamental que afecta la dinámica y el funcionamiento de los ecosistemas de pasturas. Sus componentes comprenden la forma cómo los animales buscan el alimento y lo ingieren y cómo procesan los tejidos de las plantas en diferentes escalas espacio-temporales dentro del proceso de pastoreo. Actualmente existe un énfasis creciente en el manejo del pastoreo y en el papel de los animales en pastoreo respecto a los servicios de ecosistemas, conjuntamente con el descenso del énfasis en el manejo de pastoreo con fines de producción animal. El comportamiento de pastoreo incorpora ambos enfoques, los cuales no necesariamente son dicotómicos; puede proporcionar la base para innovaciones en los sistemas de pastoreo. No obstante no es claro cómo los avances significativos del conocimiento en esta área de investigación, desde que las disciplinas de agronomía y ecología comenzaron a interactuar, han contribuido a la creatividad en la ciencia del pastoreo. Aparentemente existe un vacío en este contexto, y esto fue una de las preocupaciones principales de investigadores líder como Harry Stobbs. En el presente documento se rinde homenaje a este científico y se revisan las investigaciones recientes en comportamiento de pastoreo, priorizando estudios procedentes de zonas favorables del trópico y subtrópico. Se presenta una nueva evidencia de la forma cómo la estructura de una pastura limita el consumo del forraje tanto en pasturas homogéneas como heterogéneas. Se asume que las estrategias de manejo del pastoreo, diseñadas a maximizar el bocado y su ingestión por unidad de tiempo de pastoreo, son dirigidas a promover tanto la producción animal como el valor paisajístico. Para concluir, se presenta un estudio de caso en Brasil (PISA) que ilustra y describe brevemente cómo la investigación en el comportamiento de pastoreo puede llegar a los productores para contribuir a su bienestar solo con la adopción de estrategias sencillas de manejo (la regla del "tome lo mejor y deje el resto"), con el apoyo de enfoques reduccionistas que se aplican en marcos holísticos.

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Introduction

Harry Stobbs had a strong desire that results of scientific research would reach practicing farmers in the field and be adopted. He believed that most scientists worked to solve problems/issues identified by themselves, and that much knowledge generated did not turn into practice. As an outstanding researcher of issues at the plant-animal interface, he passed from this life too early in 1978. He lived during a transition period, where pasture studies, focused on the end product, were being expanded to include an understanding of underlying processes driving grassland ecosystem dynamics. His legacy on grazing behavior research appears to have been embraced more within temperate grassland research than in the tropics, where a knowledge gap still exists (da Silva and Carvalho 2005).

In the late 90s, agronomists and ecologists conducted grazing behavior investigations aimed at understanding plant-herbivore relationships and their influence on the sustainability and equilibrium of grassland ecosystems (Milne and Gordon 2003). Despite this advance, there are no clear examples of how grazing ecology research has produced innovations in pasture management (but see Gregorini 2012).

Nowadays, pasture management is no longer oriented primarily towards secondary productivity from the grassland (animal products), but has a multifunctional focus including the whole pasture ecosystem, i.e. processes involved in pasture production, utilization and sustainability (Lemaire et al. 2011). Kemp and Michalk (2011) stated that desirable outputs of new pastoral farming systems should be minimizing soil erosion from wind or water, delivering clean water into river systems, and maintaining a diversity of plants and associated species. This is the current reality in grassland research in most countries.

Accepting the importance of moving forward in this direction, it is worth mentioning that an interruption in the advancement of grazing behavior investigations appears to have occurred in order to support the emergence of innovations in pasture management, oriented towards secondary productivity. This is of particular concern in developing countries, where grazing livestock is an important provider of income and employment (Herrero et al. 2013). This disrupted continuum, when knowledge generated by research does not translate into technology benefiting farmers in the field, was a major concern for Harry Stobbs.

This review aims to pay tribute to Harry Stobbs by reviewing grazing behavior research that aims to support grazing management and secondary production in the favorable tropical/subtropical areas. A case study (PISA) is presented briefly in order to illustrate how grazing behavior research can be used to improve the lives of farmers in the field.

Grassland Science and the new context for grazing behavior

Grassland Science during the last century was oriented towards production systems, and the maximization of both primary and secondary production of pasture (Humphreys 2007). The main goal was to identify the potential productive boundaries, and the management tools to reach them. Maximizing profits and enhancing efficiencies in animal production on pastures were essential.

In the late 1980s, Grassland Science, in relation to grazing management, evolved from the debate on stocking rate, grazing methods and livestock production to focus on sward structure as a determinant of pasture productivity and the main connecting link between plant composition and animal grazing behavior (Hodgson 1985). Harry Stobbs led this research approach in tropical pastures, but greater advances were made with temperate pastures, because his premature death resulted in a termination of this research endeavor, until recently (see Benvenutti et al. 2008a, 2008b, 2009; da Silva et al. 2012; Fonseca et al. 2012).

This focus on the plant-animal interface required original approaches to understand causal relationships. The concept of ecological hierarchy adapted to grazing ecology introduced the different spatial and temporal scales of the grazing process (Senft et al. 1987). Bailey et al. (1996) functionally defined spatial and temporal scales based on characteristic behaviors that occur at different rates, so grazing behavior was investigated in a continuum from bite up to home range. The underlying relationships between plants and grazing animals have been investigated in relation to variations in behavior over time and space (Bailey and Provenza 2008). Provenza et al. (2013) pointed out that current behaviors are often consequences of past conditions, and that many consequences are delayed in time and distant in space. Those approaches were important to understand landscape utilization by the grazing animal, which is critical for management of rangelands and pastures.

Grazing systems are now being re-designed to link production with environmental management to meet the desired multifunctional aspects of grasslands (Kemp and Michalk 2007; Boval and Dixon 2012). Grazing management has been assessed in terms of reducing the environmental impact of the most intensive systems, so the multifunctional role of the grassland ecosystem becomes an important component of grazing systems. Doré et al. (2011) presented this paradigm of ecological intensification, based on intensification in the use of the natural functionalities that ecosystems offer. In some way, this demand for a multifunctional role for pastures arose before grazing behavior research became a component of grazing management. Provenza et al. (2013) criticized the "reductionistic control of researchers" and their traditional inability to create innovative practices. In fact, the current grazing behavior research scenario is more complex. Kemp and Michalk (2007) stated that the achievement of desirable outcomes in grassland management that satisfy multiple objectives will require new areas of research that seek viable solutions for farmers and society. Whether grazing ecology can support these new outcomes is not totally clear, but there is evidence that grazing management, which promotes higher individual animal production (e.g. moderate grazing), fosters both environmental parameters (see Carvalho et al. 2011).

The atom of the grazing process: harvesting bites in homogeneous and heterogeneous pastures

Grazing is an essential component of pastoral farming, and affects ecosystem properties and functions (Carvalho et al. 2013). In general, grazing herbivores select plants and morphological components in order to optimize nutrient intake, as well as minimizing energy cost and intake of harmful phytochemicals.

Laca and Ortega (1996) defined bite as the atom of grazing. The grazing animal gathers thousands of bites throughout the day, which ultimately defines daily dry matter intake and animal performance (Figure 1).

Allden and Whittaker (1970) provided the mechanistic basis to study this process, first defining forage intake as components of grazing behavior, i.e. the product of bite mass, bite rate and grazing time. This classical paper was influential in underpinning the effects of pasture structure on intake, and describing the reciprocal relationship between bite mass and bite rate.

Grazing time was then depicted in terms of meal number and duration (Rook 2000), while daily dry matter intake was a consequence of intake per meal and the number of meals during the day (Gibb 1998).

Shipley (2007) argued the importance of bite scale, as it falls at the very bottom of the foraging hierarchy. Any systematic error grazing animals make in selecting bites will be compounded over days, seasons and lifetimes. With increasing time and spatial scales of the grazing process, the influence of abiotic factors in determining daily dry matter intake increases (Bailey et al. 1996). Therefore, grazing behavior is highly bite scale dependent (Fryxell et al. 2001).

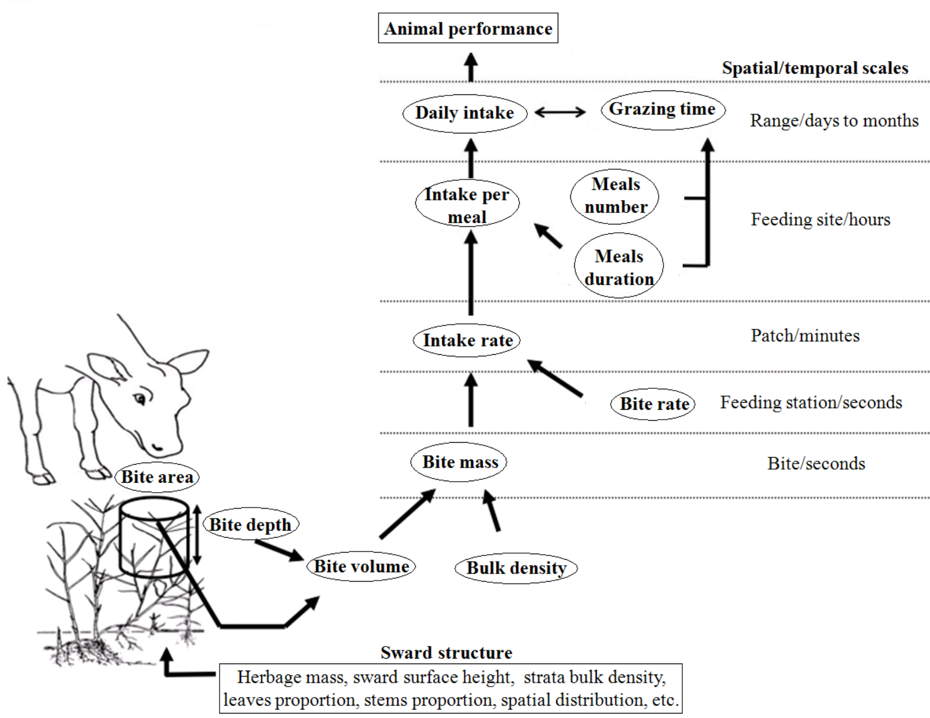

Figure 1. Spatial and temporal scales of grazing (adapted from Bailey et al. 1996; Cangiano et al. 1999; Bailey and Provenza 2008).

Spalinger and Hobbs (1992) developed a mechanistic model depicting intake rate as an asymptotic function of bite mass based on three processes of resource acquisition. Time per bite is described as a function of time committed to sever and process a bite. Bite mass is the only component of the grazing process that directly converts to plant biomass gathered, bite rate and grazing time being related mainly to the time scale (processing rates) of the grazing process.

There is an asymptotic relationship between plant biomass and intake rate in herbaceous grasslands (type II functional response, see Gross et al. 1993), because bite mass is usually correlated with biomass density (Shipley 2007; Hirata et al. 2010; Delagarde et al. 2011). The pioneer work of Stobbs (1973a; 1973b) and Chacón and Stobbs (1976) indicated bite mass was the major parameter influencing daily dry matter intake in tropical pastures. Stobbs (1973a; 1973b) highlighted the influence of bulk density in tropical pastures in imposing behavioral constraints that would severely limit forage intake. There has been little follow-up research on this aspect (but see Carvalho et al. 2001; Benvenutti et al. 2006; Hirata et al. 2010), and the prevailing idea is that lower animal production in tropical pastures is associated with low forage quality. Sollenberger and Burns (2001) reported that tropical pastures produce low-quality forage with high bulk density of pseudostems, and will support only low levels of animal performance. However, da Silva and Carvalho (2005) revisited this discussion and concluded that pasture structure was more important in constraining forage intake than previously supposed. In fact, basing pasture management on degree of canopy light interception and avoiding stem development has supported new management strategies (e.g. Montagner et al. 2012), resulting in unexpected high levels of animal production.

The meta-analysis presented in Figure 2 demonstrates novel evidence of how tropical pasture structure influences forage intake. The results suggest that grazing animals take more time to gather a given bite mass in tropical than in temperate pastures. The intercept of the model refers to the time to prehend the bite, independently of bite mass. The regression coefficient refers to the time to process a bite with increasing bite mass. There are many implications of these models in discussing the functional response of grazing animals, but for the purposes of this paper it is worth noting that tropical pasture structure is time jeopardizing. Consequently, the low daily dry matter intakes registered in animals grazing tropical pastures cannot be a function of only poor forage quality, as previously suggested by da Silva and Carvalho (2005). This is particularly significant when total foraging time cannot compensate for the higher time per bite demanded for biting tropical forages, a condition commonly observed in pastures with low forage masses or high-demanding animals.

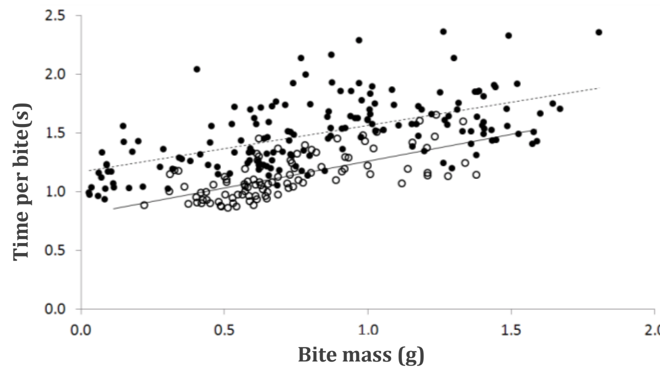

Figure 2. Temperate pastures (○, solid line): 1 – *Lolium multiflorum* (Amaral et al. 2013); 2 – *Avena strigosa* sward under continuous, and 3 – rotational stocking (Mezzalira 2012); 4 – *Lolium multiflorum*, *Avena strigosa* and avena + ryegrass mixture (G.C. Guzatti, pers. comm.). Tropical pastures (●, dotted line): 5 – *Cynodon* sp. under rotational, and 6 – continuous stocking (Mezzalira 2012); 7 – *Sorghum bicolor* under rotational, and 8 – continuous stocking (Fonseca et al. 2013); 9 – *Brachiaria brizantha* under rotational stocking (da Trindade 2007); 10 – natural grassland under continuous stocking (Bremm et al. 2012); 11 – *Pennisetun glaucum* under rotational stocking (Mezzalira et al. 2013a). Regression equations have been generated for each species in each experiment, and then compared by parallelism test and equality of intercepts ($P<0.05$). There are no differences between stocking methods in each group of pastures. Temperate pastures model: $y = 0.457x + 0.800$; $R^2 = 0.724$; $P<0.0001$; s.e. = 0.142; n = 98. Tropical pastures model: $y = 0.395x + 1.166$; $R^2 = 0.489$; $P<0.0001$; s.e. = 0.239; n = 185.

Carvalho et al. (2009) argued that pasture structure is both cause and consequence of the grazing process. Defoliation provokes differential tissue removal, altering vegetation competition and plant growth patterns; thus pasture structure is altered by defoliation. At the same time pasture structure determines defoliation patterns and forage intake, ultimately determining body condition and fitness of animals. In heterogeneous pastures, these cause and consequence relationships are more evident, contrasting structures being built by distinct grazing intensities (Cruz et al. 2010). Regardless of the scale-dependency of this heterogeneity (Laca 2008), a challenging environment results, where grazing animals constantly need to sample to be able to correctly perceive it.

Grazing animals face potential bites to be harvested in a vegetation continuum. Diet selection, as a result of internal and external signals perceived by the animal (Gregorini et al. 2009a, 2009b; Villalba et al. 2009), determines which bites will be effectively gathered. The more complex the grazing environment, the greater the difference (beneficial) between the diet selected and the average botanical and chemical composition of the vegetation. Excessive grazing intensities decrease floristic and functional diversity in complex heterogeneous pastures, diminishing the difference between forage offered and selected. In this circumstance, grazing intensity determines that plant species with avoidance strategies are the only successful ones in the vegetation community. In contrast, moderate grazing promotes floristic and functional diversity, because defoliation patterns allow for a diverse community, comprising plant species with both tolerance and avoidance mechanisms (Briske 1999; Skarpe 2001).

The benefits of diversity are well known in terms of primary (Huyghe et al. 2012) and secondary productivity (Dumont and Tallowin 2011) in grassland ecosystems. Grazing animals respond positively to diversity and generally select mixed diets even when a unique diet is possible. This is classically demonstrated by the ryegrass-white clover model and the associated preference studies (Parsons et al. 1994a). However, there are fewer illustrations in natural heterogeneous pastures. In this context, bite diversity and its relationship with grazing management are illustrated by a long-term trial, where pasture structures resulted from various grazing intensities applied over 26 years. Biting behavior was described by visual assessment and classified, generating bite structural types (see Agreil and Meuret 2004, Figure 3).

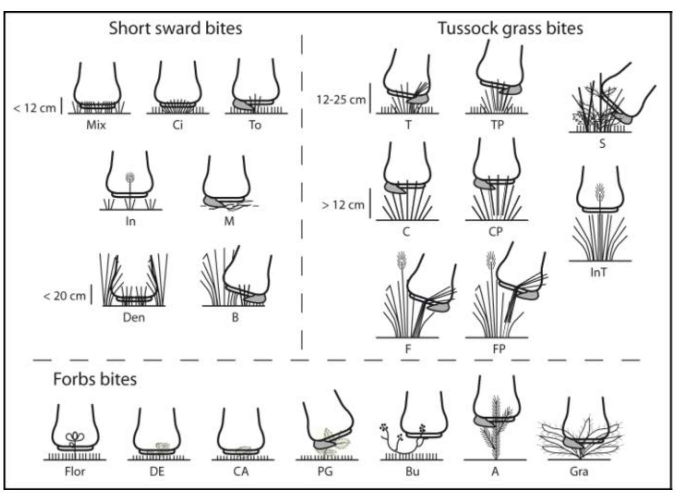

Figure 3. Bite types recorded for heifers grazing native Pampa vegetation in subtropical Brazil. Bite types attempt to separate bites based on the physical structure of the plant part consumed and on biting behavior. The codes for each bite type appear below the drawings and are used again in Figure 4.

The mass of each bite type is estimated by the hand-plucking method (Bonnet et al. 2011), so cumulative forage intake and diet selection can be described visually bite by bite. Figure 4 illustrates bite structural diversity and the associated range in mass observed at high (4% daily forage allowance) and moderate (12% daily forage allowance) grazing intensities.

Characteristics of vegetation communities resulting from grazing management determine the array of bite options potentially available to the grazing animal. At higher grazing intensities, bite diversity is lower (9 bite types among 33 species), as a consequence of decreasing species and vegetation structural diversity by overgrazing.

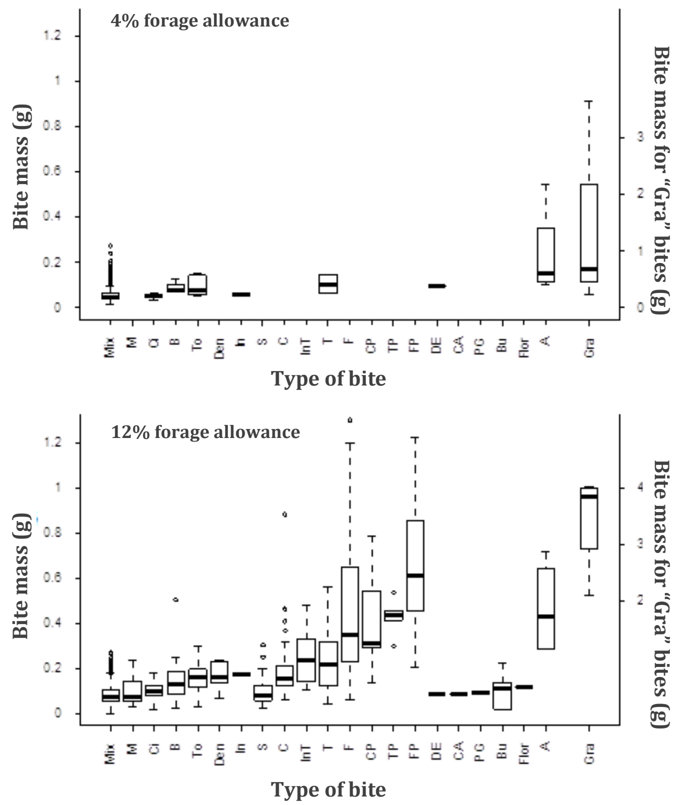

Figure 4. Comparison of the structural diversity of bites gathered by heifers in continuous stocking on native vegetation managed under low (4%, top) or medium (12%, bottom) daily forage allowance (kg dry matter in relation to kg live weight). The codes reported on the X-axis correspond with a classification of observed bites based on the physical structure of the plant part consumed (as illustrated in Figure 3). The Y-axes represent the range in bite mass assessed for each structural type of bite. Horizontal lines are median values; boxes include the central 50% of the bite mass distribution; and vertical dashed lines the smaller between the entire distribution and two standard deviations. The bite type "Gra" is out of scale and follows a different scale for bite mass reported on the right.

In contrast, moderate grazing promotes species and vegetation structural diversity, so grazing animals are able to gather 22 different bite types among more than 60 plant species (bite masses ranging from 0.01 to 4.025 g). Consequently, the possibility of acquiring nutrients and secondary plant compounds in order to consume an optimal combination of nutrients (Revell et al. 2008) is enhanced. Shipley (2007) reported the central role of bite masses offered by plants in determining intake rates within and among patches. Delagarde et al. (2001) reviewed bite masses of growing cattle in homogeneous temperate pastures and reported a maximum of 0.7 g per bite, in comparison with the 3.5 g of "Gra" bite type observed with moderate grazing in this example. It is worth noting that bite masses of the same bite type are higher at moderate grazing, reflecting plant structural benefits (i.e. plant height) by decreasing grazing intensity. Therefore, grazing animals under moderate grazing can gather bites of different types and higher masses. Under similar conditions, da Trindade et al. (2012) registered higher daily dry matter intake, and Carvalho et al. (2011) reported highest animal production, supporting the idea that grazing animals respond positively to the diversity of bite options.

Ingestive behavior generating tools for grazing management: homogeneous pastures

Assuming bite mass is the main determinant of intake rate, which in turn ultimately defines animal production, for purposes of grazing management it seems reasonable to define pasture management targets based on pasture structures that optimize bite mass. This situation applies particularly where output from pastoral farming systems is fundamentally oriented to animal production (but see Carvalho et al. 2013 for potential converging with environmental outputs), and based on homogeneous sown pastures. In this context a question emerges: what would be the best pasture structure to be offered to a grazing animal, assuming that bite mass is the main indicator of this condition? Figure 5 illustrates this reasoning.

The overall response patterns of bite mass and short-term intake rate to pasture height are similar, despite the two contrasting growth habits of the forage species and grazing methods (Mezzalira 2012). Bite mass and short-term intake rate are highly correlated and indicate similar optimal pasture structures. At low pasture heights, bite mass, and so intake rate, is constrained mainly by bite depth, which is well registered in the literature (Laca et al. 1992, 2001; Flores et al. 1993; Gregorini et al. 2011). At higher pasture heights, bite mass and intake rate decrease, a phenomenon less commonly registered.

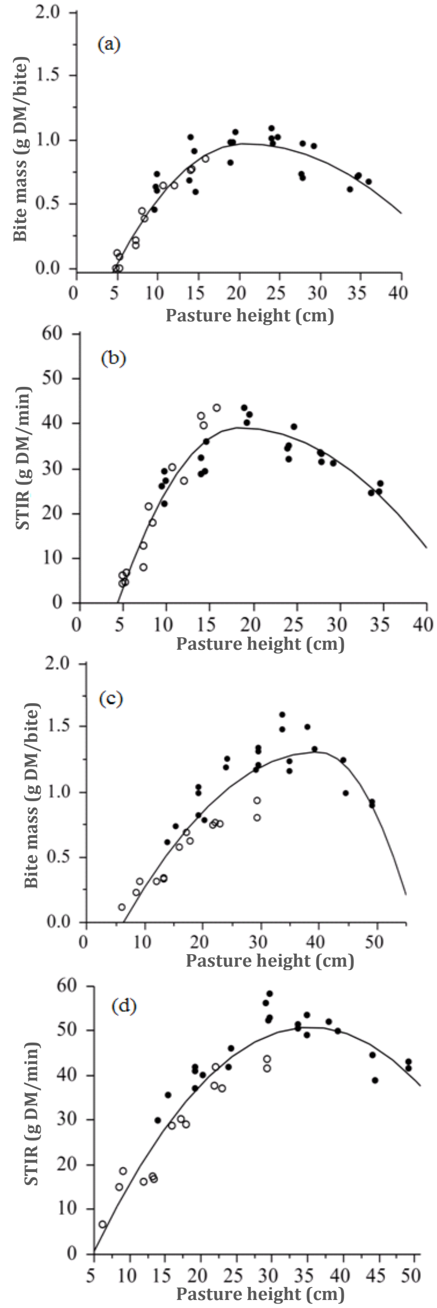

Figure 5. Bite mass and short-term intake rate (STIR) as a function of pasture height in four experiments: (a) and (b) with *Cynodon* sp.; and (c) and (d) with *Avena strigosa* under (**o**) rotational stocking, or (●) continuous stocking. Models: (a) *Cynodon* sp. – bite mass (mg DM/bite) = 0.97 - 0.003(20.64 - x)^2, if x<20.64, or 0.001(x - 20.64)^2, if x>20.64; P<0.0001; R^2 = 0.43; s.e. = 0.2379; n = 36; (b) *Cynodon* sp. – STIR (g DM/min) = 39.16 - 0.20(18.34 - x)^2, if x<18.34, or - 0.06(x - 18.34)^2, if x>18.34; P<0.0001; R^2 = 0.65; s.e. = 6.9358; n = 36; (c) *Avena strigosa* – bite mass (mg DM/bite) = 1.31 - 0.0011(39.84 - x)^2, if x<39.84, or 0.005 (x - 39.84)^2, if x>39.84; P<0.0001; R^2 = 0.68; s.e. = 0.2235; n = 36; (d) *Avena strigosa* − STIR (g DM/min) = 50.86 - 0.05(35.39 - x)^2, if x< 35.39, and - 0.05(x - 35.39)^2, if x>35.39; P<0.0001; R^2 = 0.78; s.e. = 6.1943; n = 36. (From Mezzalira 2012).

This fact is related to the increasing time per bite associated with decreasing bulk density in the upper pasture layers.

Stobbs (1973a; 1973b) described this process in tropical pastures, but not the fundamental cause. This phenomenon has been observed with similar response curves in other tropical pastures, e.g. *Panicum maximum* cv. Tanzania (Marçal et al. 2000), *Panicum maximum* cv. Mombaça (Palhano et al. 2007) and *Sorghum bicolor* (Fonseca et al. 2013), in studies aiming to define the optimal pasture structure for grazing animals. In the context of grassland management, this structural indicator defines the optimal pasture structure at the feeding station level for continuous stocking. Theoretically, average pasture height in continuous stocking would be in between the pasture currently being grazed (optimal height) and pasture recently grazed (~50% of optimal height, see above). This optimal average pasture height can be identified by protocols, where different pasture heights are maintained by continuous stocking and regression curves used to determine the optimal average height (e.g. da Silva et al. 2012). However, these types of grazing experiments are delineated at higher spatio-temporal scales and do not define the optimal pasture structure at bite/feeding station level.

In terms of rotational stocking, this optimal structure at bite level can be regarded as a target for pre-grazing structure of pasture. At bite level, there is no difference between grazing methods in the definition of the optimal structure, as shown in Figure 5. This probably indicates that tiller size/number compensation (Sbrissia and da Silva 2008) does not affect dry matter gathered in the same bite volume.

In contrast, with continuous stocking, where animals rarely bite in succeeding layers and there is no direct control of the defoliation interval, a second question emerges: what would be the best pasture structure to be left after a visit by the grazing animal? The underlying question regards the harvest efficiency definition and the characterization of an "optimal post-grazing pasture structure", which is highly correlated with animal production.

When animals enter a new paddock (e.g. strips in rotational stocking), there is a succession of potential bites available in succeeding layers (Ungar 1998; Baumont et al. 2004). Bites are taken progressively from upper layers to the bottom, each succeeding layer constraining bite volume by reducing bite depth and area (Ungar et al. 2001). Nutrient concentration in the bite volume decreases as the layer being grazed approaches the soil surface. This situation is analogous to the gain function, while an animal resides in a patch (see Marginal Value Theorem, Charnov 1976). Departure rules predicted by the model consider the decreasing intake rates experienced by the animal at patch level. This picture is similar to rotational stocking, except for the fact that it is the manager who decides departure time (i.e. change for a new strip). This decision defines post-grazing pasture structure. In general, the manager defines the period of occupation (residence time) and grazing density in order to increase harvest efficiency, so post-grazing masses are commonly very low.

Therefore, an anthropogenic point-of-view defines departure rules based on vegetation indicators under rotational grazing of domestic herbivores in agricultural systems. Carvalho (2005) proposed instead that animal ingestive behavior should define departure rules, mimicking animals' nature. This proposal is exemplified by Figure 6, where short-term intake rate is described along gradients of grazing down in relation to pre-grazing pasture structure (height).

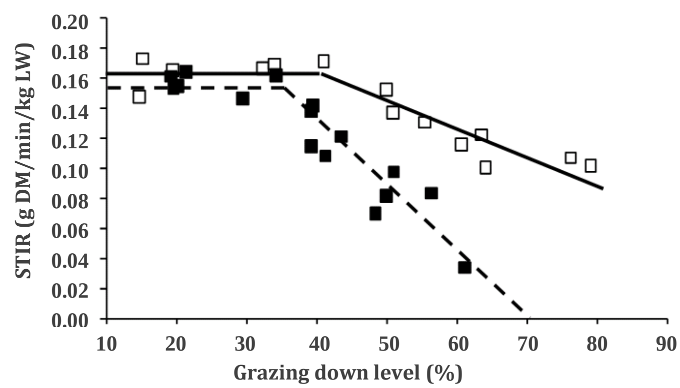

Figure 6. Short-term intake rate during the grazing down (% reduction of initial pasture height) in *Sorghum bicolor* (□; Fonseca et al. 2012) and *Cynodon* sp. (■; Mezzalira 2012). Initial pasture height and models: *Sorghum bicolor* − 50 cm; $y = 0.16 + 0.001(40 - x)$, if $x>40$, and $y = 0.16$, if $x<40$; $R^2 = 0.81$; $P<0.0001$; EPM = 0.014; *Cynodon* sp. − 19 cm; $y = 0.16$, if $x<37$, and $y = 0.16 + 0.006(37 - x)$, if $x>37$; $R^2 = 0.73$; $P<0.0001$.

Both experiments consider the initial pre-grazing pasture height would maximize bite mass and intake rate. Hence, when animals enter the paddock (beginning of the 'grazing down') and the first bites are taken, pasture structure is considered ideal and intake rate is at a maximum. Despite contrasting pasture structures, the overall response function was similar for the 2 pastures. As 'grazing down' progresses, short-term intake rate is initially constant, and then decreases linearly as forage mass is depleted. Short-term intake rate in *Cynodon* sp. pastures decreases at a faster rate, because succeeding layers are more restricting to bite formation than in *Sorghum bicolor*.

It is worth noting that the constancy in intake rate with the contrasting pasture structures is interrupted at similar depletion heights of the pasture (~40% reduction). This phenomenon is associated with pasture structural changes as a consequence of changing the availability of different plant morphological parts in lower grazing horizons. Preferred leaves become scarce and pseudostem, stem and dead material become predominant in succeeding lower pasture layers (Baumont et al. 2004; Benvenutti et al. 2006; Drescher et al. 2006).

Fonseca et al. (2013) demonstrated that the number of grazing jaw movements per unit dry matter ingested started to increase from the same point where intake rate started to fall (Figure 7). The results illustrate that animals encounter increasing difficulty in gathering bites as the residence time imposed by the manager in a pasture increases. After a forage depletion of ~40% of the initial pasture height, the efficiency of nutrient harvesting per unit time of bite formation decreases sharply.

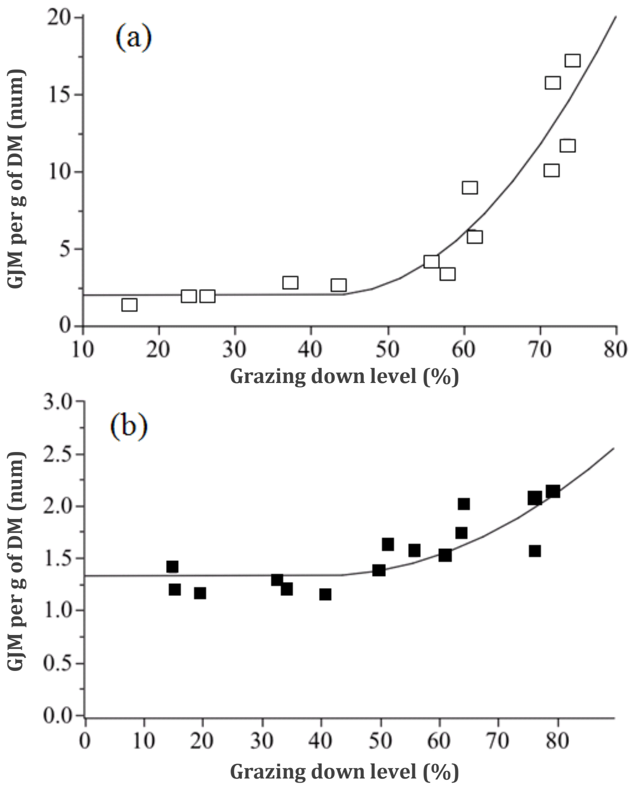

Figure 7. Grazing jaw movements (GJM) per g of dry matter (DM) during grazing down (% reduction of the initial pasture height) in: (a) *Cynodon* sp. (□; Mezzalira 2012); and (b) *Sorghum bicolor* (■; Fonseca et al. 2013). Initial sword surface height and models: *Sorghum bicolor* − 50 cm; y = 1.32, if x<40, and y = 1.32 + 0.0005$(40 - x)^2$, if x>40; R^2 = 0.636; P = 0.0004; s.e. = 0.20; n = 15; and *Cynodon* sp. − 19 cm; y = 1.97, if x<42.5, and y = 1.97 + 0.013$(42.5 - x)^2$, if x>42.5; R^2 = 0.898; P<0.0001; s.e. = 1.82; n = 13.

In general, the residence time of the animals is extended beyond this point in order to reach maximum harvesting efficiency levels (Figure 8), forcing animals to consume structural non-preferred items (Ginnett et al. 1999; Benvenutti et al. 2006; Drescher et al. 2006). A green leafy pasture regrowth is also mentioned as justification for this common management practice.

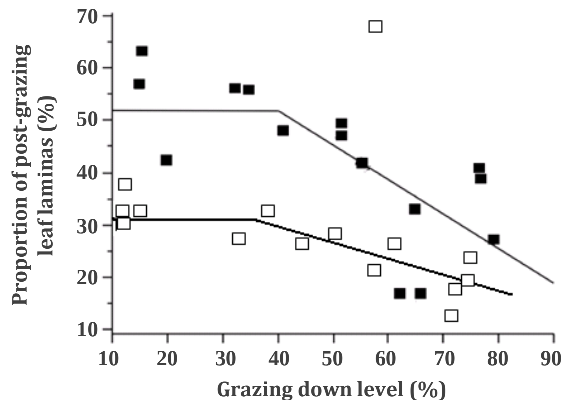

Figure 8. Proportion of leaf laminas in different proportions of grazing down in: *Sorghum bicolor* (■; Fonseca *et al*. 2012b); and *Cynodon* sp. sward (□; Mezzalira 2012). Models: *Sorghum bicolor* − 50 cm; y = 51.87 + 0.33(40 - x), if x>40, and y = 51.87, if x<40; R^2 = 0.50; P = 0.0044; s.e. = 10.55; n = 15; and *Cynodon* sp. − 19 cm; y = 31.93 + 0.45(31 - x), if x>31, and y = 31.93, if x<31; R^2 = 0.71; P = 0.0002; s.e. = 5.53; n = 14.

The issue of how many grazing horizons would be exploited is a matter associated only with rotational stocking, as animals rarely exploit succeeding grazing horizons in a grazing patch in continuous stocking, as previously mentioned. However, this discussion deserves attention, because rotational stocking is a grazing method where the managers mostly control the defoliation process. To address the dynamics and boundaries of the succeeding grazing horizons, it is necessary to refer to the defoliation process at tiller level.

Wade (1991) first demonstrated that animals defoliate tillers to a constant proportion of their height, which was verified by several authors (e.g. Laca et al. 1992; Cangiano et al. 2002), although Griffths et al. (2003) and Benvenutti et al. (2008a) found different responses under specific conditions. Figure 9 illustrates this phenomenon with different animal species grazing different pasture structures. Hodgson et al. (1994) referred to this singularity as the "concept of a constant proportionality of herbage removal". The mechanistic bases of this constancy are not totally understood, but probably are related to forces required to fracture stems (Griffiths and Gordon 2003; Benvenutti et al. 2008b).

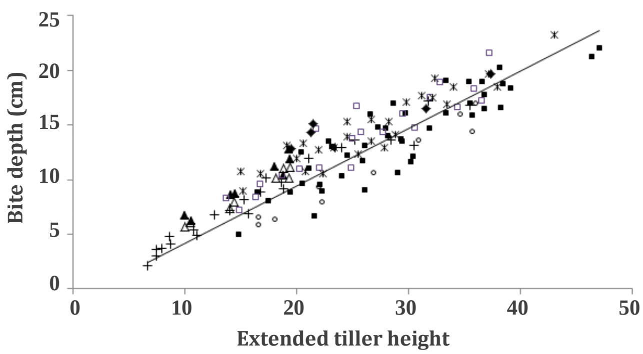

Figure 9. Relationship between bite depth and extended tiller height in: (Δ) sheep and (▲) beef heifers grazing natural grassland (Gonçalves et al. 2009); (♦) beef heifers grazing *Avena strigosa* (Mezzalira 2012); (■) beef heifers grazing *Brachiaria brizantha* (da Trindade 2007); (+) sheep grazing *Festuca arundinacea* and *Dactylis glomerata* (Carvalho et al. 1998); (o) horses in five cvv. of *Cynodon* sp. (Dittrich et al. 2005); (ж) ponies in *Cynodon* sp. and *Paspalum paniculatum* (Dittrich et al. 2007); (□) dairy cows in *Avena strigosa* (Lesama et al. 1999); (y = 1.1 + 0.52x; R^2 = 0.8391; s.e. = 1.9; P<0.0001; n = 203).

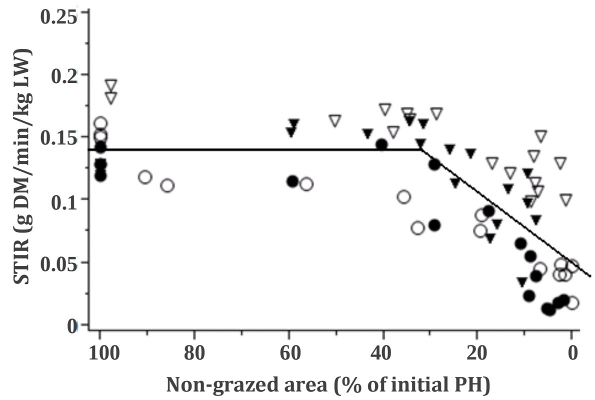

Figure 10. Changes in short-term herbage intake rate (STIR) with reduction in the proportion of non-grazed area [% of initial pasture height (PH), L. Fonseca, pers. comm.]: (●) dairy heifers in *Cynodon* sp. sward under continuous stocking; (○) beef heifers in *Avena strigosa* sward under continuous stocking; (▼) dairy heifers in *Cynodon* sp. sward under rotational stocking; and (Δ) beef heifers in *Sorghum bicolor* swards under rotational stocking. Model: y = 0.143, if x>31, and y = 0.143 - 0.003 (31 - x), if x<31; R^2 = 0.5566; s.e. = 0.03; P<0.0001; n = 71.

This particular biting behavior suggests the existence of grazing horizons, which was proposed by Carvalho (1997). According to Palhano et al. (2006), the highest grazing probability of the uppermost horizons is not a passive preference only. Bite mass is maximized in taller pastures as demonstrated by Laca et al. (1994). Thus pastures can be viewed as sets of superimposed grazing horizons (compartments of bites), with the probability of grazing the lowest horizons increasing as the uppermost layers are progressively grazed (Ungar and Ravid 1999; Baumont et al. 2004). Ungar et al. (2001) described this scenario by observing heifers taking bites from the uppermost grazing horizon, almost exclusively, until approximately three-quarters of its surface area had been removed. Fonseca et al. (2013) registered similar horizon use patterns with different pasture structures under field conditions. Figure 10 presents the changes in the short-term intake rate of grazing animals with the progressive diminution of residual non-grazed surface area during grazing down of pastures.

Data presented show intake rate is constant until two-thirds of the uppermost surface layer is grazed. It is assumed that the initial constancy in intake rate reflects animals gathering the maximum bite masses available in the uppermost layer (where higher bite depths are experienced). As grazing down progresses, average pasture height decreases, but animals continue to gather bites in previously ungrazed areas (bite mass almost constant), so intake rate remains constant despite pasture depletion (Carvalho et al. 2001). This situation persists until two-thirds of the first layer is harvested. At this point, it seems that the search for preferred ungrazed areas becomes unrewarding (searching costs sensu Parsons et al. 1994b), and grazing of the lower grazing horizon commences as its relative preference increases, as predicted by Baumont et al. (2004). The progression by animals to exploit different grazing horizons is probably not abrupt, but the large decrease in short-term intake rate after two-thirds of initial pasture height is depleted illustrates the huge decline in potential intake rates with succeeding grazing horizons.

The grazing management aspect that emerges from this discussion is: how long should animals stay on a pasture when the manager controls the departure rules? The earlier they are moved to a new strip, the higher is individual dry matter intake per unit time, but the lower is total dry matter intake per unit area. The longer they stay, the lesser the individual dry matter intake but the amount of forage harvested per unit area is greater. These contrasting goals of maximizing animal dry matter intake and pasture harvest efficiency highlight the fundamental ecological dilemma encountered in pastoral farming systems: the incapacity to reach both purposes of optimization simultaneously (Briske and Heitschmidt 1991). Consequently, for a manager to determine the optimal time when animals should depart from a strip under rotational stocking, which rule does the manager respect? In other words, do only pasture utilization goals define these management strategies?

The context presented here suggests ingestive behavior must be taken into account in defining grazing management, whether or not intake maximization is a goal. However, it is important to remember that secondary productivity in pastoral systems ultimately supplies the income and not pasture harvested per se.

If one considers the statements of the Foraging Theory (Stephens and Krebs 1986) in relation to the natural behavior of grazing animals, optimizing nutrient consumption per unit time is a prime factor in animal behavior. In this sense, it seems reasonable to aim at mimicking natural behavior in order to optimize animal production in agricultural systems. However, optimizing individual animal intake has effects on post-grazing mass dynamics that need to be addressed.

Ingestive behavior generating tools for grazing management: heterogeneous pastures

Grazing behavior can provide behavioral indicators as a tool to quantify the value of "foodscapes" (sensu Searle et al. 2007). Among proposed behavioral indicators, bite formation and foraging velocity were described as animals' decisions directly determining intake rate, which in turn influence daily dry matter intake. Despite Searle et al. (2007) suggesting there were limitations in using vegetation indicators to assess landscape value, as herbivore species perceive the same parameters (e.g. forage mass) differently, Carvalho et al. (2008) argued that plant functional characteristics could provide an adjunct to behavioral indicators as bases for assessing landscape condition and management. Plant functional types and bite structural diversity are closely linked. For example, Cruz et al. (2010) demonstrated how leaf dry matter content and specific leaf area were indicators of overgrazing. In considering potential indicators for functional assessments in pastoral ecosystems, and assuming pasture structure is simultaneously both cause and consequence in the grazing process, ingestive behavior would be considered a short-term indicator, while sward structure behaves as a long-term indicator of landscape value and ecosystem functioning (Carvalho et al. 2008).

Under continuous stocking, animals spend more time in grazing activities when pasture structure constrains intake (Pinto et al. 2007; Thurow et al. 2009). Animals generally increase their grazing time by decreasing the number of grazing meals and increasing the duration of each meal (Mezzalira et al. 2012a). Since meal duration is reciprocal to meal duration interval, low forage allowance provokes a decrease in the interval between meals. At very low forage allowances, Mezzalira et al. (2012a) reported only 3 daily meals, each one lasting on average 190 minutes, for heifers grazing heterogeneous natural pastures.

During a meal, animals adapt their grazing behavior in order to allocate more or less time to harvesting and searching for forage. Mezzalira et al. (2012a) reported that, at low forage allowances, 510 minutes were devoted to forage harvesting (83% of total grazing time), while at high forage allowances this activity was restricted to 271 minutes (57% of total grazing time). In contrast, the time devoted to searching for forage was restricted to 107 minutes at low herbage allowances (17% of daily grazing time), and more than 180 minutes (43% of daily grazing time) at higher herbage allowances. Studies by C.E. Pinto (pers. comm.), using GPS collars, indicate that in natural pastures being grazed at high grazing intensities (5 cm sward height), animals can walk 3.2 km compared with 1.7 km at moderate grazing intensity (19.4 cm sward height). It was estimated that animals might increase their energetic requirements by more than 25% in such a situation.

In response to different pasture structures, animals alter their dynamics of herbage acquisition, patterns of movement and use of feeding stations. Gonçalves et al. (2009) demonstrated bite mass was the main determinant of intake rate in natural grasslands. Considering the preferred inter-tussock strata, intake rate is maximized at heights around 10.0 and 11.5 cm for ewes and heifers, respectively (Figure 11). The authors reported that under intake-limiting conditions, both cattle and sheep visit a larger number of feeding stations, harvesting fewer bites and remaining less time at each feeding station, a behavior that is in agreement with the Optimum Foraging Theory (see Prache et al. 1998).

Further, animals move faster, but with fewer steps between feeding stations, indicating an attempt to increase the rate of encountering potential feeding stations. These behavioral responses change in the opposite direction as pasture characteristics become more favorable to herbage harvesting, reaching a similar plateau for each animal species.

These results indicate short-term intake rate is maximized at intermediate pasture heights. Thus, a question arises regarding vegetation dynamics in complex heterogeneous pastures, because intermediate levels of grazing intensity increase the frequency of less preferable plants and/or structures. Consequently, the frequency and distribution of non-preferred items in pastures can present a challenge to the grazing animal. Mezzalira et al. (2013b) reported that increasing forage allowance allows greater selectivity, and therefore an increase in non-preferred area (tussock frequency in Figure 12).

The number of non-tussock feeding stations decreases linearly with the increase in herbage allowance due to

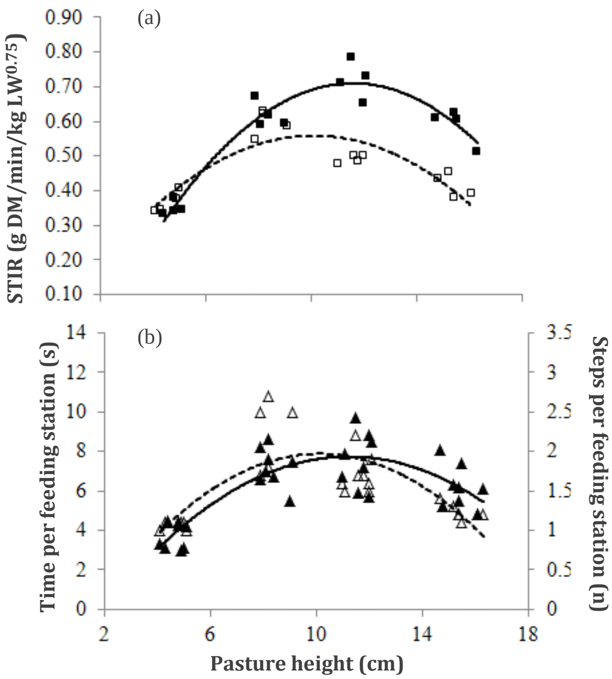

Figure 11. Short-term intake rate: (a) by heifers (■; Y = - 0.326 + 0.178x - 0.0077x^2; R^2 = 0.9229; SD = 0.04; P<0.001), and sheep (□; Y = - 0.016 + 0.113x - 0.0056x^2; R^2 = 0.7342; SD = 0.05; P<0.001); and (b) time per feeding station (▲; Y = 3.95 + 2.1x - 0.09x^2; R^2 = 0.6995; s.e. = 1.1; P<0.0001); and steps per feeding station (Δ; Y = -0.83 + 0.55x - 0.03x^2; R^2 = 0.6191; s.e. = 0.3; P<0.0001) by heifers and sheep in natural grasslands under different pasture heights (adapted from Gonçalves et al. 2009).

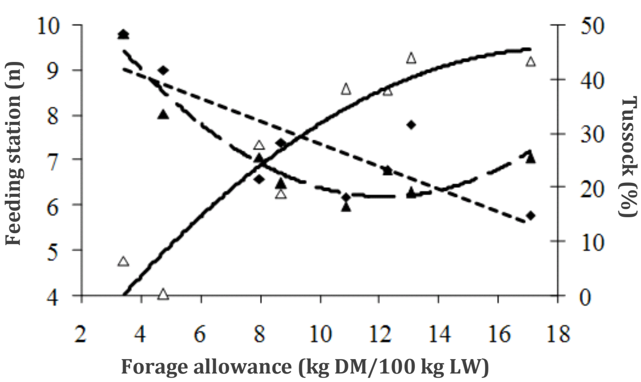

Figure 12. Frequency of tussocks (Δ) y = 28.6 + 8.71x - 0.279x^2; R^2 = 0.924; SD = 5.1; P = 0.036; number of feeding stations effectively grazed every 10 steps (▲) y = 12.38 - 1.003x + 0.041x^2; R^2 = 0.906; SD = 0.4; P = 0.005; and potential encounter rate of non-tussock feeding stations (♦) y = 9.85 - 0.248x; R^2 = 0.641; SD = 0.9; P = 0.017; of heifers grazing in natural grassland under distinct forage allowances (Mezzalira et al. 2013b).

an increase in tussock frequency. Initially, at lowest forage allowances, the number of effectively grazed feeding stations is similar to the number of encountered feeding stations, with practically no rejected feeding stations. With the increase in forage allowance, the proportion of feeding stations effectively grazed decreases, indicating that animals express higher selectivity in the choice of the feeding stations they used. Furthermore, the fact that the proportion of feeding stations effectively grazed decreases more rapidly than the potential encounter rate of non-tussock feeding stations (distance between the two dotted declining lines in Figure 12) reflects the additional cost for the animal of searching for preferred feeding stations during the selection process.

A slight increase in the proportion of effectively grazed feeding stations is noticed when forage allowance reaches 11%, which corresponds to a 6 cm pasture height. Then, a strong inversion occurs in those processes, until most of the feeding stations found along the path of displacement are used at 14% forage allowance (7.5 cm sward height), interpreted as a reduction in selectivity.

Mezzalira et al. (2013b) suggest this may be associated with the increasing percentage of tussocks, which is close to 40% at 14% herbage allowance. In fact, animal performance reaches a maximum at forage allowances of 12% (Pinto et al. 2008; Nabinger et al. 2011; Mezzalira et al. 2012b), and data from Bremm et al. (2012) support the conclusion that at tussock frequency above ~35%, intake rate of animals is decreased by the costs related to the time spent avoiding tussocks when searching for better feeding stations. However, this impact depends on the animal species, as evidence suggests that, for each 1% increase in frequency of tussocks, time spent grazing on the inter-tussock areas by heifers reduces by 0.6%, while the reduction by ewes is only 0.36% (Bremm et al. 2012).

The effect of frequency distribution of non-preferred food items upon the accessibility of the preferred diet item for grazing animals was studied by Bremm et al. (2012). Ewes adjusted their foraging strategies and maintained a constant short-term intake rate regardless of percentage of tussock cover. Beef heifers exhibited the highest short-term intake rate with 34% tussock cover (Figure 13).

Bite mass of beef heifers decreased when tussock cover increased above 44%, whereas no trend was detected for ewes. Data demonstrated that non-preferred items might act as a vertical and/or horizontal barrier, interfering with the process of bite formation and affecting bite mass of beef heifers.

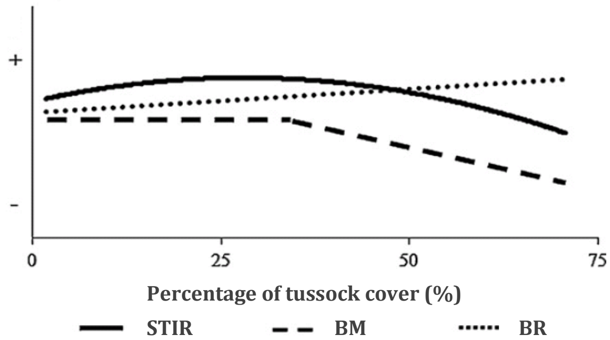

Figure 13. Grazing behavior patterns (STIR – short-term intake rate, BM – bite mass, BR – bite rate) of beef heifers grazing a natural grassland with distinct percentages of tussock cover of *Eragrostis plana*, assumed as the non-preferred food item (Bremm et al. 2012).

Considering the influence of pasture height of tussocks (non-preferred) and inter-tussock areas (preferred) in determining ingestive behavior in heterogeneous pastures, Figure 14 explores boundaries of pasture targets for continuous stocking and its impact on short-term intake rate.

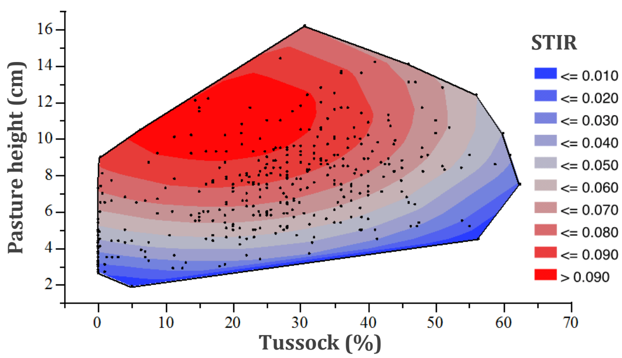

Figure 14. Relationship between tussock frequency (%) and inter-tussock pasture height (cm) in determining dry matter intake rate (STIR, mg DM/min/kg LW) of beef cattle grazing natural grasslands in southern Brazil. Data calculated from Goncalves et al. (2009) and Bremm et al. (2012).

It is assumed that short-term intake rate is well correlated with animal performance, and the frequency of tussocks and the inter-tussock pasture height as a model of the balance between non-preferred and preferred items, respectively. Response curves in Figure 14 show intake rate is depressed when pasture height is lower than 10 cm or tussock frequency is higher than 35%, with pasture height affecting intake rate proportionately in a more pronounceable form.

These boundaries are subsiding recommendations and support new management targets for natural grasslands in southern Brazil. Formerly, tussocks were viewed only as undesirable components of natural grassland ecosystems.

Recent grazing behavior experiments have demonstrated that grazing animals use tussocks in order to gather strategic high bite masses throughout the day (see Figure 4), contributing to a diverse diet. Tussocks are good indicators of grazing intensity management, because they are normally associated with higher grazing intervals (allowing plant strategies for resource conservation typical of tussock plants, with low rates of herbage accumulation and high leaf life span). Hence, if moderate grazing is being recommended to foster both animal production and ecosystem services (Carvalho et al. 2011), it is inevitable there will be low levels of less preferred items. Formerly, farmers tended to cut tussocks in order to recover presumed wasted areas, regardless of tussock frequency levels. Nowadays, they are requested to interfere only when tussock frequency exceeds 35%, when there is a probability that animal production will decline.

Innovations in grazing management: From bites to farmers

According to van den Pol-van Dasselaar (2012), the popularity of pastoral farming systems based on grazing is declining in Europe. Labor is an important factor to consider, as average herd size is increasing, and large herds are difficult to manage. This explains why continuous stocking is attracting new interest in Europe, and at the same time illustrates the lack of innovation in grazing management.

Carvalho et al. (2013) reported a contrasting situation in the favorable tropics (i.e. Brazil), where new understanding of underlying processes at the plant-animal interface has resulted in recent improvements in animal production from grasslands. Da Silva and Nascimento Jr (2007) reviewed trends in grassland management towards the planning of sound and efficient management practices, and concluded that targets developed for tropical pastures based on pasture structure are changing paradigms related to grassland management. Canopy light interception and dynamics of forage accumulation are being linked with pasture targets and supporting new management strategies for both continuous and rotational stocking methods (e.g. da Silva et al. 2012; Montagner et al. 2012), so old forage cultivars are reaching new unexperienced animal production levels.

Besides, animal-based pasture targets oriented to maximize instantaneous intake rate for grazing dairy cows are being proposed to support new rotational stocking strategies aiming to maximize the intake of herbage per unit grazing time (Fonseca et al. 2012). As presented earlier, grazing behavior research indicated pre-grazing pasture targets in order to optimize intake rate, which is maintained at a high level if pasture is not depleted more than ~40% of the initial pre-grazing pasture height ("take the best and leave the rest" rule, concept adapted from Provenza et al. 2003). In order to illustrate how these insights can support pasture management at a farm level, a successful extension program named PISA (Produção Integrada de Sistemas Agropecuários[1]), currently being applied in Brazil, is briefly described.

PISA is a sustainable intensification production model oriented to increase food production at farm and landscape levels, based on sustainable pillars as no-till conservation agriculture, animal welfare, integrated crop-livestock systems, traceability and certification of farm products, among other good farming practices. It is not oriented to any specific agricultural sector, and its ambition is to diminish environmental impacts, while enhancing food security in the context of sustainable intensification.

In southern Brazil it involves mainly small-scale dairy operations, encompassing presently 575 families in 25 municipalities, which are the dominant farm type. In general dairy cows are fed maize silage + concentrate (60−70% of the diet) and annual temperate (mainly *Lolium multiflorum* and *Avena strigosa*) or tropical (mainly *Sorghum bicolor*, *Pennisetum glaucum* and *Cynodon* sp.) pastures (30−40% of the diet). On average, farmers milk 14 cows, for a total daily milk production of approximately 150 liters.

Many management interventions have been implemented during the 3-year duration of PISA, but modifications in grazing management have produced the most important short-term effects. In general, pastures are managed under rotational systems, with fixed resting periods designed to favor biomass accumulation. The period of occupation and stocking density are oriented to maximize forage harvest efficiency so as to use all forage accumulated. Post-grazing forage mass is viewed as waste. Two daily milking periods, occurring prior to dawn and to dusk, restrict grazing time (see consequences in Chilibroste et al. 2007; Mattiauda et al. 2013).

PISA modifies the prevailing production pattern and aims to make pastures the main nutrient source for animals. Grazing management is modified in order to enhance animal nutrient consumption per unit time. The basis for this strategy is ingestive behavior (pasture structure that maximizes bite mass), as mentioned earlier. Pasture management targets are defined to optimize dry matter intake rate, assuming that nutrient consumption is optimized at the same time. Pre-grazing and post-grazing pasture heights are defined so cows can always ingest forage at the highest intake rates, making maximum use of the few hours animals can devote to grazing. This is particularly important in dairy systems, where cows have a limited period to gather forage by grazing. Table 1 shows proposed pasture targets based on grazing behavior and bite mass maximization being applied at farm level.

The layout of pastures rotationally stocked using this management concept changes to the use of fewer subdivisions of larger size. Farmers appreciate this, because it results in lower labor requirement. Post-grazing pasture mass is high, so overall pasture structure equates with that of continuously stocked pasture moderately grazed. Accordingly, this proposed "take the best and leave the rest rule" is colloquially named "rotatinuous stocking". Resting periods are flexible due to typical fluctuations in pasture growth, and are usually one-third of resting periods previously applied. Post-grazing pasture mass is high, but as resting period is very low (usually less than a week for tropical and annual temperate pastures), senescence and tiller recruitment are apparently maintained at reasonable levels, again similar to continuous stocking at moderate grazing. Finally, post-grazing pasture structure does not deteriorate during the grazing period, and pasture growth seems to be continuously located at the linear phase of the classical sigmoid model of pasture accumulation (see Parsons and Chapman 2000). At the moment, part of this process is empirically described, but there is current research quantifying those fluxes. The rapid increase in soil organic matter measured in PISA farms indicates high carbon sequestration promoted by pasture growth, and supports the hypothesis of almost uninterrupted pasture growth with "rotatinuous stocking" strategy.

Since the lactating cows graze only the upper parts of the plants, the contribution of pasture dry matter in the total diet is increased, decreasing silage and concentrate consumption by almost half. On average, milk yield per cow rose by 30%, reducing feeding costs by 20% at the end of the first year of the PISA program. The number of lactating cows per farm expanded from 14 to 19 in the first year, reflecting increases in pasture production due to the constancy of leaf area able to intercept light and capture solar energy. Consequently, annual milk yield per farm increased from 4800 to 11 250 kg/ha.

[1] PISA is a public-private initiative led by MAPA (Brazilian Ministry of Agriculture). Farmers apply voluntarily to the program, and the Universities are responsible for proposed technologies. The Program is funded by SEBRAE/SENAR/FARSUL, a public-private partnership, and technologies are applied at farm level by SIA private consultants capacitated in PISA.

Table 1. Pasture targets based on grazing behavior and bite mass maximization being applied at farm level.

Forage species	Pasture target* (cm)	Reference
Sorghum bicolor	50	Fonseca et al. 2012
Pennisetum glaucum	60	Mezzalira et al. 2013a
Cynodon sp.	19	Mezzalira 2012
Native grassland (mainly *Paspalum notatum*, *Axonopus affinis*, *Desmodium incanum* and *Paspalum plicatulum*)	11.5	Gonçalves et al. 2009
Panicum maximum cv. Aruana	30	Zanini et al. 2012
Panicum maximum cv. Mombaça	95	Palhano et al. 2006
Avena strigosa	29	Mezzalira 2012
Lolium multiflorum	19	D.F.F. Silva, pers. comm.

*Pasture targets are considered the pasture structure where bite mass is maximized. In rotational stocking pasture, target refers to pre-grazing pasture height. Post-grazing pasture height should not exceed 40−50% of the pre-grazing height. In continuous stocking, it refers to optimal pasture height at the patch being grazed (average pasture height being lower).

There are a few farmers with more than 3 years in PISA, and these have reached more than 17 000 kg/ha. The social impact in those communities has been quite significant.

The overall technological packages and the way they are applied at farm level are more complex than described here. However, it is worth noting that "rotatinuous stocking" based on grazing behavior insights is the pathway in the short-term by which other technologies can ultimately be applied (e.g. no-till or diversity in crop rotations). In contrast with many other technologies (e.g. no-till to increase soil carbon stocks), increased milk production derived from changes in grazing management is "a week time scale response", so farmers became confident to accept additional structural changes in their activities. It is exciting to monitor farmers' responses throughout this process, how they are initially reactive to change for a new grazing management orientation, how they overestimate the role of silage (apprehension to not have enough feed for cows), and how they rapidly become adapted to looking at pasture structure, and not only cow body condition.

Concluding remarks

Building multifunctional pastoral farming systems requires that managers cannot dictate grassland management only by their anthropogenic assessment. Mimicking nature increases the possibility of creating sound production systems and promoting sustainable intensification. In this context, managers would learn with grazing animals in order to reproduce their behavioral requirements in commercial operations. An understanding of grazing behavior is essential to support grassland management and innovative grazing systems, as demonstrated by the PISA case study based on the "rotatinuous grazing" strategy.

Appropriate use of grazing behavior can support innovations in grassland management, but this is not the current trend, because the anthropogenic way of thinking determines management actions based on human goals (e.g. forage harvest efficiency), that rarely correspond with animal goals. Reconciliation is needed for all agricultural systems that suffer from side-effects originating from human pre-potency. In this sense, there is huge potential to include consideration of grazing behavior when making primary management decisions in grassland ecosystems, as the visionary Harry Stobbs identified so many years ago.

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Challenges and opportunities for improving eco-efficiency of tropical forage-based systems to mitigate greenhouse gas emissions

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Abstract

Forage-based livestock production plays a key role in national and regional economies, for food security and poverty alleviation, but is considered a major contributor to agricultural GHG emissions. While demand for livestock products is predicted to increase, there is political and societal pressure both to reduce environmental impacts and to convert some of the pasture area to alternative uses, such as crop production and environmental conservation. Thus, it is essential to develop approaches for sustainable intensification of livestock systems to mitigate GHG emissions, addressing biophysical, socio-economic and policy challenges.

This paper highlights the potential of improved tropical forages, linked with policy incentives, to enhance livestock production, while reducing its environmental footprint. Emphasis is on crop-livestock systems. We give examples for sustainable intensification to mitigate GHG emissions, based on improved forages in Brazil and Colombia, and suggest future perspectives.

Resumen

La producción ganadera a base de forrajes desempeña un papel clave en las economías nacional y regional en cuanto a seguridad alimentaria y mitigación de la pobreza. No obstante, se considera como un factor importante que contribuye a las emisiones de gases de efecto invernadero (GEI) producidos por la agricultura. Mientras que se prevé que la demanda de productos pecuarios seguirá en aumento, existe presión política y social para no solo reducir los impactos ambientales sino también para convertir parte del área en pasturas a usos alternativos como la producción agrícola y la conservación del medio ambiente. Por tanto, es esencial desarrollar enfoques para la intensificación sostenible de sistemas pecuarios para mitigar las emisiones de GEI, abordando desafíos biofísicos, socioeconómicos y políticos.

En este documento se destaca el potencial de los forrajes tropicales mejorados, junto con incentivos a nivel de políticas, para mejorar la producción pecuaria mientras se reduce su huella ambiental. Se hace énfasis en sistemas mixtos (cultivos-ganadería) y se dan ejemplos de intensificación sostenible para mitigar las emisiones de GEI con base en forrajes mejorados en Brasil y Colombia, y se señalan algunas perspectivas para el futuro.

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Global importance of forage-based crop-livestock systems and the challenge to improve eco-efficiency

Livestock play a central role in global food systems and thus in food security, accounting for 40% of global agricultural gross domestic product; at least 600 million of the world's poor depend on income from livestock (Thornton et al. 2002). Livestock products supply one-third of humanity's protein intake, causing obesity for some, while remedying undernourishment of others (Steinfeld et al. 2006). Livestock products are crucial in the context of global biomass production and consumption systems. Nearly one-third of the global human appropriation of net primary production (HANPP) occurs on grazing lands (Haberl et al. 2007). In the year 2000, livestock consumed nearly two-thirds of global biomass harvest from grazing lands and cropland (Krausmann et al. 2008). Forage grass is the most consumed feed in the world (2.3 Gt in 2000), representing 48% of all biomass consumed by livestock; of this, 1.1 Gt are used in mixed systems and 0.6 Gt in grazing-only systems (Herrero et al. 2013a). Grazing lands are by far the largest single land-use type, estimated to extend over 34–45 Mkm² (Lambin and Meyfroidt 2011). Grazed ecosystems range from intensively managed pastures to savannas and semi-deserts. Additionally, a substantial share of crop production is fed to livestock. In the year 2000, of the total of 15.2 Mkm² cropland, approximately 3.5 Mkm² provided feed for livestock. Thus, producing feed for livestock uses about 84% of the world's agricultural land (Table 1; Foley et al. 2011). The share is even higher in developing countries (FAO 2009).

Livestock production is a major contributor to greenhouse gas (GHG) emissions. Figure 1 shows the spatial distribution of GHG emission intensities by livestock (Herrero et al. 2013a). Sub-Saharan Africa (SSA) is the global hotspot of high emission intensities, due to low animal productivity across large areas of arid lands, where feed is scarce and of low quality, and animals have low productive potential. Moreover, most ruminants in SSA are raised for meat, and meat production is associated with lower feed efficiency and higher emission intensities compared with milk production, by a factor of 5 or more (Herrero et al. 2013a). Moderate emission intensities occur throughout the developing world, in arid regions with large rangeland areas, in places with important beef production (Amazonia), and in places where diet intensification in ruminants is low (large parts of South Asia). In most of the developed world, emission intensities are low, due to more intensive feeding practices, feed conversion-efficient breeds of livestock, and temperate climates, where feed quality is inherently higher.

Herrero et al. (2011) estimate livestock emit 14−18% of global non-CO_2 GHG emissions. An additional 17% of emissions is attributed to land-use changes related to agriculture and deforestation for grazing (IPCC 2007). Expansion of livestock production is often considered a major driver of deforestation, especially in Latin America, with impacts on biodiversity and the global climate system (Szott et al. 2000), although the causal relationships are debated (Kaimowitz and Angelsen 2008). Moreover, overgrazing is claimed a central force of land degradation, in particular with respect to erosion and soil

Table 1. Global land use.

	Land use class	Land use (ice-free) in 2000 (Mkm²)	(%)	Source and remarks
a	Urban & infrastructure	1.4	1.1	Erb et al. 2007
b	Forests under use	35.0	26.8	Erb et al. 2007
c	Remote, wilderness (productive)	15.8	12.1	Erb et al. 2007
d	Non-productive land	16.2	12.4	Erb et al. 2007
e	Cropland	15.2	11.6	Erb et al. 2007; FAO 2011a
f	- of which fodder crops	1.4	1.1	Monfreda et al. 2008
g	- of which area used for feedstuff production	3.9	3.0	Kastner et al. 2012
h	Permanent pastures	34.1	26.1	FAO 2011b
i*	Other land, maybe grazed	12.8	9.8	Difference between FAO 2011b and Erb et al. 2007
Agricultural land (e+h+i)		62.1	47.6	
Total ice-free (a+b+c+d+e+h+i)		130.5	100.0	
Livestock feeding (f+g+h+i)		52.2	40.0	of ice-free land
			84.1	of land used for agriculture (e+h+i)

*Productive land not used for forestry, cropping, urban, but also not remote or wild, minus the land used as permanent pastures (Erb et al. 2007).

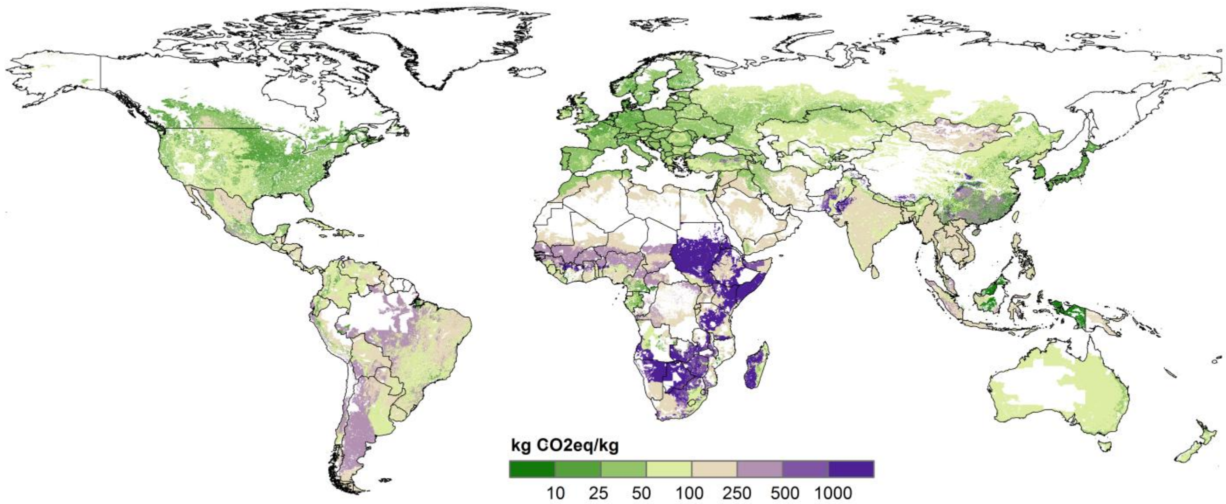

Figure 1. Global greenhouse gas efficiency per kilogram of animal protein produced (Herrero et al. 2013a).

organic carbon (C) stocks (Vågen and Winowiecki 2013). In low-income countries, the contribution of agriculture to overall GHG emissions (as a % of total emissions) is considered to be even greater, with 20% and 50% attributed to agriculture and land-use changes, respectively (The World Bank 2010).

We can expect much more intensification and industrialization in animal production systems in the near to mid-term future (Delgado et al. 1999; Haan et al. 2010), as extensive and pasture-based systems move towards mixed crop-livestock systems (Herrero et al. 2012). Havlik et al. (2013) found that this transition could reduce GHG emissions without compromising food security. Reduced methane (CH_4) production can result from land-sparing effects (less area needed to produce feed), and input-output efficiency gains that reduce the number of animals required for the same production. Almost landless, grain-fed livestock systems have economic advantages in terms of production rates and scale effects, but can potentially lead to competition in land use for direct food production (Smith et al. 2010; Erb et al. 2012). Extensive grazing systems that collectively occupy large areas of land, much of it degraded due to mismanagement and soil mining, may gradually be transformed, giving enhanced efficiency in the use of resources and land. Possible transformations include switching to monogastric species, using improved breeds and changing from roughage-based diets to high-concentrate feedstuffs from cropland.

The global feed market is 1 Gt concentrate DM/yr, and 5.4 Gt roughage DM/yr. Market feed, such as oil cakes and cereals, is essential for monogastrics and is also important in ruminant livestock systems, particularly when they are industrialized. However, ruminants can digest biomass unsuitable for human food (Erb et al. 2012). Comparing the environmental footprint of systems requires not only analysis of their direct GHG emissions but also the environmental costs of feed production. For example, transport accounts for 11–12% of GHG emissions from feedlots in Europe feeding soybean produced in Brazil (Garnett 2011), compared with feed produced near feedlots in mid-western USA (Pelletier et al. 2010). Furthermore, the potential to mitigate climate change and other environmental benefits of forage-based systems (see following sections) are often not considered.

Opportunities through forage-based systems to reduce GHG emissions

Reducing agriculture's GHG emissions and increasing C stocks in the soil and biomass could reduce global GHG emissions by 5.5−5.9 Gt CO_2-equivalent/yr (Olander et al. 2013). In 2000, non-CO_2 emissions from livestock systems ranged between 2.0 and 3.6 Gt CO_2-eq (Herrero et al. 2013b). These are expected to increase by 70% by 2050. Forage-based systems can mitigate GHG emissions by: (1) increasing C stocks; (2) reducing CH_4 emissions per unit of livestock product and net CH_4 emissions by reducing animal numbers; and (3) reducing nitrous oxide (N_2O) emissions (Peters et al. 2013).

Improving carbon accumulation

In a meta-analysis of studies on the effects of grassland management on soil C stocks, three-quarters showed increases (mean 0.54 t C/ha/yr, n = 167, Conant et al. 2001). Summarizing 74 papers on land-use change, Guo and Gifford (2002) showed that, compared with forests, pastures in areas with 2000–3000 mm/yr rainfall have a higher potential to accumulate soil C. Land-use change affected soil C stocks, which declined when pastures were converted to tree plantations and when either forests or pastures were converted to crops. In contrast, soil C stocks increased when annual crop land was converted to tree plantations, pastures or secondary forest. When either forest or savanna was converted to pasture, soil C stocks increased by 5–12% and 10–22%, respectively (Powers et al. 2011). When forests are cleared for pastures, most of the above-ground C is lost, but soil C stocks in the long term either remain the same or increase substantially (Amézquita et al. 2010). In the Colombian Amazon, total C stocks were highest in native forests, followed by well-managed sown pastures and silvopastoral systems; degraded pastures and degraded soils were lowest (Amézquita et al. 2010). In contrast with annual crops, well-managed pastures maintain soil cover, reduce fluctuations in soil temperature and add organic matter (Guo and Gifford 2002).

The main opportunities to mitigate GHG emissions by increasing soil C stocks are: (i) improved management of crops and grasslands; and (ii) restoration of degraded lands (Smith et al. 2008). Of the overall C-mitigation potential, 29% was claimed to be from pasture land (Lal 2010). In Latin America and the Caribbean, sown pastures of *Brachiaria* grasses have a high potential to increase soil C stocks (Thornton and Herrero 2010).

Sown tropical forages can accumulate large amounts of C in soil, particularly in the deeper layers (Fisher et al. 2007). The potential of sown forages under adequate pasture and animal management to increase C stocks is second only to forest (Mosier et al. 2004; Fisher 2009). Pastures in Bahia, Brazil, accumulated only half as much C as those in the Colombian Llanos, probably because lower temperatures limited net primary productivity (Fisher et al. 2007). Pastures generally have the capacity to accumulate C, but magnitudes and rates are likely to be site-specific (e.g. Conant et al. 2001; da Silva et al. 2004). The controlling factors are imperfectly understood.

Reducing methane emissions

CH4 from enteric fermentation in ruminants accounts for 25% of GHG emissions from livestock, or 65% of non-CO_2 emissions (Thornton and Herrero 2010). In terms of CH_4 emissions, monogastrics (largely pigs and poultry) produce protein more efficiently than ruminants. The comparison is simplistic, however, by not accounting for the suitability of land only for pasture or feed production, and the nutritional value of the produce beyond protein or the use of by-products (Garnett 2009). Forage diets with high digestibility plus high energy and protein concentrations produce less CH_4 per unit of meat or milk produced (Waghorn and Clark 2004; Peters et al. 2013). Forages integrated in tropical agropastoral systems provide enhanced soil fertility and more crop residues of higher quality, giving higher system efficiency (Ayarza et al. 2007). Use of forages in mixed crop-livestock systems can not only reduce CH_4 emissions per unit livestock product but also contribute to the overall GHG balance of the system (Douxchamps et al. 2012). Dietary additives such as oils to ruminant feed (Henry and Eckard 2009), and feeding silage instead of hay (Benchaar et al. 2001), reduce CH_4 emissions by changing the rumen flora (Henry and Eckard 2009). Condensed tannins from some legumes can reduce CH_4 production in ruminants (Woodward et al. 2004), but they often reduce feed digestibility leading to lower animal performance (Tiemann et al. 2008).

Reducing nitrous oxide emissions

The soil microbial processes of nitrification and denitrification drive N_2O emissions in agricultural systems. Nitrification generates nitrate (NO_3^-) and is primarily responsible for the loss of soil nitrogen (N) and fertilizer N by both leaching and denitrification (Subbarao et al. 2006). Current emissions of N_2O are about 17 Mt N/yr and by 2100 are projected to increase four-fold, largely due to increased use of N fertilizer. Up to 70% of fertilizer N applied in intensive cereal production systems is lost by nitrification (Subbarao et al. 2012). If this could be suppressed, both N_2O emissions and NO_3^- contamination of water bodies could be reduced substantially.

Some plants release biological nitrification inhibitors (BNIs) from their roots, which suppress nitrifier activity and reduce soil nitrification and N_2O emission (Subbarao et al. 2012). This biological nitrification inhibition (BNI) is triggered by ammonium (NH_4^+) in the rhizosphere. The release of the BNIs is directed at the soil microsites where NH_4^+ is present and the nitrifier population is concentrated. Tropical forage grasses, cereals and crop legumes show a wide range in BNI ability. The tropical *Brachiaria* spp. have high BNI capacity, particularly *B. humidicola* and *B. decumbens* (Subbarao et al. 2007). *Brachiaria* pastures can suppress N_2O emissions and carrying over their BNI activity to a subsequent crop might improve the crop's N economy, especially when substantial amounts of N fertilizer are applied (Subbarao et al. 2012). This exciting possibility is currently being researched and could lead to economically profitable and ecologically sustainable cropping systems with low nitrification and low N_2O emissions.

The Intergovernmental Panel on Climate Change (IPCC) (Stehfest and Bouwman 2006) did not consider BNI in estimating N_2O emissions from pastures and crops. For example, 300 Mha in the tropical lowlands of South America are savannas with native or sown grasses such as *Brachiaria* spp. that have moderate to high BNI ability. Substantial areas of these savannas have been converted to production of soybean and maize, which lack BNI ability. Continuing conversion has important implications for N_2O emissions (Subbarao et al. 2009), but the impact might be reduced if the system included agropastoral components with a high-BNI pasture phase (Ayarza et al. 2007).

Role of silvopastoral systems

Agroforestry is the practice of growing of trees and crops, often with animals, in various combinations for a variety of benefits and services. It is recognized as an integrated approach to sustainable land use (Nair et al. 2009). Agroforestry arrangements combining forage plants with shrubs and trees for animal nutrition and complementary uses, are known as silvopastoral systems (SPSs) (Murgueitio et al. 2011). The main SPSs include scattered trees in pastures, live fences, windbreaks, fodder-tree banks for grazing or cut-and-carry, tree plantations with livestock grazing, pastures between tree alleys and intensive silvopastoral systems (ISPSs).

The main benefits of SPSs compared with treeless pastures are: (i) increased animal production per ha (up to 4-fold) (Murgueitio et al. 2011); (ii) improvement of soil properties due to increased N input by N-fixing trees, enhanced availability of nutrients from leaf litter and greater uptake and cycling of nutrients from deeper soil layers (Nair et al. 2008); (iii) enhanced resilience of the soil to degradation, nutrient loss and climate change (Ibrahim et al. 2010); (iv) higher C storage in both above-ground and below-ground compartments of the system (Nair et al. 2010); and (v) improved habitat quality for biodiversity (Sáenz et al. 2007). ISPSs are a form of SPSs that combine the high-density cultivation of fodder shrubs (more than 8000 plants per ha) for grazing with: (i) improved tropical grasses; and (ii) trees or palms at densities of 100–600 per ha (Calle et al. 2012). In the 1970s, Australian graziers started sowing *Leucaena leucocephala* at high density integrated with grasses for grazing by cattle. There were about 150 000 ha of this highly productive system in 2006 (Shelton and Dalzell 2007). In Latin America, ISPSs are being adopted in Colombia, Mexico, Brazil and Panama (Murgueitio et al. 2011).

Owing to the positive interactions between grasses and trees (in particular N-fixing trees), SPSs produce more DM, digestible energy and crude protein (CP) per ha than grass-alone pastures and increase the production of milk or meat, while reducing the need for chemical fertilizers. Tree incorporation in croplands and pastures results in greater net C storage above- and below-ground (Nair et al. 2010). For SPSs, the above-ground C accumulation potential ranges from 1.5 t/ha/yr (Ibrahim et al. 2010) to 6.55 t/ha/yr (Kumar et al. 1998), depending on site and soil characteristics, the species involved, stand age and management practices (Nair et al. 2010).

Animals fed with tropical legumes produced 20% less CH_4 than those fed with C4 grasses (Archimède et al. 2011). Thornton and Herrero (2010) estimated that, by replacing some concentrates and part of the basal diet with leaves of *L. leucocephala*, the GHG emissions per unit of milk and meat produced were 43% and 27% of the emissions without the legume, respectively. The mitigation potential was 32.9 Mt CO_2-eq over 20 years, 28% coming from the reduction in livestock numbers, and 72% from C accumulation.

Despite their on- and off-farm benefits, SPSs are not widely established in the tropics and subtropics. The main barriers to adoption are financial capital barriers as SPSs require high initial investment, which is contrary to the prevailing view of tropical cattle ranching as a low-investment activity, and knowledge barriers, as the technical complexity of some SPSs requires specialized knowledge, which farmers often do not have (Murgueitio et al. 2011).

Economic analysis and environmental and policy implications

Adoption of improved forage-based livestock systems

Each of the principal forage-based livestock system alternatives has its environmental costs, benefits and impacts (Table 2). Some of these systems have been shown to reduce GHG emissions, while improving productivity (Fearnside 2002). However, the question remains why adoption of improved forage-based crop-livestock systems is low. Their adoption is related to the costs and benefits to the farmer and land, capital, labor and technology barriers, and depends also on a delicate balance between short-term benefits as a direct incentive (often market-related and in situ) and the long-term, usually environmental and often ex-situ, benefits. Thus, research on mitigation of climate change by forage-based livestock systems must address the trade-offs between the livelihood concerns of farmers, market- and value-chain-

Table 2. Principal forage-based livestock system alternatives: Environmental costs, benefits and impacts.

System/ technology/ option	Costs and benefits to the farmer			Costs and benefits to society		
	Livelihood benefits	Initial investment	On-going investment	Climate change mitigation impacts	Biodiversity impacts	Hydrological impacts
Native savannas	Limited by low productivity	Usually little initial investment	Usually little or none	Emissions or sequestrations depend on stocking rate and pasture degradation	Maintained species biodiversity	Increased runoff and soil erosion when overstocked
Business as usual (improved forage species but subsequent pasture degradation)	Higher animal production initially with decrease as pastures degrade	Seeds, land preparation, planting, fertilizer; overall large initial investment	Usually very low	Initial reduction in carbon stocks with land clearing, higher biomass in improved pastures	Reduction in species diversity due to monoculture planting	Increased runoff with overstocking; soil erosion
Improved and well-managed pastures	Higher stocking rate and higher animal productivity	Seeds, land preparation, planting, fertilizer; overall large initial investment	Fertilizer	Higher biomass in improved pastures; carbon accumulation in the soil	Reduction in species diversity with monocultures, but could have positive effects on soil fauna	Higher water demand; less runoff
(Agro-) Silvopastoral systems	Income from livestock; income in long-term from trees; higher productivity benefits from soil maintenance	Forage and tree seeds, nursery, land preparation, planting, fertilizer, fencing; overall large initial investment	Fertilizer (but reduced when N-fixing trees are used)	Carbon stocks increased from biomass in trees; carbon accumulation in the soil	Biodiversity benefits from trees (not great)	Less runoff, higher regulation of discharge, high water demand

related incentives, and societal and environmental considerations.

Livelihood considerations for farmers

The nature of livelihood benefits of forage-based systems for reducing GHG emissions and improving productivity depends very much on the context of the farm and the farmer (Table 2). For example, native savanna systems have low productivity, but require very little investment by the rancher. If land is abundant, there may be little incentive to improve these systems (White et al. 2001). A common alternative scenario is to replace native vegetation by introduced ("improved") forages, which are utilized for many years with little or no annual maintenance. After the initial investment at establishment, this system costs little, but pastures will degrade over time without annual investment in fertilizer, especially if they are overstocked, leading to soil degradation and loss of productivity. If the sown pasture is managed with applications of modest amounts of maintenance fertilizer, usually N and P, and with stocking rates that match pasture productivity, pasture systems can maintain productivity and reduce GHG emissions for many decades (Peters et al. 2013). More recently, SPSs combining trees and forages have received increased attention, because of their potential to improve productivity and reduce GHG emissions (Ibrahim et al. 2007), but the initial investments in these systems are substantial (see previous section).

Ex-situ environmental considerations

While improved forage-based livestock systems can improve productivity and mitigate GHG emissions, ex-situ environmental costs and benefits vary widely with respect to GHG emissions and impacts on biodiversity and water (Table 2). Unwise fertilizer use could result in downstream contamination of the watershed. Where farmers introduce improved pasture varieties and subsequently allow the pastures to degrade, C stocks are substantially reduced. Compared with degraded pastures, improved and well-managed systems have many positive benefits for the hydrological cycle, as they promote increased water holding capacity and reduce runoff and soil erosion (Peters et al. 2013). Silvopastoral systems improve soil quality, particularly when they involve N-fixing trees, provide shade for livestock, accumulate soil organic carbon, enhance biodiversity compared with monospecific pastures, and reduce runoff and soil erosion as they regulate the hydrological system (see above).

Carbon insetting

There are 2 types of carbon market: the regulatory compliance; and the voluntary markets. The compliance market is used by companies and governments that, by law, have to account for their GHG emissions. It is regulated by mandatory national, regional or international carbon reduction regimes. The voluntary market trades carbon credits on a voluntary basis. The size of these markets differs considerably. In 2008, the regulated market traded US$119 billion, while trades on the voluntary market were only US$704 million (Hamilton et al. 2009). Carbon insetting refers to any GHG emission reduction/carbon accumulation activity that is linked to the supply chain or direct sphere of influence of the company, which acquires or supports the insetting activity. Benefits are therefore directly transferred to actors of the chain including smallholder producers. This can take the form of credit trading or other forms of compensation or support for the insetting activity. Carbon-insets are intended to generate mutual benefits between the partners, that are additional to the climate change mitigation itself. On the other hand, carbon offsetting refers to compensation of GHG emissions outside the company's supply chain or sphere of influence, lacking additional benefits. For most food products, these GHG mitigation potentials are concentrated at the farm level. Integrating carbon credit purchases into a company's own supply chain, or carbon 'insetting' (vs. carbon offsetting), has multiple benefits. For farmers, it will improve animal productivity, increase adaptability to climate change and provide supplementary income. For companies, it will reduce the environmental 'hoofprint' of the livestock sector and enable companies to keep carbon mitigation activities within their own supply chain.

Political considerations for use of integrated crop-livestock systems in Brazil and Colombia

In Brazil and Colombia, as part of national policies, sustainable intensification of pasture/forage-based livestock production has been recognized as a means to contribute to mitigating GHG emissions. Improved forages and agroforestry systems are key strategies in these endeavors. Pathways include both increased C accumulation through reversing pasture degradation and maximizing accumulation through tree integration, as well as freeing land areas for conservation purposes and other agricultural uses.

Brazil

Brazil is the country with the largest forecast increase in agricultural output until 2050 (Alexandratos and Bruinsma 2012), but, in addition to this agricultural expansion, the country also aims to reduce deforestation in the Amazon by 80% and in the Cerrados by 50% of historic levels by 2020. The latest estimates indicate that Brazil is on course to reach this target, but there are doubts about the long-term sustainability of recent reductions. A major pathway for reaching these ambitious goals simultaneously is through the sustainable intensification of pasture lands (Strassburg et al. 2012). Native and sown pasturelands (189 Mha) comprise about 70% of Brazil´s area under agriculture (including forest plantations). These lands support 212 million cattle (IBGE 2011), offering substantial scope for increasing stocking rates. Improvements are also possible in herd management. For example, Brazil´s slaughter rate of 18% is the lowest among the top 20 beef-producing countries. The GHG mitigation potential of improving agriculture, in particular cattle ranching, has been recognized by the Brazilian government through its Low Carbon Agriculture Plan (*Plano ABC*, Table 3). The recuperation of 15 Mha of Brazil´s estimated 40 Mha of degraded pastures would supply two-thirds of planned mitigation activities in the agricultural sector. This estimate does not include the associated reduction in deforestation, which is forecast to mitigate an additional 669 Mt CO_2-eq. The ABC plan also has a target of increasing planted forests from 6 to 9 Mha and treating animal waste, the latter estimated to mitigate 6.9 Mt CO_2-eq.

Table 3. The Low Carbon Agriculture Plan (*Plano ABC*) in Brazil (Brasil 2011).

Action	Target area (Mha)	Associated mitigation (Mt CO_2-eq)
Recuperation of degraded pasturelands	15.0	83−104
Integration of crop-livestock-forest systems	4.0	18−22
Expansion of no-tillage systems	8.0	16−20
Biological nitrogen fixation	5.5	10

Colombia

In Colombia, currently 39.6 Mha of land are used for livestock production (34.7% of the Colombian territory), with an average of 0.6 animals/ha, while crops occupy 3.3 Mha (2.9%) (MADR 2011). The agricultural sector in Colombia contributes 7% of the national GDP, with livestock production contributing 1.6% (FEDEGAN 2012). Agriculture is responsible for 7.8% of national exports, the livestock sector for 0.64% (MinCIT 2012). The livestock sector is responsible for 17.6% of total national GHG emissions, while crops account for 18.9% (IDEAM 2010). The goal of the government is to reduce the area under pastures by almost 10 Mha by 2032, while increasing meat and milk production by 95.4% and 72.6%, respectively (FEDEGAN 2011). Major pathways identified for sustainable intensification of livestock production include reversing pasture degradation, enhancing pasture management, and introducing improved pasture and management systems such as silvopastoral systems as key strategies.

Future perspectives and overall synthesis

The livestock sector is important at the global scale, accounting for 40% of agricultural GDP, while at least 600 million of the world's poor depend on income from livestock production. However, livestock production is also a large source of GHG, with extensive ruminant systems producing more emissions, because they are less efficient in feed conversion than intensive feedlot systems and monogastric systems. Thus, shifting meat consumption from ruminant to non-ruminant systems could have environmental benefits (Wirsenius et al. 2010). A thorough analysis of the effects of livestock production, however, will need to contrast emissions with compensating factors such as C accumulation and reduction of N_2O emissions, especially in pastures. We argue that the environmental cost of feed production from different livestock systems would need to be analyzed through inclusive life-cycle analyses (de Vries and de Boer 2010; Pelletier et al. 2010; Thoma et al. 2013). For example, assessments of grain-based feedlots must account for the whole GHG cost of the feed supplied and the analysis should also take into account that forages are often produced on land less suitable for crop production (Peters et al. 2013).

As described in examples from Brazil and Colombia, sustainable intensification of pasture-based livestock production is being implemented as a major strategy to mitigate GHG impacts and reduce GHG emissions per unit livestock product (Bustamante et al. 2012). Thus, sustainable intensification of forage-based systems is critical to mitigate GHG emissions from livestock production, while providing a number of co-benefits, including increased productivity, reduced erosion, improved soil quality and nutrient and water use efficiency. The international community would need to pay much greater attention to forage-based livestock systems, if a reduction of GHG emissions in agriculture is the goal, considering that more than 70% of agricultural land is covered by these systems. In our view, ignoring the importance of forage-based systems may leave 50−80% of the mitigation potential of agriculture untapped (Peters et al. 2013). This also needs to be seen in the context of human nutrition. Reduced consumption of animal products may be desirable in rich countries, but from a nutritional and socio-cultural standpoint, it is probably not an option for countries where consumption is currently low (Anderson and Gundel 2011).

Further research is required in both the biophysical and socio-economic fields to:

- Assess in detail the carbon accumulation potential of forage-based systems. There is very limited information on the long-term accumulation potential. Few studies such as by INRA-CIRAD in French Guiana (Blanfort et al. 2010) and Corpoica-CIAT in Colombia (G. Hyman and A. Castro, unpublished results) suggest that C may accumulate over a longer time span and at a greater soil depth than previously expected. Guianese tropical grasslands are capable, under certain conditions, of compensating partly for the loss of soil carbon caused by deforestation.
- Quantify differences between well-managed and degraded pastures in their capacity to accumulate C and determine the role of legumes and trees in further improving the potential for C accumulation.
- Analyze trade-offs between C accumulation in soil and N_2O emission in grass alone, grass-legume and grass-legume-tree associations, and determine the role of soil fauna (e.g. earthworms) and flora in GHG balance and improvement of soil quality. Use Brazil and Colombia as examples to stimulate policy influencing mitigation of GHG emissions in other tropical countries.
- Estimate the impacts of forage-based systems as either trade-offs or win-win-win options for productivity, food security and environmental benefits at different scales (from plot to farm to landscape to globe), and compare them with alternative scenarios.
- In this context, assess direct economic benefits for farmers through product differentiation of environmentally friendly products (e.g. consumers paying premium prices for beef produced with low environmental impact).
- Develop payment-for-ecosystem-services (PES) schemes to stimulate optimization of pasture management.
- Target forage interventions to different farming systems, from extensive to semi-intensive, identifying entry points for each system.

In summary, there is a need for strategies that allow for reducing GHG emissions through sustainable intensification of forage-based systems to enhance productivity without compromising the ability of ecosystems to regenerate and provide many ecosystem services. We suggest that transformation of forage-based systems directed at these goals through enhancing eco-efficiency is essential for balancing livelihood and environmental benefits.

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Nitrogen management in grasslands and forage-based production systems – Role of biological nitrification inhibition (BNI)

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Abstract

Nitrogen (N), the most critical and essential nutrient for plant growth, largely determines the productivity in both extensive and intensive grassland systems. Nitrification and denitrification processes in the soil are the primary drivers of generating reactive N (NO_3^-, N_2O and NO), largely responsible for N loss and degradation of grasslands. Suppressing nitrification can thus facilitate retention of soil N to sustain long-term productivity of grasslands and forage-based production systems. Certain plants can suppress soil nitrification by releasing inhibitors from roots, a phenomenon termed 'biological nitrification inhibition' (BNI). Recent methodological developments [e.g. bioluminescence assay to detect biological nitrification inhibitors (BNIs) from plant-root systems] led to significant advances in our ability to quantify and characterize BNI function in pasture grasses. Among grass pastures, BNI capacity is strongest in low-N environment grasses such as *Brachiaria humidicola* and weakest in high-N environment grasses such as Italian ryegrass (*Lolium perenne*) and *B. brizantha*. The chemical identity of some of the BNIs produced in plant tissues and released from roots has now been established and their mode of inhibitory action determined on nitrifying *Nitrosomonas* bacteria. Synthesis and release of BNIs is a highly regulated and localized process, triggered by the presence of NH_4^+ in the rhizosphere, which facilitates release of BNIs close to soil-nitrifier sites. Substantial genotypic variation is found for BNI capacity in *B. humidicola*, which opens the way for its genetic manipulation. Field studies suggest that *Brachiaria* grasses suppress nitrification and N_2O emissions from soil. The potential for exploiting BNI function (from a genetic improvement and a system perspective) to develop production systems, that are low-nitrifying, low N_2O-emitting, economically efficient and ecologically sustainable, is discussed.

Resumen

El nitrógeno (N), el nutriente más crítico y esencial para el crecimiento de las plantas, es determinante para la productividad de las pasturas, tanto de tipo extensivo como intensivo. Los procesos de nitrificación y denitrificación en el suelo son los principales responsables de la generación de formas de N reactivo (NO_3^-, N_2O y NO) y, como consecuencia, de la pérdida de N y la degradación de las pasturas. Por tanto, la supresión de la nitrificación puede facilitar la retención de N en el suelo necesario para mantener, a largo plazo, la productividad de pastizales y sistemas de producción basados en forrajes. Algunas plantas pueden suprimir la nitrificación en el suelo mediante la liberación de sustancias inhibidoras desde sus raíces, un fenómeno llamado 'inhibición biológica de la nitrificación' (BNI, por su sigla en

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inglés). Metodologías recientemente desarrolladas, por ej., pruebas de bioluminiscencia para detectar inhibidores biológicos de la nitrificación (BNIs) en el sistema radicular de plantas, han permitido mejorar las posibilidades de cuantificar y caracterizar la función de BNI en gramíneas forrajeras. Dentro de las gramíneas, la más alta capacidad de BNI se ha encontrado en especies de ambientes bajos en N como *Brachiaria humidicola*, y la más baja en especies de ambientes altos en N como *Lolium perenne* y *B. brizantha*. Actualmente se conoce la identidad química de algunos BNIs producidos en tejidos de plantas y liberados en las raíces, igualmente su modo de acción inhibitoria sobre la nitrificación de las bacterias *Nitrosomonas*. La síntesis y liberación de los BNIs es un proceso altamente regulado y localizado, estimulado por la presencia de NH_4 en la rizósfera, lo que facilita la liberación de los BNIs cerca de los sitios de nitrificación en el suelo. En *B. humidicola* se ha encontrado una amplia variación genotípica en la capacidad de BNI, lo que abre un camino para su manipulación genética. Estudios a nivel de campo sugieren que las gramíneas del género *Brachiaria* reducen la nitrificación y la emisión de N_2O del suelo. Se discute el potencial de explotar la función de BNI, desde la perspectiva de mejoramiento genético y de sistema, para desarrollar sistemas de producción con baja nitrificación y baja emisión de N_2O, y que sean económicamente eficientes y ecológicamente sostenibles.

Introduction

Grass pastures are the largest land user, occupying 3.2 billion ha of the 4.9 billion ha of available agricultural land worldwide (Steinfeld et al. 2006). In addition, a significant portion of the cultivated land (0.5 billion ha) is used for growing forage grasses and feed-grain crops (e.g. sorghum, barley, maize and soybean) to support intensive livestock production (Steinfeld and Wassenaar 2007; Herrero et al. 2010, 2011). Mineralization of soil organic matter (SOM) is the major N source in extensive grassland systems. For intensive grass pastures, fertilizer N inputs can reach from 200 to 600 kg N/ha/yr, with only 30% recovered by plant protein and entering into the animal system, while the remaining 70% is lost to the environment in reactive N forms (i.e. NO_3^-, N_2O, NO) (Galloway et al. 2009). Nitrogen-use efficiency (NUE) in grassland systems (meat or milk protein produced/kg plant protein N intake) ranges from 5 to 10%, depending on whether milk or meat is the output (van der Hoek 1998). Grazing animals typically retain about 5% of the N intake (from the grass consumed) in their bodies and excrete the rest through urine (about 90% of the total N intake) and dung, which becomes an N source for the grass pasture (Worthington and Danks 1992). Much of this N, however, is lost through NO_3^- leaching and gaseous N emissions (N_2O, NO and N_2), causing ecological damage and economic loss (Tilman et al. 2002; Steinfeld and Wassenaar 2007; Herrero et al. 2011; Subbarao et al. 2013b).

N losses from agricultural systems impact the global environment and contribute significantly to global warming

Due to the development of high-nitrifying soil environments (where NO_3^- accounts for >95% of the plant N uptake), intensive pasture and feed-grain production systems have become extremely "leaky" and inherently inefficient (Subbarao et al. 2012); nearly 70% of the 150 Mt N fertilizer applied annually to global agricultural systems is lost through NO_3^- leaching and N_2O and NO emissions; annual economic loss from the lost N is estimated to be US$ 90 billion (Subbarao et al. 2013b). Fertilizer N use is projected to reach 300 Mt/yr by 2050 (Tilman et al. 2001) and N lost through NO_3^- leaching from agricultural systems could reach close to 61.5 Mt N/yr (Schlesinger 2009). Currently 17 Mt N is emitted as N_2O and this is expected to quadruple by 2100, due largely to an increase in the use of N fertilizers (Galloway et al. 2008).

Nitrification opens several pathways for N loss and weakens the soil N retention capacity in grassland systems

Nitrification, the biological oxidation of NH_4^+ to NO_3^-, opens several pathways for production of N_2O and NO, generated through nitrifier-denitrification or heterotrophic denitrification processes (Davidson and Verchot 2000; Zhu et al. 2013). Nitrification and denitrification are the major drivers for global emissions of N_2O, the most aggressive and powerful greenhouse gas, directly affected by human activity, with a global warming potential 300 times greater than that of CO_2 (Hahn and Crutzen 1982). As a cation, NH_4^+ is held by the negatively charged surfaces of clay minerals and SOM, that reduce the NH_4^+ loss by leaching. In contrast, the negatively charged NO_3^- does not readily bond to the soil, and is sufficiently labile to be leached out of the root zone. Nitrogen enters grass pastures primarily as N fertilizers (in intensive systems) or is derived from SOM-mineralization (in extensive systems) or hydrolysis of urea N from urine excreted from grazing animals, where NH_4^+ is produced either through SOM-mineralization-ammonification or urea hydrolysis, as the first product of inorganic N. Heterotrophic soil microorganisms convert NH_4^+ into microbial N, i.e. immobilization, and pasture roots and nitrifying bacteria compete for this NH_4^+ as an N source (Figure 1). Nitrogen flow into microbial immobilization or plant uptake is desirable. However, N flows into nitrification pathways generate reactive N forms (NO_3^-, N_2O and NO), that are not retained by the soil, and are lost to the environment, leading to the degradation of grassland systems.

Restricting the N flow to the nitrification pathway by inhibiting soil nitrifier activity facilitates NH_4^+ uptake by plants; this also allows N flow into the microbial pool (Hodge et al. 2000). The immobilization and mineralization loop of the N cycle dominates to keep soil N cycling within the system, and creates a slow-release N pool to sustain grassland productivity in such systems (Figure 1). Most plants have the ability to use NH_4^+ or NO_3^- as their N source (Haynes and Goh 1978; Boudsocq et al. 2012). Reducing nitrification rates in agricultural systems does not alter the intrinsic ability of plants to absorb N, but does increase retention time of N in the root zone as NH_4^+, which is less mobile and less energetically costly for uptake and assimilation than NO_3^-, providing additional time for plants to absorb N. Many of the advantages, associated with inhibiting nitrification to improve productivity and NUE of intensive grassland systems and feed-grain production systems, have been demonstrated using chemical nitrification inhibitors (Subbarao et al. 2006a; Dennis et al. 2012).

Biological nitrification inhibition (BNI)

The BNI concept

The ability to produce and release nitrification inhibitors from plant roots to suppress soil nitrifier activity is termed 'biological nitrification inhibition' (Figure 1).

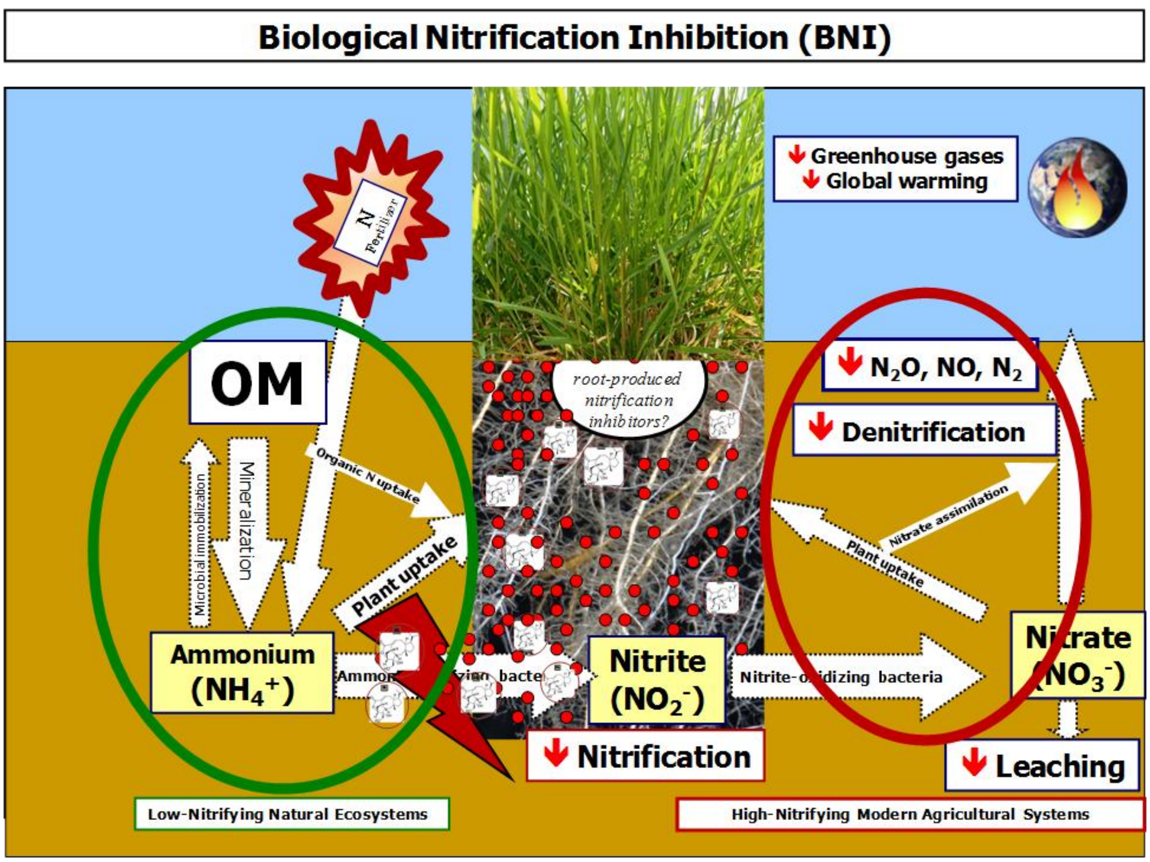

Figure 1. Schematic representation of the biological nitrification inhibition (BNI) interfaces with the N cycle. The BNI exuded by roots inhibits nitrification that converts NH_4^+ to NO_2^-. In ecosystems with large amounts of BNI (e.g. brachialactone), such as in *Brachiaria* grasses, the flow of N from NH_4^+ to NO_3^-, via NO_2^-, is restricted, and it is NH_4^+ and microbial N rather than NO_3^- that accumulates in the soil. In systems with little or no BNI, such as modern agricultural systems, nitrification occurs rapidly, leaving little time for plant roots to absorb NO_3^-; thus NO_3^- is lost from the system through denitrification and leaching; (adapted from Subbarao et al. 2012).

Nitrification largely determines the N-cycling efficiency (i.e. proportion of N that stays in the ecosystem during a complete N-cycling loop); the BNI function has the potential to improve agronomic NUE (Subbarao et al. 2012; 2013b). Recent modeling studies coupled with in-situ measures suggest that tropical grasses, which inhibit nitrification, exhibit a 2-fold greater productivity than those that lack such ability (Lata 1999; Boudsocq et al. 2012).

BNI characterization in pasture grasses

Recent methodological advances have facilitated the detection and quantification of nitrification inhibitors from intact plant roots using a recombinant *Nitrosomonas* construct (Subbarao et al. 2006b). Nitrification inhibitors released from roots measured as 'BNI activity', are expressed in ATU (allylthiourea unit) and this ability is termed BNI capacity (Subbarao et al. 2007b). Root systems of tropical pasture grasses showed a wide range in BNI capacity. *Brachiaria humidicola*, a grass adapted to low-N production environments of South American savannas, showed the greatest BNI capacity (range from 15 to 50 ATU/g root dry wt/d) (Subbarao et al. 2007b). By contrast, *Lolium perenne*, *B. brizantha* and *Panicum maximum*, that are adapted to high-N environments, showed the least BNI capacity (2−5 ATU/g root dry wt/d) (Figure 2). Sorghum is the only field crop that showed a significant BNI capacity (5−10 ATU/g root dry wt/d) among the cereal and legume crops evaluated (Subbarao et al. 2007b; 2013b).

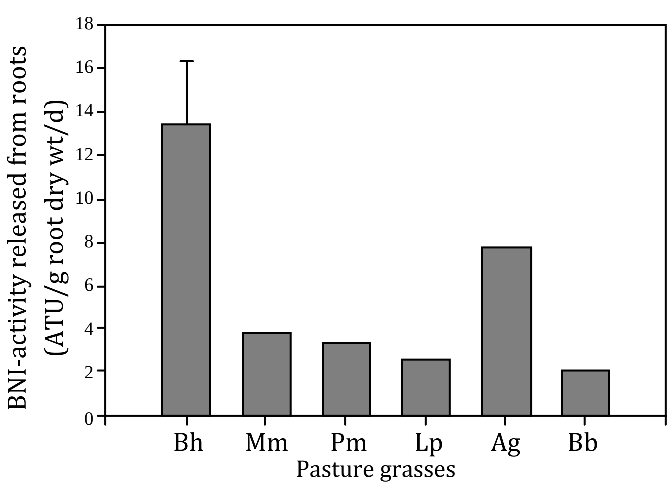

Figure 2. BNI activity released from intact roots of various pasture grasses grown in sand-vermiculite (3:1 v/v) culture for 60 days; Bh – *Brachiaria humidicola*, Mm – *Melinis minutiflora*, Pm – *Panicum maximum*, Lp – *Lolium perenne*, Ag – *Andropogon gayanus*, Bb – *B. brizantha*. Vertical bar represents LSD (0.05); (based on Subbarao et al. 2007b).

The BNI capacity of root systems arises from their ability to release 2 categories of BNIs: (a) hydrophobic BNIs; and (b) hydrophilic BNIs. These BNI fractions differ in their mobility in the soil and their solubility in water; the hydrophobic BNIs may remain close to the root as they could be strongly adsorbed on the soil particles, increasing their persistence. The mobility of the hydrophobic BNIs is via diffusion across a concentration gradient; thus this form is likely to be confined to the rhizosphere (Raynaud 2010; Subbarao et al. 2013a). In contrast, the hydrophilic BNIs may move further from the point of release due to their solubility in water, and this may improve their capacity to control nitrification beyond the rhizosphere (Subbarao et al. 2013a). The relative contributions of hydrophobic BNIs and hydrophilic BNIs to the BNI capacity may differ among plant species. For *Brachiaria* grasses, both fractions make equal contributions to the BNI capacity; for sorghum, the hydrophobic BNIs play a dominant role in determining the BNI capacity, whereas in wheat, hydrophilic BNIs determine the root system's inhibitory capacity (G.V. Subbarao and T. Tsehaye, unpublished data).

For *Brachiaria* spp., the amount of inhibitors released from root systems could be substantial. Based on the BNI activity release rates observed (17−50 ATU/g root dry wt/d) and assuming the average live root biomass from a long-term grass pasture at 1.5 t/ha (Rao 1998), it was estimated that BNI activity of 2.6 x 10^6−7.5 x 10^6 ATU/ha/d is potentially released (Subbarao et al. 2009a). This amounts to an inhibitory potential equivalent to that achieved by the application of 6.2−18.0 kg of nitrapyrin/ha/yr, which is large enough to have a significant influence on the functioning of the nitrifier population and nitrification rates in the soil. Field studies indicate a 90% decline in soil ammonium oxidation rates due to extremely small populations of nitrifiers (ammonia-oxidizing bacteria, AOB, and archaea, AOA, determined as *amoA* genes) within 3 years of establishment of *B. humidicola* (Figure 3). Nitrous oxide emissions were suppressed by >90% in field plots of *B. humidicola* compared with soybean, which lacks BNI capacity in its root systems (Subbarao et al. 2009a).

Chemical identities of BNIs and their mode of inhibitory action

The major nitrification inhibitor released from the roots of *B. humidicola* is a cyclic diterpene, named 'brachialactone' (Subbarao et al. 2009a). This compound has a dicyclopenta (a,d) cyclooctane skeleton (5-8-5 ring system) with a γ-lactone ring bridging one of the 5-membered rings and the 8-membered ring (Figure 4)

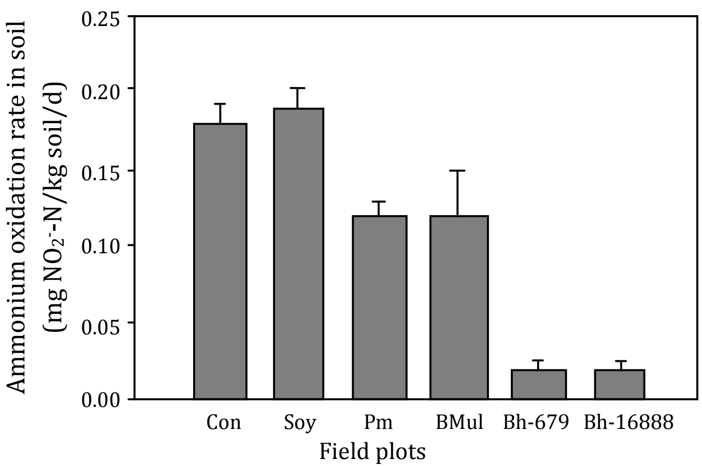

Figure 3. Soil ammonium oxidation rates in field plots planted to tropical pasture grasses (differing in BNI capacity) and soybean (lacking BNI capacity in roots); grasses: covering 3 years from establishment (September 2004−November 2007), soybean: 6 seasons of cultivation over 3 years. Con – control plots (plant free); Soy – soybean; Pm – *Panicum maximum*; BMul – *Brachiaria* hybrid cv. Mulato (apomictic hybrid that contains germplasm from *B. ruziziensis*, *B. decumbens* and *B. brizantha*, but NOT from *B. humidicola*); Bh-679 – *B. humidicola* CIAT 679 (standard cultivar Tully); Bh-16888 – *B. humidicola* accession CIAT 16888. Values are means ± s.e. of 3 replications; (adapted from Subbarao et al. 2009a).

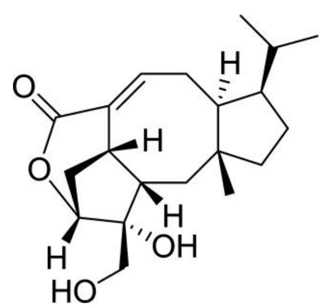

Figure 4. Chemical structure of brachialactone, the major nitrification inhibitor isolated from root exudates of *Brachiaria humidicola*; (from Subbarao et al. 2009a).

(Subbarao et al. 2009a). Brachialactone, with an IC_{80} of 10.6 µm, is considered one of the most potent nitrification inhibitors as compared with nitrapyrin or dicyandiamide (DCD), 2 of the synthetic nitrification inhibitors most commonly used in production agriculture ($IC_{80,}$ concentration for 80% inhibition in the bioassay, of 5.8 µm for nitrapyrin and 2200 µm for DCD). Brachialactone inhibits *Nitrosomonas* sp. by blocking both ammonia monooxygenase (AMO) and hydroxylamine oxidoreductase (HAO) enzymatic functions, but appears to have a relatively stronger effect on the AMO than on the HAO enzymatic pathway. About 60−90% of the inhibitory activity released from the roots of *B. humidicola* is due to brachialactone. Release of brachialactone is a regulated plant function, triggered and sustained by the availability of NH_4^+ in the root environment (Subbarao et al. 2007a; 2009a). Brachialactone release is restricted to those roots that are directly exposed to NH_4^+, and not the entire root system, suggesting a localized release response (Subbarao et al. 2009a).

Genetic improvement of BNI capacity of pasture grasses

Significant genetic variability (ranging from 7.1 to 46.3 ATU/g root dry wt/d) exists for BNI capacity in *B. humidicola*, indicating a significant potential for genetic manipulation of BNI capacity by conventional plant breeding (Subbarao et al. 2007b; 2009b). Recent findings suggest substantial genetic variability for brachialactone release among *B. humidicola* germplasm accessions, nearly 10-fold differences, suggesting the potential for breeding *Brachiaria* genotypes with high brachialactone capacity. Efforts are underway to develop molecular markers for brachialactone release capacity in *Brachiaria* spp.

Perspectives

Sustainable intensification of grasslands and feed-crop production systems is needed to meet the global demands for meat and milk, particularly in developing countries. As the demand for meat and milk is expected to double by 2050 (Herrero et al. 2009), there will be further efforts to intensify grasslands and feed-crop-based systems. Most increases in productivity are, however, achieved through massive inputs of industrially produced N fertilizer. Nearly 70% of the 150 Mt N applied to global agricultural systems is lost, largely due to the high nitrifying nature of soil environments (Tilman et al. 2001; Subbarao et al. 2013b). As nitrification and denitrification are the primary biological drivers of NO_3^-, N_2O and NO production (i.e. reactive N forms largely responsible for environmental pollution), suppressing nitrification is critical to reduce N losses and to retain soil N for longer periods in the grassland systems. The BNI function in forage grasses and feed-crops such as sorghum can be exploited using genetic and crop- and/or production system-based management to design low-nitrifying agronomic environments to improve NUE. In addition, the high BNI capacity in *Brachiaria* spp. can be utilized for the benefit of feed-crop systems such as maize, that receive most of the N fertilization but do not have inherent BNI capacity in their root systems. This could be achieved by integrating *Brachiaria* pastures with high BNI capacity and maize production using agro-pastoral systems (Subbarao et al. 2013b). In grazed grassland systems, most of the plant protein N is excreted by livestock (through urine) and thus returned to the soil. Grassland systems that retain N excreted by livestock are likely to maintain/sustain productivity over time. The BNI function could be most effective in controlling nitrification in grassland systems if genetically manipulated, either by conventional plant breeding or by genetic engineering. Most grasses develop extensive root systems and are perennial (Rao et al. 2011); if this is combined with high BNI capacity, these grassland systems can potentially suppress soil nitrifier activity to retain and use N more efficiently than at present. As grazing animals usually deposit urine and dung in a random, patchy manner, soil N is redistributed. The patchy distribution makes it difficult to control nitrification using synthetic nitrification inhibitors. The BNI function in forage grasses could be more effective in controlling nitrification to sustain system productivity and to protect these systems from degradation.

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Brazilian agroforestry systems for cattle and sheep

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Abstract

Agroforestry systems for animal husbandry in Brazil, including integrated crop-livestock-forest systems (ICLF), are very diverse, and present several technical, environmental and socio-economic benefits. For each of the country's 5 regions (Southeast, Central-West, North, Northeast and South) the prevailing agroforestry systems holding animals are presented, their potential and constraints discussed and research needs identified. In general, such systems are not broadly adopted, mainly because of their level of complexity compared with traditional systems, as well as some lack of understanding by farmers regarding their benefits. To change this situation, in the last 5 years, the Brazilian Government has allocated financial resources in terms of credit for development as well as for research and technology transfer addressing ICLF systems, including good agricultural practices and mitigation of greenhouse gas emissions. The goal is to improve competitiveness of the Brazilian agribusiness sector.

Resumen

Los sistemas agroforestales para producción animal, que incluyen sistemas integrados de cultivos, ganadería y árboles (ICLF, por su sigla en inglés), son bastante diversos en Brasil. Estos sistemas presentan varios beneficios técnicos, ambientales y económicos. Para cada una de las 5 regiones del país (Sureste, Centro-Oeste, Norte, Nordeste y Sur) se presentan los sistemas prevalentes de agroforestería con animales, se discuten su potencial y limitaciones y se identifican tópicos de investigación. En general, estos sistemas no han sido ampliamente adoptados por los productores, debido principalmente a su alta complejidad que dificulta su implementación comparados con los sistemas tradicionales, pero también por cierta falta de reconocimiento de sus beneficios por parte de los productores. Para cambiar esta situación, durante los últimos 5 años el gobierno de Brasil ha destinado recursos financieros para créditos, investigación y transferencia de tecnología hacia los sistemas ICFL, incluyendo buenas prácticas agrícolas y la reducción de emisión de gases con efecto invernadero para, de esta forma, mejorar la competitividad de la agricultura del país.

Introduction

Agroforestry systems are being used in all Brazilian regions (Southeast, Central-West, North, Northeast and South), with combination of several plant and animal species, using many arrangements of components in time and space. They can have many purposes and functionalities in only one system, usually focused on subsistence agriculture. In turn, the Brazilian ICLF systems (ILPF in Portuguese), have the tendency to be commercial operations. They usually encompass two or three components handled as mechanized plantations with rotation of crops and pastures using no-till systems (Macedo 2010; Balbino et al. 2011a). These systems allow high land use efficiency, with resulting technical, environmental and socio-economic benefits.

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Information about traditional cattle systems, integrated crop-livestock systems (without the tree component) and the evolution of studies with forage species and pastures in Brazil can be found in Ferraz and Felício (2010), Carvalho et al. (2010) and Euclides et al. (2010), respectively.

According to Costa et al. (2011), despite favorable environmental conditions and land availability in Brazil, sheep husbandry is not well developed in terms of total production or yields of meat and hides, when compared with countries like Uruguay, Argentina, New Zealand and Australia. About 54% of the flock in Brazil are hair sheep breeds, concentrated in the semi-arid environment of the Northeast (Table 1). The remainder are spread in the other regions, especially Rio Grande do Sul (southern Brazil) with 23% of the national flock. With a cattle herd of 212.8 M head (IBGE 2011), Brazil is one of the largest beef exporters in the world. Cattle ranching is spread throughout the country, being a very important economic activity. However, statistics for herd rearing in agroforestry systems are limited.

Official data indicate that only 10.7% of sown pasture areas are degraded, even though some authors indicate, in recent decades, that more than half of the sown pastures in Brazil are degraded to some degree, either in the Cerrado biome (Sano et al. 1999; Zimmer and Euclides 2000) or Rain Forest biome (Serrão et al. 1993).

According to Balbino et al. (2011b), Brazil has around 67.8 Mha of land suitable for different ICLF models, with no need for further clearing of areas of original vegetation. In 2010, it was estimated that a total area of 1.6 Mha was covered with specific ICLF systems, while the official census from 2006 indicated an area of 4.12 Mha with agroforestry systems holding cattle (Table 1).

In the context of livestock husbandry, ICLF systems display micro-climate improvement for grazing animals and have been adopted as alternatives for sown pasture reclamation, farm diversification and intensification. According to Zimmer et al. (2012), average beef yields on natural grasslands and sown, i.e. "improved" pastures under traditional management, are, respectively, 30 and 90 kg/ha/yr, while potential yields for improved pastures, either using traditional reclamation or adopting ICLF systems, are, respectively, 180 and 340 kg/ha/yr. This illustrates the substantial progress the Brazilian cattle industry can achieve in the next few years if ICLF systems are adopted to satisfy domestic and export demand for beef.

From an environmental perspective, ICLF systems with 250–350 eucalypt (*Eucalyptus* spp.) trees per hectare, designed for harvesting trees between 8 and 12 years, would yield 25 m^3 wood/ha/yr (Ofugi et al. 2008).This corresponds to an annual sequestration of around 5 t/ha carbon or 18 t/ha CO_2-eq, which would compensate for GHG emissions of 12 adult beef animals. However, due to the higher complexity of ICLF systems, their adoption remains limited, though growing in the last 5 years.

Availability of official credit for implementing ICLF systems from 2008, through the '*Programa de Produção Sustentável do Agronegócio* (*Produsa*)' (Sustainable Agribusiness Program), has attracted farmers to adopt these technologies. In 2009, from the commitment made at the COP-15, Copenhagen, the Brazilian Government created a program named ABC, '*Agricultura de Baixa Emissão de Carbono*' (Low Carbon Emissions Agriculture), with the goal of stimulating voluntary reduction of GHG emissions from the agricultural sector. This program makes available credit for reclaiming 15 Mha of degraded pastures, including implementation of ICLF systems on 4 Mha by 2020. Demand for professionals specialized in design and implementation of ICLF projects exceeds their availability and is a critical limit to development of such systems (Almeida et al. 2012b). The Brazilian Agricultural Research Corporation (Embrapa), together with some state research organizations, universities and private companies, has

Table 1. Cattle and sheep herds (data from 2011), areas of natural grasslands, sown pastures in good condition and degraded, and areas with agroforestry systems (AFS) holding cattle (data from 2006) per region.

Region	Cattle[1]	Sheep[1]	Natural grasslands[2]	Sown pastures[2]		AFS[3]
				Good condition	Degraded	
	M head (%)		M ha (%)			
Southeast	39.34 (19)	0.77 (4)	10.96 (19)	15.21 (17)	1.66 (17)	0.58 (14)
Central-West	72.66 (34)	1.21 (7)	13.81 (24)	41.87 (45)	3.36 (34)	0.56 (14)
North	43.24 (20)	0.63 (4)	6.00 (10)	18.70 (20)	2.20 (22)	0.61 (15)
Northeast	29.59 (14)	10.11(57)	16.03 (28)	12.34 (13)	2.24 (23)	2.15 (52)
South	27.99 (13)	4.95 (28)	10.84 (19)	4.39 (5)	0.45 (4)	0.22 (5)
Brazil	212.82	17.67	57.64	92.51	9.91	4.12

[1]Source: IBGE 2011; [2]source: IBGE 2006a; [3]source: IBGE 2006b.

focused on demonstrating the benefits of these systems in an endeavor to expand their promotion, through establishing Technology Reference Units (TRUs) in several strategic locations throughout Brazil. These demonstration fields are usually located on private farms, in a partnership arrangement. While serving as a demonstration, these TRUs are also used for technical and scientific observations for improving the systems, based on observations by farmers and scientists involved (Porfírio-da-Silva and Baggio 2003). In 2011 there were 194 TRUs in operation throughout Brazil (Balbino et al. 2011b; Almeida et al. 2012b). More recently, Embrapa and its national and international partners created the Pecus Network (www. cppse.embrapa.br/redepecus/) with the aim of studying integrated cattle production systems, comparing improved management techniques with traditional systems, reducing GHG emissions and increasing carbon sequestration in order to provide guidelines for official policies regarding the sector in Brazil.

The next sections will discuss integrated systems for animal husbandry in the 5 Brazilian regions, based on an array of economic, social and political peculiarities and their interactions with local conditions.

Southeast Region

The Southeast region encompasses the States of Espírito Santo, Minas Gerais, Rio de Janeiro and São Paulo, covering an area of 0.92 Mkm^2, representing 11% of the Brazilian territory. It is the most industrialized and richest part of Brazil. Its climate is predominantly tropical, with some areas having high-elevation tropical climate, subtropical and humid-coastal. The region usually has 2 well-defined seasons, one hot and rainy (Spring–Summer) and the other with little rain and lower temperatures (Fall–Winter). Tropical forest (Atlantic Forest) was the original dominant vegetation, which, as a result of deforestation, now occupies less than 10% of the original area.

The Southeast region has 27.8 Mha of pastures, supporting 39.3 M cattle and 0.7 M sheep (IBGE 2006a; 2011), and has a well-developed and diversified agribusiness sector. Cattle production, especially dairy, is important in the region. It was originally based on *Melinis minutiflora* and *Hyparrhenia rufa* pastures, which were later replaced by *Brachiaria* and *Panicum* grasses, which dominate the grazing systems in the area. The first integrated systems in the region were non-systematic, mainly through cattle grazing in eucalypt plantations held by commercial afforestation companies at the end of the1970s and early 1980s (Garcia and Couto 1997). In such systems, cattle grazing reduced implementation costs and helped to control understory vegetation, reducing fire risk in the establishment years. From the 1990s onwards, research on actual silvopastoral systems, in which tree and cattle components were intended to co-exist in the system during its whole productive cycle, was intensified. In both systems, the main tree species used were from the genera *Eucalyptus* and the closely related *Corymbia*, while *Brachiaria* was used for pastures. At that time, a pasture shading model was started, using leguminous tree species to reduce in-loco temperatures and therefore to reduce heat stress on animals. This would also contribute nutrients to the system, especially nitrogen, through biological fixation of atmospheric N by these species. In the long term, improving soil fertility would improve yields and the better pasture would reduce soil exposure, promoting pasture sustainability (Carvalho et al. 2001).

Systematically including a crop component in the model, characteristic of ICLF systems, happened only in the late 1990s, mainly using maize, sorghum, rice or soybean integrated with *Eucalyptus* spp. and *Brachiaria* spp. Adoption of integrated systems had been limited by scarce resources for implementation as well as by the small number of qualified professionals for technical advice. The high initial investment problem has been solved by availability of financial resources through federal and state credit policies for the sector. In parallel, regular training opportunities for agriculture-related professionals, through continued education and courses, have improved the availability of technical advice in the area. Such initiatives are starting to show results, as demonstrated through the increasing numbers of integrated systems implemented in different parts of the Southeast region. The model, using eucalypt tree plantations, cultivated in rows 10–20 m apart over *Brachiaria* spp. pastures, with or without integrating annual crops, has expanded over traditional grazing areas. For beef production, the cattle breed is usually Nelore, whereas for dairy, a crossbred Holstein x Zebu cow is mostly used.

With integrated systems, competition for light, nutrients and water increases as trees grow. Degree of shading on understory species progressively increases, causing morphological and physiological changes in the forage. Intense shading, usually eliminating more than 50% of photosynthetically active radiation, drastically reduces forage yields from pastures, endangering their persistence and therefore the sustainability of the system (Paciullo et al. 2010). For this reason, management strategies for the tree component must allow only moderate reduction of radiation incidence on pastures. When using *Eucalyptus* spp., the most convenient distances between tree rows result in densities from 150 to 450 trees per hectare. One must also consider aspects like: tree component purpose (timber, fodder, shade/shelter); local relief characteristics, especially slope; machinery specifications when cultivating crops integrated with pasture; and finally on-farm management (paddock sizes, erosion control).

If the main goal is to produce higher quality timber (added value), a lower tree density is recommended (150–300 trees/ha) in single rows. On the other hand, higher densities using partial thinnings (4–5 years, 8–9 years and 12–15 years) to allow higher radiation into the understory allows for financial income every 4 years. Regarding animal production, results have been satisfactory. Managed pastures in silvopastoral systems, with little or no fertilization, have shown carrying capacities from 1.5 to 2.5 AU/ha, weight gains of 0.5–0.7 kg/animal/d and beef production of 200–350 kg/ha/yr (Bernardino et al. 2011; Paciullo et al. 2011). Some studies have shown that efficient fertilization can be carried out with moderate doses under moderate shading (Andrade et al. 2001; Bernardino et al. 2011). However, despite the growing adoption, the total area under these systems is still modest, when compared with the potential they have to improve agribusiness in the Southeast region.

Central-West Region

The Central-West region, or Central Brazil, is composed of the States of Goiás, Mato Grosso, Mato Grosso do Sul and the Federal District. The total area is 1.61 Mkm^2, representing 19% of the Brazilian territory, with an economy based essentially on agricultural activities. Having mostly a tropical climate with some subtropical areas in the southern part of the region, it has the largest cattle herd in Brazil with 72.6 M head and 1.2 M sheep, on a grazing area of 59 Mha (IBGE 2006a; 2011). The common cattle husbandry systems are dual-purpose and beef, with a predominance of Zebu cattle, especially the Nelore breed. Goiás State shows the most developed dairy systems of all states in the region.

The region has 3 major biomes: Pantanal, Rain Forest and Cerrado (savanna). The Pantanal biome is a floodable plain covering about 15% of the region. Its cattle systems are traditionally extensive cow-calf operations on natural grasslands, resulting in low production coefficients. In some non-flooded areas, *Brachiaria* spp. are sown for pasture.

In the Rain Forest biome in Central Brazil, the development of agroforestry systems for cattle is similar to those in Northern Brazil. Main forage used are *Brachiaria* species (*B. brizantha*, *B. decumbens* and *B. humidicola*) and, to some extent also *Panicum maximum* (cvv. Tanzânia, Mombaça and Massai). Grass-legume mixed pastures contain mostly *Pueraria phaseoloides* as the legume species (Teixeira et al. 2000).

The Cerrado biome, with a savanna type vegetation, covers over 50% of the region. Cattle systems are more variable. Integrated systems are predominantly associated with no-till crop systems mostly growing soybean, maize, sorghum and rice. The most used trees in these systems are from the genera *Eucalyptus* and *Corymbia*. According to Macedo (2005), the predominant forage species, ranked by area, are: *Brachiaria decumbens* (55%), *B. brizantha* (20%), *Panicum maximum* (12%), *B. humidicola* (9%) and others (4%). In transition areas between Cerrado and Rain Forest, silvopastoral systems usually have a greater variety of trees, using either native (*Schizolobium amazonicum*, *Swietenia macrophylla*, *Astronium fraxinifolium* and *Hevea brasiliensis*) or introduced (*Tectona grandis*, *Ochroma pyramidale*, *Khaya ivorensis*, *Acacia mangium* and *Azadirachta indica*) species.

Under ICLF systems, crops are grown between tree rows for the first 2 or 3 years, so that trees can grow strong enough to tolerate animal browsing. Crops are then replaced by pastures until tree harvesting. Pasture production decreases with increased shading caused by trees; however, with densities from 227 to 357 trees per hectare, stocking rates range from 1.3 to 1.8 AU/ha, weight gains from 0.4 to 0.7 kg/animal/d and beef production from 130 to 245 kg/ha/yr (Almeida et al. 2012a; 2012b).

Silvopastoral systems are usually used in areas with limitations for grain crops, like poor soils, unfavorable climate, inadequate infrastructure and logistics.

With regard to research, there were only few experiments involving ICLF systems in Central Brazil until the early 2000s (Daniel et al. 2001); thus guidelines were based on studies carried out in Southeast Brazil. Looking at future research and technology transfer demands, the formal research group '*Sistemas de produção sustentáveis e cadeias produtivas da pecuária de corte (GSP)*' (Sustainable production systems and beef cattle value chains) from Embrapa Beef Cattle, carrying out research in the Cerrado biome (Zimmer et al. 2012), has identified the following needs: (1) to evaluate new forage grass options adapted to shading under ICLF; (2) to evaluate forage legume options aiming to interrupt the cycle of parasites and diseases, while improving nitrogen fixation, reducing production costs and improving animal diets, with emphasis on yield; (3) to select tree species to broaden options beyond eucalypts; (4) to develop cultivation strategies to allow tree planting while retaining pastures, without sowing grain crops, when local conditions are unsuitable for planting a grain crop or farmers are unwilling to sow one; (5) to expand experiments with extensive dairy and sheep production; (6) to improve assessments of carbon balance and life-cycle analysis of products from ICLF systems; (7) to improve long-term experiments in strategic locations, in order to evaluate carbon dynamics and soil quality changes; (8) to expand technology transfer initiatives and assessment of economic aspects of ICLF systems, especially on commercial farms in different areas; and (9) to establish a strategic zoning for different ICLF systems, considering soils, climate and existing infrastructure.

North Region

The North region covers the States of Acre, Amapá, Amazonas, Pará, Rondônia, Roraima and Tocantins, and is the largest area, with 3.86 Mkm^2 (45% of the national territory). As the region with the lowest population density, it is currently the Brazilian agricultural frontier. An equatorial climate is predominant, and Amazon or Equatorial Rain Forest covers 90% of the surface, with some fragments of Cerrado. Pastures occupy 26.9 Mha, carrying 43.2 M cattle and 0.6 M sheep (IBGE 2006a; 2011).

Most of the research on silvopastoral systems in Northern Brazil involves isolated and incremental studies to: (1) select forage species tolerant of shading; (2) identify promising native tree species for silvopastoral systems; (3) broaden knowledge on selected native tree species; (4) evaluate introduced tree species like eucalypts (*Eucalyptus* spp.), teak (*Tectona grandis*), African mahogany (*Khaya ivorensis*) and Indian neem (*Azadirachta indica*); and (5) evaluate certain interactions among system components, especially tree-forage-soil.

As a whole, there is a lack of studies about productive and reproductive performance of animals in these systems, especially long-term, multi-disciplinary studies carried out in mature silvopastoral systems.

Despite advances in the last 15–20 years, silvopastoral and ICLF systems can still be considered developing technologies in Northern Brazil. For this reason, adoption levels are still low and a series of technical and socioeconomic hindrances have been identified (Dias-Filho and Ferreira 2008): (1) the need for relatively high initial investments with tree plantation and cultivation practices; (2) low turnover, with low initial profitability (first 3–4 years); (3) higher intrinsic complexity of integrated systems, demanding more commitment and higher level of knowledge regarding tree species and future market prospects for tree products; and (4) farmers' incomplete perception regarding benefits of silvopastoral systems beyond shading for cattle.

The most common silvopastoral system in Northern Brazil is the scattered trees on pastures model, usually with native trees from natural recovery. This happens because shading is the major motivation for farmers to have trees on pastures, since local high temperatures and humidity cause remarkable thermal stress on cattle, especially crossbreds with higher European content. In this region, potential losses in milk production caused by thermal stress range from 10 to 20% in cows yielding 15 L/d (INMET 2012). In the Cerrado pockets in the Northern region, integrated systems follow the patterns used in Central Brazil.

Northeast Region

The Brazilian Northeast encompasses the States of Alagoas, Bahia, Ceará, Maranhão, Paraíba, Pernambuco, Piauí, Rio Grande do Norte and Sergipe, with a total area of 1.55 Mkm^2 or 18% of Brazil. From that, 0.96 Mkm^2 are located in the semi-arid zone of the country. Pastures occupy 30.6 Mha, of which 52% is natural grasslands, supporting a total of 29.6 M cattle, 10.1 M sheep and 8.5 M goats (91% of the national goat herd) (IBGE 2006a; 2011).

The predominant climate is hot semi-arid with annual rainfall ranging from 400 to 650 mm, and irregular precipitation, with dry periods up to 8 months per year. Sometimes the dry season can be even longer; this phenomenon is cyclical and can occur from once in 3 years to once in 10 years. Caatinga is the main vegetation type, composed of a variety of xerophytic plant types including monocots and dicots, and from thorny woody species to succulents (Araújo Filho 2006). Average biomass production in Caatinga is 4 t DM/ha/yr, of which only 10% is considered edible forage. Animal and plant production systems are diversified, with cattle usually kept along with sheep and goats. In cropping areas, subsistence agriculture is carried out, with animals grazing crop residues. In the traditional systems, 'slashing and burning' of native vegetation for establishing new cultivation areas, as well as overgrazing of natural grasslands, has caused negative impacts on the ecosystem, increasing the area undergoing degradation and desertification (Carvalho 2006).

Production systems based on agroforestry have been proposed as an alternative to the traditional model. The goal is to ensure both ecosystem stability and sustainability of agricultural production by means of adapted land use practices in this difficult environment. The agrosilvopastoral system proposed aims to stabilize agriculture, efficiently use native vegetation as forage and rationalize wood extraction in an integrated and diversified way (Araújo Filho et al. 2006). Strategies for reaching these goals start by eliminating fire and complete deforestation. Next, tools for forage budgeting are used to adjust stocking rate and, finally, a systematic pruning management of native trees is proposed to exploit local wood and timber potential. The resulting system is composed of 3 modules: crop, pasture and forest.

Selective thinning of forest occurs instead of complete land clearing, with 10–15% of the area kept mainly with native trees (Araújo Filho et al. 1998a). Subsequently, bush/tree species, mainly *Gliricidia sepium* and *Leucaena leucocephala*, are planted to be used as green manure in the rainy season. They are combined with crops like maize, beans, sesame, cotton, castor bean and sorghum. Legume trees are kept low and their canopy, at the end of the rainy season, can be used as hay for animal feeding. From the second year, these legumes can be browsed by sheep and goats at the beginning of the dry season. With forest thinning, available understory forage vegetation increases and can be grazed after crop harvesting at the end of the rainy season. In the dry season the grass component and crop residues on the area can be grazed. The crop component, therefore, contributes to both plant and animal production.

The pasture component is a Caatinga area where 30–40% of the tree cover is kept, varying according to the floristic composition. The maximum level of utilization of the pasture allowed is 60%. Knowing the floristic composition is essential for setting the management plan, which might estimate stocking rates based on forage availability. This is important to avoid degrading the forage potential of native grasslands. Forest thinning as a management strategy for Caatinga can increase the amount of forage available to grazing animals from 10 to 90% (Araújo Filho et al. 2002). As a strategy to improve forage production, perennial grass species like *Cenchrus ciliaris*, *Urochloa mosambicensis* and *Panicum maximum* cv. Massai, can be introduced, producing up to an additional 3 t of forage per ha. Stocking rates have varied from 0.5 to 3 ha per adult sheep or goat. Areas combining thinning with improved grasses show the highest carrying capacities.

The forest component is the original Caatinga vegetation itself. Some species with timber potential are cut in 7-year average cycles and can be used either for timber or forage (Carvalho et al. 2004). This forest area can be used for grazing during the dry season (Araújo Filho et al. 1998b). The basis of agrosilvopastoral systems for the Caatinga is manipulating the woody component to allow development of the understory. This procedure is still done by hand, for both the system implementation and maintenance, so one of the major limitations for such systems is rural labor scarcity (Campanha et al. 2010). As a possible solution, there is a current trend of developing appropriate machinery for mechanizing this activity, specific to Caatinga conditions, including its topography. These machines must be able to cut trees and regrowth bushes as well as grinding their branches and stems, reducing demand for labor.

Seeding and crop maintenance are also carried out manually. The fact that this model precludes the use of herbicides and chemical pesticides increases the need for labor. Mechanization of activities and the use of biological pest control and plant-based products to restrain growth without eliminating native grasses, can help solve the labor problem.

In animal production the use of plant-based products is recommended for control of the main diseases, especially worms. In the integrated system, this problem is more acute in goats than sheep (Campanha et al. 2010), making sheep husbandry more viable than dairy goats. The latter represent a very interesting option to ensure a quick return on investment. In the semi-arid region, this activity is currently included in several governmental programs; thus, it should not be left aside as an option for the system. To succeed, farmers must have some previous experience with dairy animal management, in order to avoid sanitary problems, which mostly affect the system's economic viability.

Adjusting stocking rates through grazing management is also a challenge (Campanha et al. 2010). It is important that, when working with the native grass components, local forage resources are known, in order to make stocking rate adjustments based on both quality and quantity of biomass. Basing decisions only on biomass quantity can lead to degradation through overgrazing of highly palatable forage species, leaving behind the less palatable ones. Establishing a workable grazing management policy, with well-defined grazing and resting periods, is crucial for this kind of system.

There is also a need to make better use of the timber potential of some native Caatinga species that are part of the system's forest component.

Since these systems present some differentiated characteristics like sustainable use of natural resources, family labor and traditional goods, costs are higher and yields are lower, making it difficult to compete in the regular market with conventional products from the area. Therefore, it is necessary to better explore specific market niches like fair trade and organic product markets, adding value to goods coming from such production systems. Another important aspect is the need for an environmental services compensation policy. At least 3 services from the system can be identified: plant biodiversity; carbon sequestration; and organic matter deposition in the soil (Aguiar 2011).

In short, agrosilvopastoral systems for the Brazilian semi-arid areas are a group of aggregated technologies aiming at sustainable plant and animal agriculture. These technologies can be grouped according to the 3 components:

- Crop component: no burning, improved maize and sorghum varieties adapted to the area, crops for biodiesel production, environmental service as biodiversity preservation and organic matter deposition, no-tillage seeding.
- Cattle component: sustainable management of

Caatinga vegetation through management of the woody component for animal grazing, use of locally produced low-cost supplements (e.g. sorghum silage, crop residues and protein-forage reserves).

- Forest component: *Mimosa caesalpiniifolia* ('*sabiá'*) management for wood and forage production.

Agrosilvopastoral systems in the Brazilian semi-arid areas, despite their technological challenges, have been adopted mainly by rural communities, whose production model is based on agroecological principles and land redistribution projects. Such communities adhere to the basic principles of the model, like no use of fire, selective cutting of tree species and preservation of gallery forests. Additionally, these communities have inserted some new elements into the system, expanding product diversity through growing different traditional crops like cassava, castor bean and melons and harvesting wild honey.

These systems are evolving; the basic principles are well defined. Therefore it is necessary to solve minor technical hindrances and focus on broader aspects, involving policies and markets, so that the full potential of agrosilvopastoral systems in the semi-arid areas can generate better living conditions for the significant population in this part of Brazil.

South Region

The Brazilian Southern region encompasses the States of Paraná, Rio Grande do Sul and Santa Catarina, and covers 0.58 Mkm^2 (7% of the national territory), being the second most developed region in the country and the one with the largest Human Development Index (HDI). It keeps about 13% of the Brazilian cattle herd and 28% of the sheep flock, with pastures covering around 16 Mha (IBGE 2006a; 2011). In Rio Grande do Sul and Santa Catarina, natural grasslands constitute more than 80% of the total pasture area. Climate varies from tropical to humid subtropical, with a predominance of the latter. Vegetation is characterized by tropical forests at the coast and subtropical forests in the inland. In the southern part, the biome is called *Campos Sulinos* (Southern Plains, a grass-bush steppe). Cattle in this region enjoy a good level of herd management; however, production is still less than its technical potential because of limiting factors like seasonal feed deficiency and pasture degradation.

In Southern Brazil, Paraná State has the longest record of silvopastoral systems, especially in beef cattle operations. The main driver for their adoption is the beneficial presence of trees on pastures, serving as shelter for cattle and reducing frost effects on the forage in colder months (Ribaski et al. 2012).

Other initiatives developed in the region, particularly in Rio Grande do Sul, emphasize silvopastoral systems as an important strategy for sustainable rural development. At the *Campos Sulinos*, forage production of tropical and subtropical grasses is markedly seasonal. This kind of vegetation has a major influence on the socio-economic life of farmers, due to its importance as a forage source for their cattle and sheep herds plus other livestock species (Coelho 1999). However, natural fragility of soils, together with their low suitability for crops, as well as traditional land use for extensive cattle ranching, has accelerated erosion, leading to a gradual increase of areas with scattered vegetation and large bare areas with sandy soils. These environmental losses have had negative impacts on socioeconomic conditions, leading to a decline in farmers' livelihoods. Sustainable development in the area has been the subject of several studies and there is consensus on the need to diversify the local production matrix, in order to improve income of the productive sector. The use of silvopastoral systems has been seen as an important strategy for sustainable land use, and also as a new source of added value for farmers through wood production (Ribaski et al. 2012).

Conclusion

Despite many benefits from ICLF systems for cattle production and availability of appropriate technologies, there are still limiting factors for their broader adoption in Brazil, especially related to research, technology transfer, capacity building and credit availability. However, in the last 5 years, the Brazilian Government has strongly invested in these aspects, aiming to overcome the above limitations. Implementation of research on those issues raised as priorities will improve the likelihood of increased adoption of these production systems.

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Technical challenges in evaluating southern China's forage germplasm resources

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Abstract

The present status of the collection, preservation and utilization of pasture germplasm in tropical and subtropical zones in China is reviewed. The Tropical Pasture Research Centre (TPRC) of the Chinese Academy of Tropical Agricultural Sciences (CATAS) has been engaged in this research since the 1940s. A low-temperature gene bank, an in-vitro plant library and a nursery station have been established. In total, 5890 indigenous fodder accessions belonging to 478 species, 161 genera and 12 families have been surveyed and collected in South China; 1130 exotic accessions belonging to 87 species and 42 genera of grasses and legumes have been introduced and are preserved. In the seed bank, 3769 accessions from 301 species, 127 genera and 12 families are maintained; in the form of in-vitro culture, 482 accessions belonging to 6 species, 6 genera and 3 families are preserved; and in the plant preservation nursery 388 accessions belonging to 10 species, 8 genera and 3 families. A list of 12 forage legume and 9 grass cultivars released by CATAS during 1991-2011 is presented and suggestions are made for developing and utilizing southern Chinese grassland germplasm resources.

Resumen

Se hace una revisión del estado de la colección, conservación y utilización del germoplasma de forrajes en las zonas tropical y subtropical de China. Desde la década de 1940, el Centro Tropical de Investigaciones en Pastos (TRC, por su sigla en inglés) de la Academia China de Ciencias en Agricultura Tropical (CATAS, por su sigla en inglés) ha estado dedicado a las investigaciones en pastos y forrajes tropicales y subtropicales. Se han establecido un banco de germoplasma para preservación de semillas a baja temperatura, facilidades para la preservación in vitro y facilidades para el mantenimiento de colecciones vivas a nivel de invernadero y campo. En el Sur de China se han hecho exploraciones botánicas y se recolectaron en total 5890 materiales forrajeros nativos pertenecientes a 478 especies, 161 géneros y 12 familias; además, 1130 accesiones exóticas pertenecientes a 87 especies y 42 géneros de gramíneas y leguminosas fueron introducidas y están siendo preservadas. En el banco de semillas se están conservando 3769 accesiones de 301 especies, 127 géneros y 12 familias. La colección conservada en forma de cultivos in vitro comprende 482 accesiones pertenecientes a 6 especies, 6 géneros y 3 familias, y la de plantas vivas mantenidas en invernadero o campo comprende 388 accesiones pertenecientes a 10 especies, 8 géneros y 3 familias. Se presenta una lista con cultivares de 12 leguminosas y 9 gramíneas forrajeras liberadas por CATAS durante 1991-2011 y se hacen algunas recomendaciones para el desarrollo y la utilización de los recursos forrajeros en el Sur de China.

Introduction

China's tropical and subtropical zones are located between 15° and 33° N and 100° and 125° E. The region has 121 M people, 13% of the total population in China (Liu et al. 2008) and covers 260 Mha, including: the entire areas of the Provinces of Guangdong, Hainan, Guangxi, Hunan and Fujian; most parts of Yunnan, Guizhou, Jiangxi, Zhejiang and Sichuan; the southern area of Hubei and Anhui; and small districts of southeast Tibet and southwest Jiangsu Province. The tropical area accounts for 5% of the South China zone, predominantly in the southern district of Guangdong (Leizhou Peninsula) and all of Hainan Province. Arable land occupies 28 Mha (10.7% of the region), forests 90 Mha (34.6%) and grasslands 79 Mha (30.4%).

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Tropical China is a warm climate area with plentiful rainfall without an obvious winter and separate wet (generally May–October) and dry seasons. The range of average annual rainfall in the region is 1200–2500 mm, the average annual temperature 20–26 °C and the accumulated temperature above 10 °C is 7900 degree days. It is more mountainous in the northern and western areas, with upland and river plain topographies in the coastal areas of the southeast. The mountainous and upland area covers more than 30% of the region and is unsuitable for cash crops except forage production. Forage plant resources are abundant in cleared areas. The current status of vegetation is secondary forest (coniferous, broad-leaf, shrubland and coppiced forests), grassland and agricultural land. The grasslands include savanna, shrubland, coppiced forest and arable land sown with exotic legumes and grasses. Most of the grasslands are distributed in small areas belonging to smallholder farmers, with a potential for forage intercropping with cash crops, rubber and fruit tree plantations. Most of the tropical and subtropical regions of South China experience good climatic conditions with enough heat and water to support good growth of forage plants. Despite the degradation resulting from fire, overgrazing and cutting of vegetation for fuel and organic matter input for cropland, native plants with forage potential remain a valuable resource.

This paper reviews the scale of forage plant resources in southern China and the programs to identify, evaluate and utilize these forages, and concludes with a discussion of current issues and possible solutions.

Surveys of tropical and subtropical forage genetic resources

In the past 50 years, 6707 forage and feed plant species belonging to 1545 genera in 246 families were surveyed. During 1978–1990, the Chinese Academy of Agricultural Science (CAAS) collected: 4125 species of natural forages for possible cultivation and breeding, belonging to 879 genera within 127 families; 972 species from 173 grass genera; and 646 species from 81 legume genera. The species came from Hainan (1067), Guangdong (482), Yunnan (698), Guizhou (1400), Sichuan (232), Jiangxi (733), Anhui (255) and Hubei (931). In 1980, the National Grassland Survey identified more than 1000 species belonging to 190 grass genera, and 791 species belonging to 120 legume genera on natural grassland areas of the 14 southern provinces (Flora of Hainan 1979; Flora of Fujian 1995; Flora of Yunnan 2003; Flora of Guangdong 2007).

In South China, there are 4680 known species with forage potential (Table 1), mostly dicotyledons. The most highly regarded potential forage plant resources in South China include 687 species (“productive species” in Table 2), among them 364 grass species and 87 legume species. Among these indigenous species, 354 species are endemic, including 67 grass and 45 legume species; some are already used for livestock production (Wu 1961; Liu 2000). The variable topography and climate in Hainan Island have produced a very large number of tropical species within the rich Chinese flora, composed of 25 000 species of higher plants. CAAS first surveyed the indigenous forage plant resources in 1983, and recorded 119 species (Li 2000; Shi et al. 2008). Hainan provincial research units then surveyed forage resources in 1986 and recorded 567 species. Subsequently CATAS in Hainan recorded 1048 forage plant species in 1993. During 2004–2009, a total of 242 species of grasses were investigated and details recorded, including morphological characteristics, habitat and ecogeographic distribution. Some of these forage germplasm resources are species introduced from outside Hainan (Wu 1961; Flora of Fujian 1995; Liu 2000; Flora of Yunnan 2003; Flora of Guangdong 2007; Yin et al. 2008).

Forage germplasm resources exploitation is based on collection and effective preservation as part of a long-term strategy to identify, evaluate and utilize forages. So far about 6000 forage germplasm samples have been

Table 1. Composition of indigenous plants with forage and feeding potential in South China.

Category	Families (No.)	Proportion of total families (%)	Genera (No.)	Proportion of total genera (%)	Species (No.)	Proportion of total species (%)
Ferns	14	5.3	31	2.3	46	1.0
Gymnosperms	8	3.1	16	1.2	63	1.4
Angiosperms	240	91.6	1303	96.2	4571	97.7
Dicotyledons	218	83.2	1068	79.1	3704	79.2
Monocotyledons	22	8.4	235	47.4	567	18.5
Total	262	100.0	1350	100.0	4680	100.0

collected; most are preserved and only a limited number have been evaluated for their forage potential. There are still many other plant materials to be preserved and evaluated. For example, it is reported that the indigenous forage and feed plant resources in South China comprise 123 families (Table 2), but only 12 families have been collected. According to the Floras of Hainan, Guangdong, Guangxi and Fujian, there are 364 grass species in 92 genera, but only 38 species have been collected and preserved. Future work in South China will place more emphasis on collecting rare and endangered populations with forage potential, including those with pest and disease resistance.

Table 2. Categories of potential forage and feeding resources in South China.

Category of forage resource	Families (No.)	Genera (No.)	Species (No.)
Indigenous species	123	587	1432
Endemic species	85	128	354
Rare and endangered species	53	120	152
Productive species	25	243	687

Methodological aspects of collection, reproduction and preservation

Collection and investigation

The collection of indigenous forage germplasm resources includes 3 stages: finding and identifying forage genera and species; recording ecological descriptors (local vegetation type, soils, topographical features and climatic data); and passport data on location (latitude, longitude, elevation and map reference), registration numbers, collector names etc. The investigation of indigenous forage germplasm uses 4 stages: field investigation, including visiting local farmers; data descriptors of forages; planting in greenhouse, reproduction, vegetative multiplication and preliminary evaluation; and field investigations. The collection and investigation processes overlap. Identification of sites for collection will sometimes be based on experience or every 30–50 km along accessible roads or tracks. Collectors aim to obtain mature seeds where possible, or else tillers, stems, seedlings, tubers or other propagule material. When exotic forage genetic resources are introduced, the aims are to obtain similar levels of background information and to maintain bio-security.

Reproduction

The number of seeds collected in the field is usually limited, so there is need to produce enough seeds for preservation and further evaluation. Reproduction is done in the greenhouse, shadehouse or in the field. Seeds are treated to enhance germination, e.g. breaking hardseededness in some groups. Some legumes and grasses are propagated vegetatively.

Preservation

The storage of seeds is the most efficient way to preserve tropical and subtropical forage germplasm resources. Seeds are stored at low temperature, humidity and oxygen to increase their longevity. Both long-term and short-term storage are used at TPRC, CATAS. Long-term storage uses -20 to -15 °C and relative humidity (RH) of 12–15%, which should maintain seed viability for >25 years; short-term storage uses 0–5 °C and RH 12–15% to keep seeds for up to 5 years. Seeds are sealed in aluminium foil bags containing ~15 000 seeds. Germination and moisture content of seeds are tested before storage and again every 3–5 years.

Current status of forage genetic resources evaluation and preservation in South China

By 2006, the National Animal Husbandry and Veterinary Service, Ministry of Agriculture, had evaluated national forage germplasm resources preservation for more than 10 years. The national forage germplasm resources preservation system that was established includes a central gene bank, 2 duplicate gene banks, 15 nurseries and 10 collaboration teams from different ecosystem-regions in China. The central seed bank of the state forage germplasm resources center has collected, from 1998 to 2006, 9500 samples of forage germplasm resources from 1000 species, 411 genera and 67 families from all over the country. To date, more than 18 000 accessions have been collected and are preserved in the central gene bank, and the agronomic characteristics of more than 12 000 accessions have been described. The productivity of more than 1500 accessions was evaluated. A total of 45 grasses and 28 legumes were identified with good forage potential; 96 plant lines became the basis for recent forage breeding.

Forage genetic resources have been under severe threats resulting from: (1) natural factors, including environmental and climate change, greenhouse effect, ozone increase, fire, soil degradation and serious pollution; (2) infrastructure development, land management and land use changes, such as building of roads and railways, mining, new industrial developments, urbanization, transformation of forests or grasslands into cropland, cutting of vegetation for fuel, overgrazing and other activities that destroy farmland; (3) scientific and technological innovation, including the planting of new varieties, application of fertilizer and mechanization of agriculture; and (4) the replacement of old locally evolved varieties by introduced species, cultivars and agronomic practices (Jiang 1996; Li 2000; Zhang et al. 2003; Wang et al. 2007; Zhao 2009). The TPRC at CATAS assumed responsibility for the collection and preservation of tropical and subtropical forage resources in 1940; 5890 indigenous accessions, belonging to 478 species, 161 genera and 12 families, have been surveyed and collected in Hainan, Guangdong, Guanxi, Fujian and South Yunnan provinces.

Tropical areas account for only 5% of South China; here, tropical indigenous plant resources are very limited. To date cultivated forage varieties have come mostly from 4 centers of origin in the world (He 1986): The tropical African savannas are the source of many cultivated grasses, such as bluestem (*Andropogon* spp.), panic and guinea grasses (*Panicum* spp.), pennisetum grass (*Pennisetum* spp.), bristlegrass (*Setaria* spp.) and brachiaria grasses (*Brachiaria* spp.). Tropical America is the source of a number of cultivated tropical grasses, such as carpet grass (*Axonopus* spp.), paspalum (*Paspalum* spp.) and gama grass (*Tripsacum* spp.), but is mainly the source of many tropical cultivated forage legumes, such as stylo (*Stylosanthes* spp.), centro (*Centrosema* spp.), large-wing bean (*Macroptilium* spp.), leucaena (*Leucaena* spp.) and calopo (*Calopogonium* spp.). Tropical Africa is the source of other cultivated legume varieties such as cowpea (*Vigna* spp.), indigo (*Indigofera* spp.) and alysicarpus (*Alysicarpus* spp.) (Liu 2000; Yu et al. 2006).

The introduction of tropical forages into China started as early as the 1940s, when elephant grass (*Pennisetum purpureum*) was first introduced from Southeast Asian countries. In 1982 the NSW Department of Primary Industries, Australia introduced and tested a wide range of tropical and subtropical grasses and legumes in Hainan (Michalk et al. 1993a; 1993b) and Guangdong (Michalk and Huang 1994a; 1994b). After that TPRC began to gradually introduce forage genetic resources from the International Center for Tropical Agriculture (CIAT), the Australian Centre for International Agricultural Research (ACIAR), the Brazilian Agricultural Research Corporation (EMBRAPA) and others. Now, a total of 1130 exotic accessions from 87 species and 42 genera, of which 12 genera are exotic, have been introduced and preserved (Table 3).

In 2009, TPRC launched a project for the preservation of tropical and subtropical forage germplasm resources. As the leading unit in South China, it established a seed gene library using low temperature preservation, an in-vitro preservation library and a nursery station for plant propagation. The seed copy bank of tropical and subtropical forage germplasm resources has collected and is preserving 3769 accessions, the conservation library has 482 accessions and the nursery station has 388 accessions (Table 4).

Table 3. Tropical and subtropical regional forage genetic resources in South China.

Family	Genera (No.)	Species (No.)	Accessions (No.)	Indigenous species (No.)	Indigenous accessions (No.)	Exotic species (No.)	Exotic accessions (No.)
Fabaceae	72	246	3390	210	2852	36	538
Poaceae	89	252	3078	224	2840	28	238
Compositae	3	3	7	3	7		
Amaranthaceae	2	6	87	6	87		
Euphorbiaceae	2	2	385	2	31	1	354
Malvaceae	1	1	2	1	2		
Sapindaceae	1	1	9	1	9		
Urticaceae	1	1	1	1	1		
Cyperaceae	13	21	47	21	47		
Convolvulaceae	1	1	1	1	1		
Labiatae	1	1	1	1	1		
Acanthaceae	1	1	1	1	1		
Cruciferae	2	3	5	3	5		
Polygonaceae	1	3	6	3	6		
Total	190	542	7020	478	5890	65[1]	1130

[1]A total of 87 species have been introduced and are preserved, of which 65 species are exotic and 23 species are both indigenous and exotic, such as cassava (*Manihot esculenta*).

Table 4. Composition of tropical and subtropical forage genetic resources in different types of preservation at TPRC, CATAS.

Type of preservation	Family	Genera (No.)	Species (No.)	Accessions (No.)
Low temperature preservation in genebank	Fabaceae	67	204	3161
	Poaceae	35	56	443
	Compositae	2	3	7
	Amaranthaceae	2	6	87
	Sapindaceae	1	1	9
	Convolvulaceae	1	1	1
	Cruciferae	2	3	5
	Polygonaceae	1	3	6
	Cyperaceae	13	21	47
	Labiatae	1	1	1
	Acanthaceae	1	1	1
	Malvaceae	1	1	1
	Total	127	301	3769
Preservation in vitro	Fabaceae	4	4	21
	Poaceae	1	1	61
	Euphorbiaceae	1	1	400
	Total	6	6	482
Preservation in nursery	Fabaceae	1	1	6
	Poaceae	6	8	58
	Euphorbiaceae	1	1	324
	Total	8	10	388

State of forage germplasm resources

The grass industry in South China has achieved productive results in the cultivation and breeding of forage species from introduced and native germplasm for grassland improvement, resistance to diseases and insect pests, intercropping between fruit or forest trees, coastal dune stabilization and utilization as livestock feed. In 1986, the National Approval Committee for Pasturage Species held its first meeting to approve forage species and by 2012, 453 cultivars had been registered, of which 120 cultivars (50 legumes and 70 grasses) are suitable for southern China (Liu et al. 2008). The TPRC at CATAS has successively selected, bred and released 19 cultivars (Table 5). These varieties have been used across the southern and southwest provinces in China. They are used not only for grazing and producing high-quality hay and forage meal, but also widely for green manure, young rubber tree gardens, soil cover in orchards, conservation of soil and water, fixing of coastal sand into soil, as well as environmental greening and beautification, expanding the function and role of tropical pasturage and bringing new concepts to the development of the grass industry in South China.

Stylosanthes guianensis Reyan No. 2 has been planted on over 2 Mha in Hainan, Guangdong, Guangxi, Hunan, Jiangxi, Jiangsu, Yunnan, Guizhou, Sichuan, Fujian and other regions. *Pennisetum americanum* (Wang grass Reyan No. 4) has been planted over 10 Mha in Xinjiang, Beijing, Hubei, southern China and the southwest, and is used as a solution to the problem of shortage of winter feed in parts of the northern region. The Fujian Agricultural and Scientific Institution has bred and released productive cultivars of *Chamaecrista* (syn. *Cassia*) *rotundifolia* and *Brachiaria* hybrid No. 1. Due to their advantages, such as fast growth, good soil cover, strong ability to fix nitrogen (in the case of legumes), good pest and disease resistance and increased nutritive value, they have obvious superiority in the conservation of water and soil, and ecological and soil fertility restoration. The Yunnan Research Centre for Beef Cattle and Pasturage has released 7 cultivars (among them Weichite Eastern *Pennisetum*, Haifa white clover, white clover and Shafulei Kenya clover), which are planted over 8 Mha in Yunnan, Guizhou and neighboring areas.

The problems

The danger of losing tropical forage resources

The acknowledged degradation problems in Chinese grassland ecology are a major threat to the preservation of indigenous forage species. With the rapid development of the economy in South China, grassland, forest and rangeland areas have been considerably reduced in area and what remains is under increased pressure to feed the large

Table 5. Tropical forage varieties released by CATAS.

Cultivar	Year of release	Extension area	Adapted to
Leucaena leucocephala cv. Reyan No. 1	1991	Hainan, Yunnan	poor soils, drought, waterlogging
Stylosanthes guianensis cv. Reyan No. 2	1991	Hainan, Yunnan	poor acid soils, drought, waterlogging
Brachiaria decumbens cv. Reyan No. 3	1991	Hainan, Guangdong	poor soils, drought, waterlogging
Pennisetum americanum cv. Reyan No. 4	1998	All provinces of South China	poor soils, drought, waterlogging
Stylosanthes guianensis cv. Reyan No. 5	1999	Hainan, Yunnan	acid soils, cold
Brachiaria brizantha cv. Reyan No. 6	2000	Hainan, Yunnan	poor soils, drought, waterlogging
Stylosanthes guianensis cv. Reyan No. 7	2001	Hainan, Yunnan	resistance to disease
Panicum maximum cv. Reyan No. 8	2000	Hainan, Yunnan	poor acid soils, drought, waterlogging, shade
Panicum maximum cv. Reyan No. 9	2000	Hainan, Yunnan	poor acid soils, drought, waterlogging, shade
Stylosanthes guianensis cv. Reyan No. 10	2000	Hainan, Yunnan	poor acid soils, drought, shade
Paspalum atratum cv. Reyan No. 11	2003	Hainan, Yunnan	acid and poor soils
Arachis pintoi cv. Reyan No. 12	2004	Hainan, Yunnan	poor acid soils, shade
Stylosanthes guianensis cv. Reyan No. 13	2003	Hainan, Yunnan	drought, poor acid soils, resistance to disease
Brachiaria dictyoneura cv. Reyan No. 14	2004	Hainan, Yunnan	acid soils, shade
Brachiaria ruziziensis cv. Reyan No. 15	2005	Tropical area, average rainfall >750 mm/yr	poor soils, drought
Desmodium ovalifolium cv. Reyan No. 16	2005	Tropical area, average rainfall >1000 mm/yr	poor acid soils, shade, drought
Pueraria phaseoloides cv. Reyan No. 17	2006	Hainan, Yunnan	shade, poor soils, drought, waterlogging
Stylosanthes guianensis cv. Reyan No. 18	2007	Hainan, Yunnan	shade, poor soils, drought
Panicum maximum cv. Reyan No. 19	2007	Hainan, Yunnan	shade, poor soils, drought, waterlogging
Stylosanthes guianensis cv. Reyan No. 20	2010	Hainan, Yunnan, Guangdong, Fujian, Guangxi	resistance to disease, tolerance to acid soil, drought, shade
Stylosanthes guianensis cv. Reyan No. 21	2011	Hainan, Yunnan, Guangdong, South Fujian, Guangxi, South Sichuan	low temperature, drought

population. Some varieties and genotypes of productive forage species are disappearing as a result of these pressures, threatening genetic diversity. Preservation practices are by necessity a compromise, which means that only some genotypes will be preserved. Field evaluation of genotypes lags considerably behind the acquisition of material, such that valuable genotypes may not be tested or could be lost in storage. Genetic drift/loss is a real risk with cross-pollinated species (Yan et al. 2008). A consequence of these factors is that forage species do need to be maintained in the wild and collections renewed at intervals.

The limited use of collections

The work on the identification and utilization of tropical pasture germplasm has not been sufficient to thoroughly appraise this resource and to maximize gains. There is still only a general understanding of what ecotypes are in the collections and a poorer understanding of any special traits that may be there. Breeding work has been limited. The cultivars released, while being an improvement on existing material, are based only on limited selection, though it is considered that the total resource is a rich one.

Limitations in preservation and preservation technology

The strategy adopted to collect and preserve material is relatively standard and designed to handle larger amounts of material with some efficiency. It has not been possible to develop and use more innovative preservation techniques, especially for those species that may have unusual reproductive strategies. It is anticipated that techniques such as asexual reproduction, tissue culture, cloning and pollen storage, as well as advanced techniques for storing

DNA etc., will need to be developed and used to maintain the collections and their genetic diversity (Yan et al. 2008). These techniques would aim to speed up the identification and utilization of improved material.

Barriers to the availability and usage of germplasm

Germplasm is a common good and arguably should belong freely to the community, although opinions vary around the world. Any benefits from exploiting these resources should be available to the community – be it at the country, provincial or local level. Intellectual property rights is, in many places, an issue that is still to be resolved. By retaining the rights of forage resources in public hands, there is more chance for the wider community to benefit.

Suggestions

Strategies to survey, collect and introduce forage resources

Any selection and breeding program needs to have significant genetic diversity to maximize the chance of producing good cultivars. Programs need to expand to include more exotic material as well as local collections of the same species.

Improvement in modification of genetic material

Research needs to identify those traits that significantly enhance the quantity and quality of forage produced. A range of techniques, including genetic engineering, then need to be used to produce germplasm for testing and eventual release.

Strengthen use of new cultivars with independent intellectual property rights

There are few tropical forage cultivars with independent intellectual property rights. This needs to be encouraged to stimulate cultivar development.

Promote sharing of resources

Scientific progress depends upon the sharing of information. Greater sharing of genetic material and collabo-ration in breeding programs to generate more productive forage cultivars would enhance the development of forage resources in southern China. Appropriate protocols for sharing material need to be developed.

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Current status of *Stylosanthes* seed production in southern India

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Abstract

India is a significant producer of seed of *Stylosanthes* spp. (stylo), mainly *S. hamata*. Most of this seed is produced by villagers and small farmers in the Anantapur district, Andhra Pradesh, southern India. This is one of the poorest regions in the State, with harsh climatic conditions, poor, zinc-deficient soils, and, in the stylo seed production area, farm sizes averaging less than 2 ha. An informal network of seed traders markets the stylo seed within a 25−30 km radius and, via the next level of traders, to other parts of India. A survey in this area in 2002/03 indicated that stylo seed production in 2001 was about 800 t from more than 400 ha. A second survey, conducted in 2012, showed that the stylo seed production area had declined to 150 ha, with annual seed production of about 300 t. Most of the decline had occurred since 2007, when the purchase of seed for watershed rehabilitation in the States of Karnataka and Andhra Pradesh was discontinued. In addition to the loss of this major market, other factors influencing the reduction in stylo seed production included: the low price of stylo seed compared with groundnut (the crop mainly competing for land use); sales of land for other purposes, and diversion of one area as a Special Economic Zone; reduced availability and increased costs of labor, particularly after the establishment in 2005 of the National Rural Employment Guarantee Agency, which provided an attractive employment option for rural workers; lack of technical support; and, in one village, delay in payment. Poor seed quality was another issue constraining prices. Despite these challenges, many farmers in the region remain positive and would continue to produce stylo seed, if profitability could be improved.

Resumen

India es un importante productor de semilla de stylo (*Stylosanthes* spp.), principalmente *S. hamata*. La mayor parte de esta semilla es producida por aldeanos y campesinos en el distrito de Anantapur, Andhra Pradesh, en el sur de India. Ésta es una de las regiones más pobres del estado, con condiciones climáticas adversas, suelos pobres y deficientes en zinc. En las áreas productoras de semilla de stylo, las fincas miden en promedio menos de 2 ha. Una red informal de comerciantes vende la semilla dentro de un radio de 25−30 km y, por medio del siguiente nivel de comerciantes, a otras partes de India. Una encuesta realizada en 2002/03 indica que en 2001 se produjeron en esta área alrededor de 800 t de semilla de stylo en más de 400 ha. Una segunda encuesta, realizada en 2012, mostró que el área de producción había disminuido a 150 ha, con una producción anual de semilla de aproximadamente 300 t. La mayor disminución ocurrió a partir de 2007, cuando se suspendió la compra de semilla para la rehabilitación de cuencas de ríos en los estados Kamataka y Andhra Pradesh. Adicional a la pérdida de este mercado mayor, otros factores que influyeron en esta reducción fueron: el bajo precio de la semilla comparado con el de maní (cacahuete), el cultivo de mayor competitividad por el uso de la tierra; la venta de tierra para otros propósitos, incluyendo la declaración de una área como Zona Económica Especial; la reducción de la disponibilidad de la mano de obra y el incremento de su costo, particularmente después de que en 2005 se estableciera la National Rural Employment Guarantee Agency, la cual otorgó una opción atractiva de empleo para trabajadores rurales; la falta de apoyo técnico; y, en una aldea, el retraso en el pago por la venta de semilla. La baja calidad de la semilla también afectó los precios. A pesar de estos retos, muchos campesinos en la región mantienen una actitud positiva y continuarían produciendo semilla de stylo si la rentabilidad pudiera ser mejorada.

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Introduction

Land degradation and associated poverty are major challenges in rural areas of India with wastelands amounting to 114 Mha or almost 36% of the land area (ICAR 2010). Various policies and programs have been devised, mainly through 5-year plans, to address the issue. The significant boost for wastelands through watershed programs was given in the IX Plan (1997/98−2001/02). Watershed development, as a poverty-alleviation measure, has been given a high priority in India, as is evident in the 20-year Perspective Plan (2002/03−2021/22) for treating around 88.5 Mha in the next 20 years with a total investment of Rs 727.5 billion.

India has 15% of the global livestock population but only 2% of the land area. Restoration of degraded lands is also aimed to meet grazing requirements of livestock and wildlife in some areas (Ramesh et al. 2007). *Stylosanthes* spp. (stylo), pioneering colonizers, establish well on poor and severely eroded soils in dryland conditions. Their ability to improve soil bulk density, infiltration rate and water holding capacity makes them useful species for the conservation, stabilization and sustainable development of land and water resources (de Leeuw et al. 1994). There is a large demand in India for stylo seed, particularly *S. hamata*, a short-lived perennial legume which has perceived perenniality in this part due to self-seeding. Only a small portion of this demand is met by public sector-operated centers for forage crops; most demand is met by farmers of Anantapur district (13°−14° S, 76°−77° E) in southern India, who sow a *S. hamata* crop once in 3−4 years and produce seed.

Initially, in the mid-1970s, production of stylo seed by farmers in this region was aided by international pilot seed programs, in which seeds were produced by small and marginal farmers of this district. Some of these farmers later converted into producers-cum-traders. Eventually an informal network of seed producers and traders emerged and grew in scale and extent. Stylo seeds produced in this region today reach even the remotest parts of the country. A survey in this area in 2002/03 indicated that stylo (*S. hamata*) seed production (SSP) in 2001 was about 800 t from more than 400 ha (Rao et al. 2004). A similar survey was taken in 2012 to quantify current seed production and to examine the factors underlying the continuity (or otherwise) of production of stylo seed by the farmers of the area.

Methods

Anantapur is one of the most economically backward districts of Andhra Pradesh province of India (Figure 1). The average annual rainfall of the district is only 550 mm and, on average, 1 year in 3 years is a drought year. This district is divided into 3 revenue divisions, and most of the stylo seed is produced in the Penukonda division within the Gorantla, Somandapalli and Chilmathur revenue blocks, where stylo is cultivated extensively. The survey was undertaken in these revenue blocks. A preliminary list of villages, where stylo seed is being produced at present, was prepared by consulting with field staff of the AHVS Department and, as in the previous (2002/03) survey, many such villages were in the Gorantla block with a few in the Somandapalli and Chilamathur blocks. Our primary surveys therefore covered the Gorantla block extensively, and a few villages in the other 2 blocks. In total, the study covered 17 villages of which 10 villages were common to the 2002/03 and 2012 surveys.

The stylo seed crop is ready for harvest in January, when farmers are relatively free from other *rabi*-season farm operations. Therefore in January 2012, we carried out primary surveys, interviews and consultations with a cross-section of people, and detailed discussions with key informants and seed traders at 2 levels (village and revenue block). Separate checklists for seed growers and traders were prepared to guide the discussions in the field. Village surveys, however, formed an important part of the study to understand what was happening at farmer and village levels.

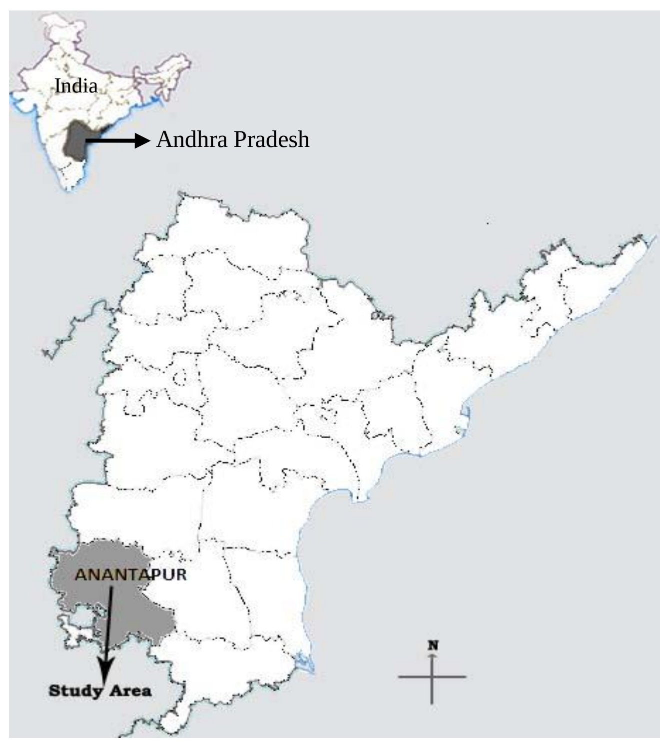

Figure 1. Map showing the study area.

Results

Estimated area under stylo seed crop in surveyed villages and reasons for decrease in the area

In almost all villages, the area under stylo had declined since the previous survey (Figure 2). The area had declined drastically in some villages, where only a few larger farmers, who were growers as well as seed traders, had continued to cultivate the crop. Farmers indicated that the steep fall in the area under stylo had occurred only after 2007, when demand for seed had decreased. This information from farmers was consistent with the banning of purchase of stylo seeds by Karnataka and Andhra Pradesh State Governments at that time, due to extreme adulteration and impurity of seeds sold by last-level middlemen. Except in a few villages, the majority of the small and marginal farmers had replaced the crop with groundnut, the traditional oilseed crop in this area. The landholdings of farmers in this dry tract are very small, and complete replacement of the stylo crop was observed in many cases. As prices of agricultural commodities including groundnut in India had increased, especially in this decade, SSP farmers reverted back to groundnut cultivation.

Palasamudram, the village with the greatest area under stylo (160 ha) in 2002/2003, had only10 ha under SSP in 2012, and this area belonged to larger farmers who were also traders of the stylo seed. Small and marginal farmers had discontinued stylo cultivation. The Government of Andhra Pradesh has earmarked 392 ha of land for a Special Economic Zone in this village, and 153.75 ha or 39% was owned by farmers who had previously cultivated stylo. This was a pioneering village for SSP, and some farmers from this village had been trained in SSP at government farms (Rao et al. 2004). Edula Ballapuram is another village where the area under stylo had been reduced remarkably, from 44 ha to 10 ha. The prime reason, expressed by the farmers of this village for discontinuing SSP, was undue delay in receipt of payment. This reason was specific to this village; in other villages payment was not a problem. The village seed trader, when consulted, however, mentioned that the problem of non-availability of labor had affected the crop. This trader had a stylo seed stock of 150 kg. Interestingly, in Guttivarapalli village there was no stylo cultivation in 2010, whereas some families resumed the cultivation of stylo in 2011 on a total area of 3.24 ha.

Some farmers said that they might resume cultivation of stylo, if prices for seed increased and if it proved more profitable than regular field crops. Cost of labor had increased 3-fold since 2002 but the price of stylo seed had remained constant. Non-availability of labor was another reason mentioned, as labor requirements for harvesting and further processing of seed are high. These operations must be carried out in the months of January

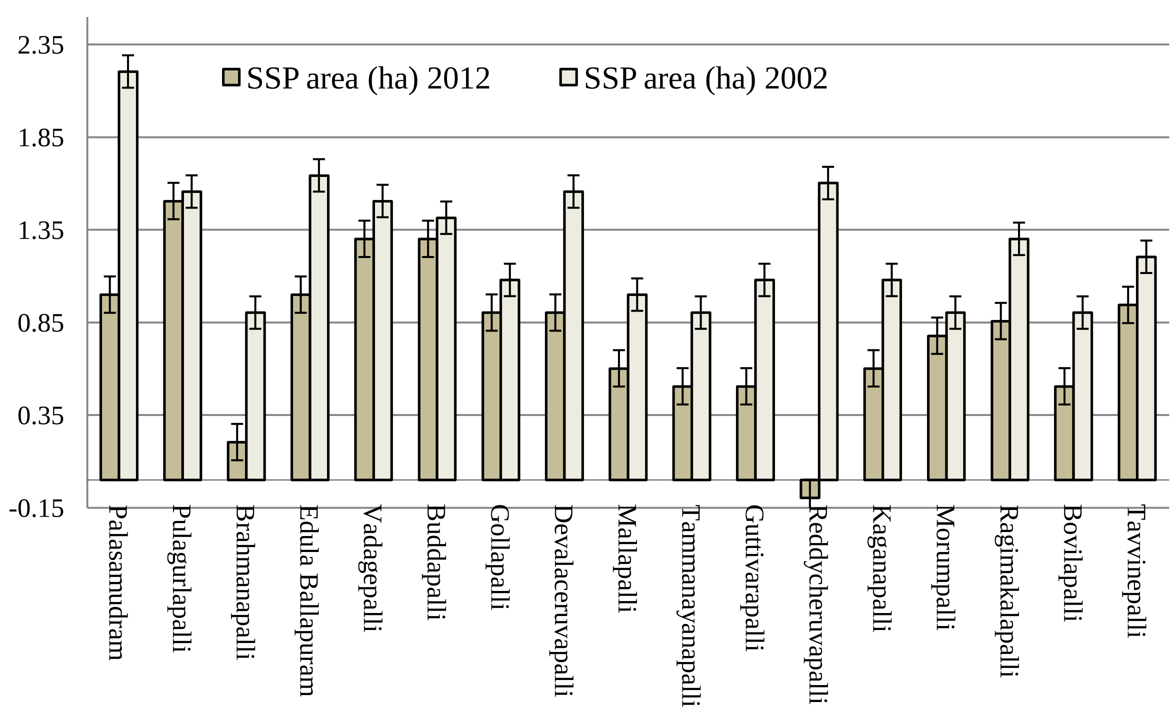

Figure 2. Area under SSP in surveyed villages (figure based on log transformed data to the base 10 with s.e. bars).

to March, when temperatures are high. Many laborers are reluctant to work under hot conditions, and would prefer to work elsewhere, especially as work opportunities have increased in the last 10 years. Many of the villages (Pulagurlapalli, Brahmanapalli, Reddy-Cheruvapalli etc.) are located adjacent to the Bangalore −Hyderabad national highway (NH-7). The completion of the Bangalore international airport at Devanahalli, less than 70 km away, had inflated land prices and many small and marginal farmers sold their land. Increased land prices and sale of land to private buyers or the government applied also to some of the stylo-growing villages located in the interior. In some of the interior villages, e.g. Ragimakalapalli, private seed companies had purchased large areas to establish seed-production centers and market the seeds from Bangalore to other parts of the country.

Cost of cultivation of stylo crop

Cost-benefit analysis (Table 1) of stylo seed production indicated that input costs had increased substantially in the last 10 years. The major component was cost of labor, which had almost tripled during the decade. There were many reasons for increased wages, the most important being the implementation of a National Rural Employment Guarantee scheme in 2005. Seed yield, fodder yield and the selling price of the seed did not show similar increases, but instead remained almost constant for a decade. As a result, the returns from the cultivation of stylo were reduced drastically; the B:C ratio decreased from 2.90 to 1.48, making it less remunerative for the farmers.

Seed demand, price and purity

There is an informal market for stylo seed, largely operated by the vast network of middlemen. No specific method exists for fixing the price or checking seed quality. The demand for stylo seed varies both from year to year and within a year. Lack of information on seed demand at the level of the village seed traders weakens their bargaining power on price, except to agree to the price offered. This results in the selling of spurious seeds by farmers and traders. Seed lots collected from various sources and places in the surveyed villages clearly indicated large scale admixtures, and average purity was only 28%. Truthfully-labelled stylo seed samples from public research farms have recorded 81% pure seed content. There is no specific method in place to assess seed demand, to fix the price or to check seed quality, thus favoring only the few big traders in the business. Rao et al. (2004) reported non-availability of data on the actual quantities of stylo seed purchased by various users.

Conclusion

The area under stylo in the region has declined considerably. Important reasons include non-availability of labor, increased wage rates and an almost constant price for stylo seed during the last decade. Mechanization of seed harvesting and processing in the area would reduce the dependence on labor. A system involving trusted agencies in the area is required to assess seed demand and to check the quality of seed in order to get a fair price. A reduction in labor usage combined with a fair price for seed could revive the ailing stylo seed production industry in the area, bringing greater stability to the livelihood of small and marginal farmers in this semi-arid area.

Table 1. Cost-benefit analysis of stylo seed production.

Factor	2012 (Rs/ha)	2002 (Rs/ha)
Input variable costs		
Seed[1]	0	0
Human labor	15 000	6000
Bullock labor/Machine labor	3250	1250
Farm yard manure	3000	1500
Inorganic fertilizer	2315	1437.5
Interest on working expense	942.5	407.5
Fixed costs		
Land rent[2]	7500	3750
Land revenue	0	0
Total costs	32 007.5	14 345
Output		
Seed yield (kg/ha)[3]	2000	2000
Price of seed (Rs/kg)[4]	18	18
Fodder yield (kg DM/ha)	2250	2250
Price of fodder (Rs/kg)	5	2.5
Gross returns	47 250	41 625
Net returns	15 242.5	27 280
Input:output ratio	1.48	2.90

[1]Fallen seeds germinate and give good crop stands, so cost of seed is considered zero.
[2]Cost imputed for owned land rent Rs 7500/ha. The Government of Andhra Pradesh does not levy any land revenue.
[3]Minimum seed yield, according to farmers; maximum about 4 000 kg; however, seed lot had high level of inert material (>50%).
[4]Relative price received by farmers over last 4 years.

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Advances in improving tolerance to waterlogging in *Brachiaria* grasses

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Keywords: Tropical grasses, poor soil drainage, root aeration traits, screening, participatory evaluation.

Abstract

An inter-institutional and multi-disciplinary project to identify *Brachiaria* genotypes, which combine waterlogging tolerance with high forage yield and quality, for use in agricultural land in Latin America with poor drainage, is underway. The aim is to improve meat and milk production and mitigate the impacts of climate change in the humid areas of Latin America. Researchers at the International Center for Tropical Agriculture (CIAT) have developed a screening method to evaluate waterlogging in grasses. Using this method, 71 promising hybrids derived from the species, *Brachiaria ruziziensis*, *B. brizantha* and *B. decumbens*, were evaluated. Four hybrids with superior waterlogging tolerance were identified. Their superiority was based on greater: green-leaf biomass production, proportion of green leaf to total leaf biomass, green-leaf area, leaf chlorophyll content and photosynthetic efficiency; and reduced dead-leaf biomass. These hybrids, together with previously selected hybrids and germplasm accessions, are being field-tested for waterlogging tolerance in collaboration with National Agricultural Research Institutions and farmers from Colombia, Nicaragua and Panama.

Resumen

Un proyecto inter-institucional y multidisciplinario para identificar genotipos de *Brachiaria* que combinen tolerancia a suelos encharcados con un alto rendimiento y calidad de forraje para uso en áreas agrícolas con mal drenaje está en curso. El objetivo es mejorar la producción de carne y leche y mitigar los impactos del cambio climático en las áreas húmedas de América Latina. Para el efecto, investigadores del Centro Internacional de Agricultura Tropical (CIAT) han desarrollado un método de invernadero para evaluar tolerancia a encharcamiento en gramíneas el cual se aplicó en 71 híbridos promisorios originados de las especies *Brachiaria ruziziensis, B. brizantha* y *B. decumbens*. Se identificaron 4 híbridos superiores por su tolerancia a encharcamiento, caracterizados por mayor producción de biomasa de hojas, proporción de hojas verdes con respecto al total de hojas, área foliar, contenido de clorofila, eficiencia fotosintética y menor biomasa de hojas muertas. Estos híbridos, junto a otros híbridos y accesiones de germoplasma previamente seleccionados, están siendo evaluados bajo condiciones de campo por su tolerancia a encharcamiento en colaboración con instituciones nacionales de investigación agrícola y productores de Colombia, Nicaragua y Panamá.

Introduction

The frequency of extreme weather events, including heavy precipitation, will likely increase in the future due to climate change (Allan and Soden 2008; O'Gorman and Schneider 2009). Poorly drained soils are found in about 11.3% of agricultural land in Latin America where physiography promotes flooding, high groundwater tables or waterlogging (Wood et al. 2000). Waterlogging drastically reduces oxygen diffusion into the soil causing

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hypoxia, which is the main limitation reducing root aerobic respiration and the absorption of minerals and water (Rao et al. 2011). Plants adapt to waterlogging conditions with traits and mechanisms that improve root aeration, such as production of aerenchyma and development of adventitious roots (Jackson and Colmer 2005).

Perennial *Brachiaria* grasses are the most widely sown forage grasses in tropical America (Miles et al. 2004; Valle and Pagliarini 2009). During the rainy season, in a large number of locations in the tropics, *Brachiaria* pastures are temporarily exposed to waterlogging conditions that severely limit pasture productivity and therefore livestock production (Rao et al. 2011). In many humid zones, livestock producers use *B. humidicola* cv. Tully because of its high tolerance to waterlogging. However, a major limitation of this cultivar is its low forage quality, which constrains animal performance.

CIAT has an on-going *Brachiaria* breeding program. Two selections from this program have been commercialized (cvv. Mulato and Mulato II). They have a number of positive attributes, but are not tolerant of waterlogging. The most economic way to reduce the negative impact of waterlogging may be to select or breed tolerant cultivars (Zhou 2010). Improving waterlogging tolerance in *Brachiaria* grasses has potential for success, since inter- and intraspecific variation has been documented (Rao et al. 2011). Therefore, the main objective of an inter-institutional and multi-disciplinary project was to identify genotypes of *Brachiaria* that combine waterlogging tolerance with high forage quality for improving meat and milk production and mitigate the impacts of climate change in humid areas of tropical Latin America.

Progress

The project aims to deliver 4 major outputs; progress towards those research outputs is described below.

Estimation of areas in Latin America with poorly drained soils to target improved Brachiaria *grasses*

Areas in tropical Latin America suitable for *Brachiaria* grasses based on soil conditions and precipitation are shown in Figure 1. Based on global climate models (GCM-ECHAM), areas in Latin America are expected to experience more days of waterlogged soils by 2020, without any major further changes by 2050 (Figure 1). This includes grasslands such as the Colombian and Venezuelan Llanos, the Guyana savannas and the Brazilian Cerrados.

Traits associated with waterlogging tolerance in Brachiaria *grasses*

Definition of morpho-physiological and biochemical traits associated with waterlogging tolerance will contribute to developing reliable screening procedures. Moreover, efficient screening procedures are required to recover the desirable traits through accumulation of favorable alleles over repeated cycles of selection and recombination (Rao 2001; Wenzl et al. 2006). Work has been carried out at CIAT to assess the responses of *Brachiaria* genotypes with different levels of tolerance to waterlogging (tolerant *B. humidicola* cvv. Tully and Llanero; moderately tolerant *B. decumbens* cv. Basilisk and *B. brizantha* cv. Toledo; sensitive *B. brizantha* cv. Marandu, *Brachiaria* hybrid cv. Mulato II and

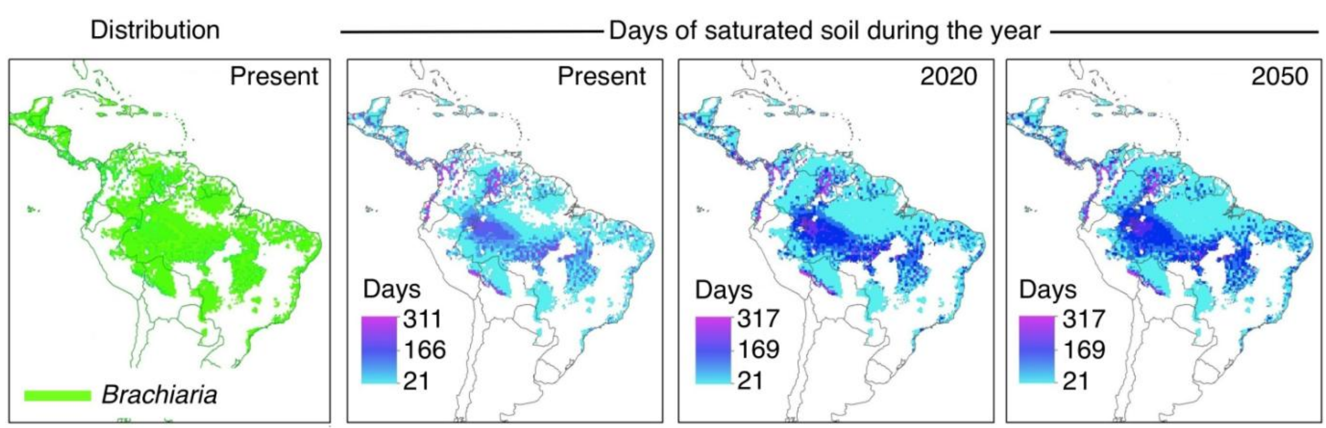

Figure 1. Estimated present areas (6 300 000 km^2) suitable for growing *Brachiaria* grasses in tropical Latin America and number of days of water-saturated soils during the year: at present and expected changes for the years 2020 and 2050.

B. ruziziensis Br 44-02). Short-term (<3 days) adaptation to hypoxic/waterlogged soil conditions involves a switch from aerobic respiration to fermentative catabolism in roots. However, longer-term adaptation is achieved by the development of aerenchyma in roots that allows oxygen transfer to improve aerobic respiration. Differences in tolerance to waterlogging among *Brachiaria* grasses are likely a consequence of differences in morphology and anatomy of roots, including aerenchyma formation, root diameter, relative volume of stele (vascular tissue) (Figure 2) and lateral root formation, all of these acting synergistically to improve root aeration and sustain root elongation. Presence of constitutive aerenchyma in roots is of immediate advantage to plants when initially exposed to oxygen shortage (Colmer and Voesenek 2009). This may explain the superior tolerance of *B. humidicola* cv. Tully to temporary waterlogging. Maximum rooting depth has been found to be positively associated with aerenchyma development at 1 cm from the root tip in commercial *Brachiaria* grasses (r = 0.4; P<0.05). As determination of aerenchyma in roots is a time-consuming process, maximum rooting depth could be a more efficient indicator of internal aeration efficiency.

Screening for waterlogging tolerance

Researchers at CIAT have developed a screening method based on morphological and physiological traits to evaluate waterlogging tolerance in *Brachiaria* grasses. Screening is carried out using soil (from target environments) in a double-pot system with a plastic bag to prevent water leakage, while maintaining a water lamina of 3 cm over the soil for 21 days. Using this method, a large number of germplasm accessions and hybrids have been evaluated under 2 fertility levels: high (mg element per kg of soil: N 40, P 50, K 100, Ca 101, Mg 35, S 28, Zn 2, Cu 2, B 0.1, Mo 0.1) and low (P 20, K 20, Ca 47, Mg 14, S 10) (Rao et al. 1992) (Table1). Some of these hybrids have shown higher level of tolerance to waterlogged soil than commercial cultivars based on higher values of leaf chlorophyll (SPAD chlorophyll meter reading units: SCMR) and the proportion of green- leaf biomass to total leaf biomass (Figure 3).

A set of 71 *Brachiaria* hybrids (*Brachiaria ruziziensis* x *B. brizantha* x *B. decumbens*) was evaluated at CIAT for tolerance to waterlogging using the same screening method; 4 hybrids were superior to the others (Rincón et al. 2008). The superior performance of these hybrids was based on greater green-leaf biomass production, greater proportion of green-leaf to total leaf biomass, greater green-leaf area, leaf chlorophyll content and photosynthetic efficiency, and lower levels of dead-leaf biomass. These 4 hybrids together with 7 other *Brachiaria* hybrids and 19 germplasm accessions of *B. humidicola* are being evaluated under field conditions for tolerance to waterlogging with participation of National Agricultural Research Institutions and farmers in Colombia, Nicaragua and Panama.

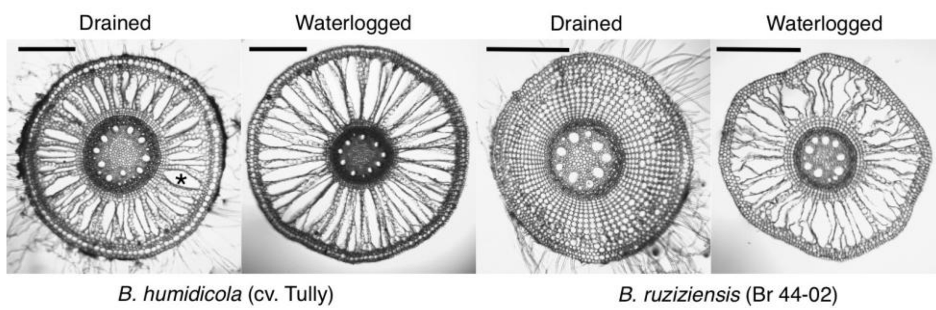

Figure 2. Root cross sections of 2 contrasting *Brachiaria* grasses (tolerant *B. humidicola* and sensitive *B. ruziziensis*) grown under drained or waterlogged soil conditions for 21 days. Sections taken at 10 cm from the root tip. * represents aerenchyma. Scale bar = 0.5 mm.

Table 1. *Brachiaria* grasses evaluated (2010) for waterlogging tolerance under controlled conditions at CIAT.

B. humidicola		Interspecific *Brachiaria* hybrids (*B. ruziziensis* x *B. brizantha* x *B. decumbens*)	
High fertility	Low fertility	High fertility	Low fertility
66 accessions 492 hybrids	66 accessions	902 hybrids	109 hybrids

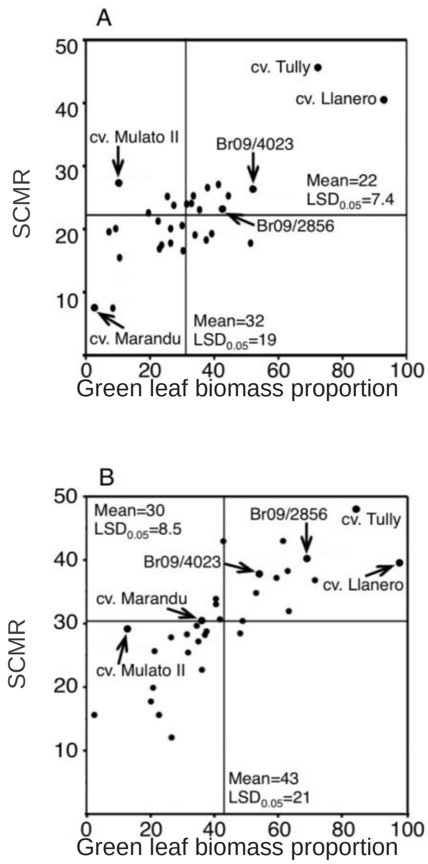

Figure 3. Genotypic variation for waterlogging tolerance in 26 *Brachiaria* hybrids and 4 commercial cultivars (*B. humidicola* cvv. Tully and Llanero; *B. brizantha* cv. Marandu; and *Brachiaria* hybrid cv. Mulato II) grown in pots for 21 days in a fertilized top soil (Oxisol) from A (Santander de Quilichao, Department of Cauca, Colombia) and B (Matazul, Department of Meta, Colombia). SCMR: SPAD chlorophyll meter reading units; green-leaf biomass proportion: proportion of green to total leaf biomass.

Field evaluation of Brachiaria *grasses*

Researchers from CIAT and Corpoica (Colombia) have developed a methodology to evaluate waterlogging tolerance in *Brachiaria* grasses under field conditions (Figure 4). This methodology is being used by researchers from INTA (Nicaragua) and IDIAP (Panama). Selected *Brachiaria* grasses (11 *Brachiaria* hybrids, 19 *B. humidicola* accessions and *B. brizantha* cv. Toledo) are being evaluated under field conditions at 3 sites in Colombia, 2 in Nicaragua and 1 in Panama. As expected, *B. humidicola* accessions are showing better tolerance to waterlogged soil conditions than the hybrids.

Researchers in Colombia, Nicaragua and Panama have also conducted interviews with livestock producers to make a quick assessment of their perceptions of problems associated with excess water in the rainy season and desirable characteristics needed in new cultivars to confront climate variability and change. Farmers associated waterlogging tolerance in grasses with a stoloniferous growth habit and indicated the need to improve pest and disease resistance in new cultivars targeted to poorly drained soils. Agronomic evaluation of promising *Brachiaria* genotypes with participation of farmers is in progress.

Conclusions

Progress with estimating areas of Latin America with poorly drained soils and using climate models to estimate the possible increase in waterlogged areas has highlighted the significant impact on pasture and animal production that climate change could have by the years 2020 and 2050. The identification of some

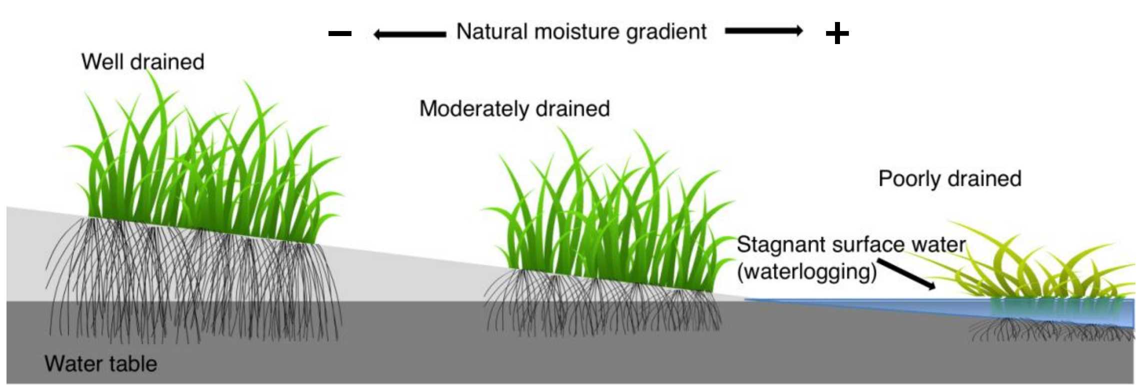

Figure 4. Methodology to evaluate *Brachiaria* grasses for tolerance to waterlogged soils under field conditions. Evaluations are carried out at monthly intervals and include determination of various parameters, such as dry matter yield, forage cover, height, visual appraisal and presence of pests and diseases.

Brachiaria genotypes with improved tolerance to waterlogging suggests that there are ways to minimize this impact. The field-testing in Colombia, Nicaragua and Panama should indicate how well these genotypes might achieve this aim. Further screening is needed to identify more potential genetic material to combat the increase in waterlogging which will inevitably occur with climate change.

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Integrated crop-livestock systems − a key to sustainable intensification in Africa

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Keywords: Integration, mixed crop-livestock intensification, sustainability.

Abstract

Mixed crop-livestock systems provide livelihoods for a billion people and produce half the world's cereal and around a third of its beef and milk. Market orientation and strong and growing demand for food provide powerful incentives for sustainable intensification of both crop and livestock enterprises in smallholders' mixed systems in Africa. Better exploitation of the mutually reinforcing nature of crop and livestock systems can contribute to a positive, inclusive growth trajectory that is both ecologically and economically sustainable. In mixed systems, livestock intensification is often neglected relative to crops, yet livestock can make a positive contribution to raising productivity of the entire farming system. Similarly, intensification of crop production can pay dividends for livestock and enhance natural resource management, especially through increased biomass availability. Intensification and improved efficiency of livestock production mean less greenhouse gases per unit of milk and more milk per unit of water. This paper argues that the opportunities and challenges justify greater investment in research for development to identify exactly where and how 'win-win' outcomes can be achieved and what incentives, policies, technologies and other features of the enabling environment are needed to enable sustainable, integrated and productive mixed crop-livestock systems.

Resumen

Los sistemas mixtos cultivos-ganadería proveen el sustento de mil millones de personas y producen la mitad de los cereales en el mundo y aproximadamente 1/3 de la carne y la leche. En África la creciente orientación hacia los mercados y la fuerte y creciente demanda por alimentos son poderosos incentivos para la intensificación sostenible tanto en el componente cultivos como ganadería en sistemas mixtos de pequeños productores. Un mejor aprovechamiento de la naturaleza de refuerzo mutuo de los sistemas mixtos cultivos-animales puede contribuir a un crecimiento que es ecológica y económicamente sostenible. En estos sistemas, la intensificación del componente pecuario a menudo recibe menor atención que los cultivos, a pesar de que puede hacer una gran contribución para elevar la productividad del sistema de producción como un conjunto. Por otro lado, la intensificación de la producción de cultivos puede proporcionar dividendos para el componente pecuario y el manejo de los recursos naturales, especialmente mediante el aumento de la biomasa disponible. La intensificación y el mejoramiento de la eficiencia en la producción pecuaria significan menos gases de efecto invernadero por unidad de leche producida y más leche por unidad de agua. En este documento se sostiene que las oportunidades y los desafíos justifican una mayor inversión en investigación para identificar en forma exacta dónde y cómo se logran resultados que sean beneficiosos para ambos componentes y qué incentivos, políticas, tecnologías y otras características de un entorno propicio son necesarios para el desarrollo de los sistemas mixtos cultivos-ganadería sostenibles, integrados y productivos.

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The global importance of mixed crop-livestock systems

Mixed crop-livestock systems produce 50% of global cereals, 34% of beef and 30% of milk. Almost one billion people rely on these systems as their primary source of livelihood (Herrero et al. 2009). A recent review and update of global farming systems assessments stressed the importance of including how crops and animals are produced and how they interact, if such information is to be used in the context of priority setting and targeting related to livelihoods (Robinson et al. 2011).

The extent and importance of these systems for livelihoods, food security and natural resource management, against a backdrop of growing demand for food, need to be balanced against potentially negative impacts on natural resources and the environment. These arise where systems have already reached a limit of natural resource use (Herrero et al. 2009), or where the environmental footprint per unit of product is high due to low animal productivity. Key interactions in integrated mixed systems relate to the following factors:

Feeding

Straw, stover and other fibrous by-products of cereal and legume production, thinnings and weeds make important contributions to ruminant diets in a wide range of agroecologies and farming systems. The role of crop residues in semi-arid areas with low and erratic rainfall is particularly significant; they may be the only source of feed in late dry seasons or drought periods (Valbuena et al. 2012).

Organic soil nutrients

Livestock manure can contribute to the nutrient needs of the crops and help to maintain soil organic matter and beneficial physical properties, such as water and nutrient retention capacities. In remote areas with inefficient supply chains for inorganic fertilizers, livestock manure can be the only source of applied nutrients. Liu et al. (2010) estimate that 23% of the nitrogen for crop production in mixed systems comes from livestock.

Provision of power

Draught or dual-purpose cattle and equines ease the drudgery and burden of hand cultivation, harvesting and other cropping operations and increase crop yields. Despite increased mechanization, animal traction continues to play an important role, especially in sub-Saharan Africa (FAO 2011).

Cash flows

The importance of cash income from livestock, which can be reinvested in another enterprise, is often ignored in considering crop-livestock integration; yet this can be very significant. In Southern Zimbabwe, for example, women sell goats to purchase inputs for their cropping enterprises, amongst other needs (Homann et al. 2007).

Integrated systems - key drivers and trends

Integrated crop-livestock systems are under considerable pressure due to rapidly rising human populations in developing countries. In addition, the trend towards increased urbanization and rising incomes in these regions leads to shift in diets – less reliance on staples (cereals and tubers); more demand for better quality and more diverse diets made up of more fruit and vegetables; and much more meat, milk, eggs and fish – the animal-source foods (Delgado et al. 1999; FAO 2011; Otte et al. 2012).

The rising demand presents environmental, economic and social challenges, such as land and water degradation, greenhouse gas emissions and smallholder marginalization. It also presents opportunities for some (not all) crop-livestock systems to be part of a positive livestock-sector transformation in developing countries (Tarawali et al. 2011). Balancing these issues necessitates addressing the current low productivity of mixed crop-livestock systems and their unfavorable environmental footprint, in the context of a complex of both technological and institutional dimensions (Pretty et al. 2011). Such a positive trajectory will include a shift from smallholders raising many low-producing animals to fewer, more productive livestock in efficient and market-linked systems. This is what is referred to here as intensification of livestock production – not a shift to industrial-style systems. In some instances, the route will facilitate a transition from agriculture-dependent livelihoods to other options, including establishment of small businesses and access to better educational opportunities for children, which opens a wider range of opportunities than were available to their parents – options which will increasingly become available to those who remain part of a vibrant, carefully managed agricultural sector too. While intensification and greater market orientation can provide additional investments for further crop-livestock intensification, migration and diversification can lead to household labor shortages on the farm. Both, however, can also be drivers for yet further intensification – or, alternatively, facilitate orderly exit from the sector.

Compared with trends in Asia, cereal yields in Africa have increased at a much slower rate; this is due to multiple factors, including poor agro-ecological conditions and governance, lack of efficient input-supply systems and dysfunctional output markets (FAO 2012). The story is similar for livestock. Africa is still characterized by large numbers of unproductive livestock and high livestock mortality rates, often above 20% per annum. Low off-take rates, typically below 3% per annum, suggest a huge potential for economic benefits if the losses could be prevented and transformed into marketable products (van Rooyen and Homann 2009).

Fortunately, there are islands of success in Africa, such as the Kenya dairy sector. Here smallholders are doing much better: best-practice technology and management options have been adopted; input and output markets function; natural resources are sustainably managed; and high-quality crops and animal-source foods are produced in an appropriate policy environment, generating a net present value of US$230 M, which is benefiting producers, consumers and vendors (Kaitibie et al. 2010).

Coupled nature of crop-livestock interactions – need for sustainable intensification

Herrero et al. (2009; 2010) distinguish 2 classes of crop-livestock systems, which differ in their degree of intensification and potential for further growth. Mixed intensive systems have higher population density, high agro-ecological potential, especially through irrigation, and good links to markets with some purchased inputs being regularly used. In contrast, mixed extensive systems have medium population density, moderate agro-ecological potential, are largely dependent on rain-fed agriculture and use few purchased inputs. The latter systems have potential for sustainable intensification, the former have in many cases reached limits in terms of biophysical aspects and some may need to de-intensify.

Market orientation and strong and growing demand for food provide powerful incentives for intensification and greater efficiency of both crop and livestock enterprises in smallholder mixed systems in Africa. We also present below some ideas on how to exploit the mutually reinforcing nature of crop-livestock systems to raise productivity in a manner that is both ecologically and economically sustainable.

In mixed systems intensification of both crop and livestock production is needed

Livestock are often the neglected element of mixed systems; research, development and extension efforts tend to favor intensification of staple crops, despite consistent evidence that 4 out of 5 of the highest value commodities are livestock products (FAO 2013). A recent study of intensification from 72 villages across the Indo-Gangetic Plain (Erenstein and Thorpe 2010) illustrated the effects of lagging livestock intensification; although crop production has intensified, livestock systems have not. Lack of intensification of livestock production contrasts with policy initiatives in the crop sector, such as heavy subsidies for fertilizer and irrigation. This asynchrony in the pace of crop and livestock intensification has environmental implications; for example, low-producing animals are less likely to be housed and more likely to consume crop residues from the field with implications for both residue and manure management and use – key dimensions of integrated systems. In sub-Saharan Africa, Haileselassie et al. (2009) showed that mixed systems have higher water productivity than crop production alone. Descheemaeker et al. (2010) reinforced such results, providing examples of 3-fold increases in water productivity for mixed as compared with single enterprise systems and explored the supporting policy and institutional issues.

Intensification of crop production can pay dividends for livestock and the environment

Crop residues are a key element of the interaction between crops and livestock in mixed systems. However, competing uses for residues are numerous and include livestock feeding, retention as sources of soil organic matter, use as household fuel and for construction, and sales to others for all these and other uses. Results from a recent 9-country study spanning sub-Saharan Africa and South Asia showed that, across all locations, livestock feeding accounted for a major proportion of crop residue use. Evidence showed that some mulching was practiced but only in the most intensive sites; elsewhere there was almost no allocation of crop residues to soil improvement. Continual removal of crop residue biomass will deplete soil organic matter and is unsustainable in the long term (Valbuena et al. 2012). The study illustrates the pressure on biomass in smallholder systems and indicates the need to increase biomass productivity. Sustainable intensification (Pretty et al. 2011) of mixed crop-livestock systems is one of the answers: although crop residues might be allocated to livestock feeding, manure can then be applied to the soil and income from sales of livestock products can be used to buy fertilizer to drive increases in crop productivity, including of improved dual food-feed crops or even forage crops, with the overall result being increased farm productivity.

Intensification of livestock production can reduce greenhouse gas production

Livestock production is often associated with high usage and pollution of water and greenhouse gas emissions (Steinfeld et al. 2006). In smallholder systems, however, livestock intensification will be essential to curb the negative environmental consequences associated with the sector, especially decreasing greenhouse gas emissions and reducing the amount of water used per unit of meat or milk produced (Capper 2011).

In India, increasing the milk yield from the current national average of 3.6 L per buffalo or cow per day to 15 L per day, which is considered attainable with current genetic quality, would roughly halve emissions per liter of milk produced (Tarawali et al. 2011). A large proportion of the water used in livestock production is used to produce feed, so increasing animal productivity has a dramatic effect in reducing the amount of water used per unit of livestock product (Descheemaeker et al. 2011).

Key considerations in increasing productivity and reducing environmental impacts include reallocation of available feed resources to fewer animals, increased per animal production and reduced numbers of animals. Plant breeders can select for improved crop-residue quality without reducing grain yield; this approach has now been adopted in a number of crop-breeding programs to produce better dual-purpose crops (Blümmel 2010).

Conclusion and ways forward

Mixed crop-livestock systems make vital contributions to global food supply and livelihoods. The contribution of livestock in these systems is, however, often neglected by research, development and extension organizations relative to crops. There is considerable potential, however, for a win-win situation, in which greater productivity of crops and livestock is achieved in a more environmentally sustainable manner, if the integration of crops and livestock in mixed systems is improved. A key challenge is how best to allocate biomass resources in these systems. The opportunities and challenges justify significantly more investment in research for development to identify exactly where and how win-win outcomes can be achieved and what incentives, policies, technologies and other features of the enabling environment are needed to encourage sustainable, integrated and productive mixed crop-livestock systems.

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Impact of tropical forage seed development in villages in Thailand and Laos: Research to village farmer production to seed export

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Abstract

Seed of 6 forage varieties, Mulato II hybrid brachiaria, Cayman hybrid brachiaria, Mombasa guinea, Tanzania guinea, Ubon stylo and Ubon paspalum, are currently being produced by more than 1000 smallholder farmers in villages in north-east Thailand and northern Laos, under contract to Ubon Forage Seeds, Faculty of Agriculture, Ubon Ratchathani University, Thailand. The seed is mainly exported overseas (95%) and the remainder is sold within Thailand. Tropical Seeds LLC, a subsidiary of the Mexican seed company, Grupo Papalotla, employs the seed producing and seed research group, Ubon Forage Seeds, to manage seed production, seed sales and export, and to conduct research on new forage species. This paper discusses in detail how the development in villages of a smallholder farmer seed production program has had positive social and economic outcomes for the village seed growers and enabled farmers in other countries to receive high quality forage seeds. The strong emphasis on seed quality, high purity, high vigor and high germination, has had a large impact on tropical pastures in more than 20 tropical countries in Asia, Africa, the Pacific and Central and South America.

Resumen

En el noreste de Tailandia y en el norte de Laos, aproximadamente 1000 pequeños productores, en contrato con Ubon Forage Seeds, Faculty of Agriculture, Ubon Ratchathani University, Tailandia, producen semillas de *Brachiaria* híbridos cvs. Mulato II y Cayman; de guinea (*Panicum maximum*) cvs. Mombasa y Tanzania; de stylo (*Stylosanthes guianensis*) cv. Ubon stylo; y de paspalum (*Paspalum atratum*) cv. Ubon paspalum. Estas semillas se exportan principalmente a otros países (95%); el resto se vende en Tailandia. Tropical Seeds LLC, subsidiaria de la compañía mexicana de semillas Grupo Papalotla, emplea el grupo de producción e investigación Ubon Forage Seeds para manejar, vender y exportar la producción de semilla y conducir la investigación en nuevas variedades de forrajeras. En este documento se discute en detalle cómo un programa de producción de semillas ha contribuido positivamente al desarrollo social y económico de comunidades de pequeños productores de semilla y ha hecho posible que productores de otros países se beneficien por el uso de semillas de buena calidad. El fuerte énfasis en la calidad, alta pureza, alto vigor y alta germinación de las semillas ha tenido un gran impacto en pasturas tropicales de más de 20 países de Asia, Africa, la región del Pacífico, Centro y Sur América.

Introduction

Seed of 6 forage varieties, Mulato II hybrid brachiaria (*Brachiaria ruziziensis* x *B. decumbens* x *B. brizantha*), Cayman hybrid brachiaria (*B. ruziziensis* x *B. decumbens* x *B. brizantha*), Mombasa guinea (*Panicum maximum*), Tanzania guinea (*P. maximum*), Ubon stylo (*Stylosanthes guianensis*) and Ubon paspalum (*Paspalum atratum*), is currently being produced by more than 1000 smallholder farmers in villages in northeast Thailand and northern Laos. The seed, 150 t in 2013, is mainly exported overseas (95%) and the remainder is sold within Thailand.

Tropical Seeds LLC, a subsidiary of the Mexican seed company, Grupo Papalotla, employs a seed producing and seed research group, Ubon Forage Seeds in the Faculty of

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Agriculture, Ubon Ratchathani University, to manage seed production, seed sales and export, and to conduct research on existing and new forage species. The decision to produce seed in Thailand was because of forage seed quality, smallholder experience and professionalism (Hare 1993) and Ubon Ratchathani University's involvement in forage seed production (Hare and Horne 2004; Hare 2007).

This paper discusses in detail the seed production of the 6 varieties and how the development in villages of a smallholder farmer seed production program has had positive social and economic outcomes for the village seed growers and enabled many smallholder farmers in other countries to receive high quality forage seeds.

Mulato II and Cayman hybrid brachiaria

Seed research

Producing good seed yields of Mulato II and Cayman has been very difficult to achieve. Both produce sufficient inflorescences, racemes and spikelets to indicate a potential for useful seed yields. However, by seed harvest, there is usually a massive failure of seed set, caryopsis maturation or both, with the cleaned seed containing less than 9% of the spikelets formed by the crops. The subsequent failure of seed set is probably due to pollen sterility (Risso-Pascotto et al. 2005) and this sterility is genetic.

A series of field trials have been conducted in an endeavor to increase seed yields through agronomic management. The trials have been mainly with Mulato II but the results can be applied to Cayman (Pizarro et al. 2013). Field trials have been on time of planting (Hare et al. 2007a), closing date (Hare et al. 2007b) and methods of seed harvesting (Hare et al. 2007c). Through this research, seed yields have increased from 250 to over 600 kg/ha.

Farmer seed production

Seed production of Mulato II and Cayman in Thailand is managed by Ubon Forage Seeds and in Laos by Happy Farmers Co. Ltd. Thailand seed is produced in Nong Saeng village, Roiet province (130 masl, 16° N) and in Laos in several villages in Nga district, Oudomxay province (500 masl, 23° N). In Thailand, the seed is swept from the ground but in Laos the seeds are knocked from seedheads tied together. Farmers in Thailand treat Mulato II as an annual crop, replanting each year. This is because Mulato II seed crops, grown on very poor soils in Thailand, produce uneconomic seed yields in the second and subsequent years, even with fertilizer. In Laos, on richer soils without fertilizer, many farmers have been producing consistently good yields (300 kg/ha) for over 5 years.

At Ubon Ratchathani University all Mulato II and Cayman seed is treated with sulphuric acid to remove the lemma and palea husks to improve seed germination, and is washed, dried and recleaned before packaging for sale and export. After acid-scarification, Mulato II and Cayman seeds average 88–91% viability (tetrazolium test), 70–90% germination and over 99.5% purity. Without acid-scarification, the seed never exceeds 30% germination. Even long-term storage will not increase germination, due to the physical dormancy imposed by the tightly bound lemma and palea husks (Hare et al. 2008).

Yields from ground-harvested Mulato II seed in Thailand have averaged 400 kg/ha since 2009 and many farmers are now harvesting over 630 kg/ha. Thailand production has increased from just under 10 000 kg in 2009/10, produced by 45 farmers, to 41 000 kg in 2012/13, produced by 107 farmers.

In Laos, seed production has increased from 155 farmers in 9 villages producing 2205 kg in 2007/08, to 600 farmers in 30 villages producing 28 000 kg in 2012/13.

Mombasa and Tanzania guinea grasses

Farmer seed production

In 2008, Ubon Forage Seeds first started producing Mombasa guinea seed for Tropical Seeds, mainly for export back to Mexico. Because Mombasa is a large, leafy and very productive grass, a strong market has recently developed for Mombasa in Asia. In 2010, Tropical Seeds asked Ubon Forage Seeds to start producing Tanzania guinea seed for export to Central America, because they wanted seed of pure true-to-type Tanzania guinea, without contamination by common varieties.

We have relied on farmer experience in producing Tanzania seed for several years (Phaikaew et al. 1995) to use the same methods to produce Mombasa seed.

Strong winds in October can be a major problem, blowing a lot of good seed to the ground. In the case of guinea grass seed, farmers do not sweep fallen seed from the ground. Seed yields of Mombasa guinea have ranged from 318 kg/ha in 2008 to 492 kg/ha in 2012.

In the past there has been too much light and empty seed in the farmers' guinea seed we purchased and it had to be cleaned again at the university, losing over 20% in weight in some instances. To overcome this problem, starting in 2010, small seed cleaners with a strong air blast were manufactured and given free to the seed growers. These cleaners have been very successful, as the farmers are able to clean their seed to over 99.5% purity, with seed of a high thousand seed weight (Mombasa 1.54 g; Tanzania 1.20 g). No further cleaning needs to be done at the university for sale and export.

Ubon stylo

Seed research

Ubon stylo produced 2.6 times the seed yield of Tha Phra stylo (*Stylosanthes guianensis*) (959 vs. 365 kg/ha) in a field trial at Ubon Ratchathani University. Closing stylo seed crops in September doubled seed yield over closing in October (Hare et al. 2007d). Germination tests on 1-year-old stored Ubon stylo seed (Hare 2007) showed that hot water and machine-scarification significantly increased germination and reduced hard and dead seed. Without scarification, seed germination was less than 10%. These days, we acid-scarify the stylo seed because it is relatively easy to do, and very high germination (99%) can be achieved.

Farmer seed production

All Ubon stylo seed is swept from the ground in January–February. Then it is acid-scarified at the university to remove soil and the thin pod integuments, and to soften the seed coat for maximum germination. The farmers' yields currently average more than 1000 kg/ha.

Ubon paspalum

Seed research

Field trials have been conducted on method and time of planting (Hare et al. 2001a), method of harvesting and closing date (Hare et al. 1999). A growth room study confirmed Ubon paspalum as a long-short day plant exhibiting a quantitative response to long days followed by a qualitative response to short days (Hare et al. 2001b).

Farmer seed production

Ubon paspalum seed is currently produced in only one village in Thailand because the market demand for seed is very small. Flowering is well synchronized and it is the first seed crop harvested each year with harvesting taking place in late September–early October.

Profitability of smallholder forage seed production in Thailand and Laos

Forage seed crops are far more profitable than rice in Thailand (Table 1), but forage seed crops cannot be planted on the low-lying, waterlogged paddies, where only rice can be grown. Mulato II is the most profitable forage seed crop, because yields from ground-swept seed are now consistently between 500 and 650 kg/ha.

Cassava is the main competitor with forage seeds for land in Thailand, particularly seed crops of Mombasa, Tanzania and Mulato II. Cassava is a relatively easy crop to grow and with the tubers in the soil, there is no risk of losing seed from climate variations as with grass seed crops. If cassava prices increase to more than US$ 0.10/kg, many farmers would prefer to grow cassava. If the cassava price drops to US$ 0.08/kg, farmers will plant more forage seed crops.

Farmers in Nga district, Laos, do not hire any outside labor for their agricultural production. Crops are sown by hand, seed is free, no fertilizer, insecticides and herbicides are used, cultivation is by hand and no machinery is hired

Table 1. Estimated costs and gross and net income (US$/ha) from rice, cassava and forage seeds in northeast Thailand.

	Rice	Cassava	Ubon paspalum	Mulato II	Ubon stylo	Mombasa
Direct Costs						
Cultivation	125	125	125	125	125	125
Raising furrows		125			125	
Fertilizer	375	415	210	210	210	210
Labor for weeding		125	65	125	125	65
Labor for harvesting	125	210	125	335	335	125
Hire digger to dig up tubers		125				
Labor for cleaning/threshing	125	125	65	335	335	65
Transport	80	105				
Total Direct Costs	830	1355	590	1130	1255	590
Sale price (US$/kg)	0.50	0.09	3.00	6.00	3.35	3.35
Yield (kg/ha)	2500	25 000	565	500	810	500
Gross Income	1250	2250	1695	3000	2714	1675
Net Income	420	895	1105	1870	1459	1085

Table 2. Estimated yield and net income (US$/ha) from rice and Mulato II seed in Nga district, Oudomxay province, Laos.

	Rice	Cassava	Maize + Soybean		Mulato II
			Maize	Soybean	
Sale price (US$/kg)	0.25	0.05	0.08	0.30	4.00
Yield (kg/ha)	1500	25 000	3500	1500	278
Net Income	375	1250	280	450	1112

or used. No costs are incurred except for family labor and time, which are common to all these crops. Mulato II seed production is very profitable compared with upland glutinous rice grown on steep hillsides, producing 6 times the income (Table 2).

The major advantage of Mulato II seed is its relatively high value per kg and less bulk, which helps offset high transport costs from remote areas like Nga district to Thailand. In Laos, Mulato II is also proving to be a sustainable and environmentally friendly agricultural crop in Nga district, because it prevents erosion by providing a dense vegetative cover on the hill slopes and growing for many years, unlike upland rice and maize, which die after seed harvest and do not provide a ground cover.

Export

Ubon Forage Seeds has achieved an international reputation for very high quality tropical forage seed, emphasizing high purity, high vigor and high germination. The seeds from ground-harvested Mulato II and Ubon stylo are acid-scarified to remove soil particles and increase seed germination.

Mombasa, Tanzania and Ubon paspalum seed are all cleaned by the farmers to over 99% purity and dried to 10% seed moisture. Farmer groups are supplied with free seed cleaners to help them reach the required purity and seed-weight standards we set. We also supply the farmer groups with small scales and measuring jugs and they are instructed carefully on how to sample to test seed weight against volume. During the past 3 years, nearly 140 000 kg of seed have been exported to 22 countries and 6000 kg have been sold within Thailand. The main markets have been in Central America (84 000 kg), Asia (32 000 kg) and the Pacific region (23 000 kg). Africa is becoming an emerging market.

Conclusion

Forage seed production in northeast Thailand and northern Laos has become an economically viable and sustainable cash crop for more than 1000 smallholder village farmers. The seed is predominantly exported to dairy and beef cattle smallholder farmers in other tropical countries in Asia, Africa, the Pacific and Central and South America.

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Dry season forages for improving dairy production in smallholder systems in Uganda

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Keywords: Napier grass, East Africa, legumes, *Brachiaria*, milk yield, income.

Abstract

Economically feasible strategies for year-round feed supply to dairy cattle are needed to improve feed resource availability, milk yield and household income for the smallholder dairy farming systems that predominate in the rural Eastern and Central African region. Currently, Napier grass (*Pennisetum purpureum*) is the major forage in zero-grazing production systems, but dry-season production is often constrained. Our results from 24 farms show that sowing forage legumes, including *Centrosema molle* (formerly *C. pubescens*) and *Clitoria ternatea*, with Napier grass and *Brachiaria* hybrid cv. Mulato improved both yield of forage and protein concentration. Sowing of 0.5 ha Napier-Centro plus 0.5 ha of Mulato-Clitoria increased milk yield by 80% and household income by 52% over 0.5 ha Napier grass monoculture. Possible income foregone from the crops which could have been grown on the additional 0.5 ha must be considered in assessing the economic viability of the system.

Resumen

Para mejorar la disponibilidad, durante todo el año, del recurso forrajero, la producción de leche y el ingreso de las pequeñas fincas lecheras que predominan en África Oriental y Central, es necesario desarrollar estrategias económicamente viables. El pasto napier (elefante; *Pennisetum purpureum*) es el principal forraje en sistemas de producción con animales en confinamiento, pero su productividad en la época seca es limitada. Nuestros resultados, obtenidos en 24 fincas, muestran que sembrando leguminosas forrajeras, como *Centrosema molle* (sin. *C. pubescens*) y *Clitoria ternatea*, en mezcla con el pasto napier y el híbrido de *Brachiaria* cv. Mulato, se logra mejorar la producción de forraje y su concentración de proteína cruda. Con 0.5 ha de pasto napier-Centrosema y adicionalmente 0.5 ha de Mulato-Clitoria se logró un incremento del 80% en la producción de leche y del 52% en el ingreso de la finca, en comparación con 0.5 ha del pasto napier solo. Sin embargo, un análisis económico a nivel de sistema de producción debe tener en cuenta la ausencia de ingresos procedentes de un alternativo uso agrícola del área adicional de 0.5 ha.

Introduction

Smallholder dairy farming systems dominate in the rural Eastern and Central African region, employ over 70% of the region's population and contribute 70–90% of the total meat and milk output in the region (Njarui et al. 2012). Small-scale dairy production plays a crucial role in food security, human health and overall household livelihoods, particularly among climate change-prone resource-poor households in the region. Zero-grazing dairy systems are increasingly promoted, owing to grazing land shortage and intensive dairy production requirements. Women are immense contributors to and beneficiaries from smallholder dairy production systems (Njarui et. al. 2012), which are progressively being devastated by rapid climate change and its attendant extreme weather conditions. The availability of livestock feeds in rural households is being affected by climate change. The lack of effective adaptation to the adverse effects of climate change is likely to jeopardize the achievement of Millennium Development Goals 1 (eradicating extreme poverty and hunger), 7 (ensuring environmental sustainability) and 3 (promoting gender equality and empowering women) (United Nations 2010).

Napier grass (*Pennisetum purpureum*) is the major forage in zero-grazing production systems in Masaka district,

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Uganda (Kabirizi 2006). However, grass productivity is constrained by long droughts, poor agronomic practices, such as lack of fertilizer application and improper cutting frequency and cutting height, and by pests and diseases, the napier stunt disease being particularly important, resulting in a reduction in fodder yield of up to 100% during the dry season. *Brachiaria* hybrid cv. Mulato (Mulato) has high biomass yield and tolerates long droughts and poor soils (CIAT 2001) and could be used to complement Napier grass. It is recommended that Mulato be grown to provide forage, when Napier grass production is low.

It is generally recommended, furthermore, that forages be grown in grass-legume mixtures in order to not only ensure energy-protein balance for livestock, but also harness atmospheric nitrogen (N) via the legume component (Thomas 1995; Kabirizi 2006). Among the best-known, but not widely used forage legumes in Uganda are *Centrosema molle* (syn. *C. pubescens*; Centro) and *Clitoria ternatea* (Clitoria); both are deep-rooting and considered as drought-tolerant. However, regardless of whether sown as a monocrop or in mixture with a legume, the officially recommended 0.5-ha Napier grass area is not sufficient to provide year-round forage for 1 cow and its calf.

This study was designed to develop economically feasible strategies for year-round feed supply to dairy cattle in order to improve feed resource availability, milk yield and household income, by comparing in on-farm trials the newly introduced drought-tolerant Mulato with commonly used Napier, both grown with a drought-tolerant legume.

Methods

The study was conducted in Masaka district, Central Uganda (00°15'–00°43' S, 31°–32° E; 1150 m asl). Annual average rainfall is 800–1000 mm with 100–120 rainy days, in 2 seasons. Mean temperature ranges between 16 °C and 30 °C, while relative humidity is 62%. The district is typically dependent on crop-livestock systems, with vegetable production as a key income generator.

The study targeted zero-grazing dairy farmers with 1–2 cows and at least 2 ha of land. The treatments involved 2 grass-legume mixtures: Napier with Centro and Mulato with Clitoria. These mixtures were established as forage banks in 0.5 ha each on 24 randomly selected farms using methods described in Humphreys (1995) and CIAT (2001). The mixtures were compared with the farmers' practice of growing Napier grass alone. Farmers participated in all stages of project implementation to enhance rapid uptake of emerging knowledge and practices. The study was laid out in a randomized complete block design with household farms as replications. Fodder and milk yields from all 24 farms were recorded for 2 years. Dry matter yields and associated feeding periods were estimated using methods described by Humphreys (1995). Data were analyzed with costs of inputs and returns from milk (including home-consumed) recorded for profitability evaluation using partial budgeting.

Results and Discussion

Intercropping Centro with Napier grass increased fodder availability by 52%, crude protein (CP) concentration by 20% and feeding period (number of days a cow was able to feed on fodder from a given area of land) by 52% (Table 1). The Mulato-Clitoria mixture provided dry matter yields and a feeding period that were intermediate between the 2 Napier treatments but the increase in CP concentration was 73 respectively 44% higher.

Table 1. Fodder availability and quality, and feeding period for different forage banks. Figures refer to 2 years.

Parameter	Forage bank			s.e.
	Napier grass monocrop	Napier grass-Centro	Mulato grass-Clitoria	
Mean DM yield (kg/ha)	10 354	15 790	12 119	307
Feeding period from 0.5 ha (days)	167.0	254.6	195.5	20.9
Mean crude protein concentration (%)	7.0	8.4	12.1	0.14

Higher total fodder yields and CP concentrations in intercrops (Table 1) could be attributed to the presence of forage legumes that improved growth of the grass. The legume acted as a cover crop to control weeds and conserve soil moisture during the dry periods, apart from the possibility of augmenting N supply to the grass component through symbiotic N-fixation (Kabirizi 2006).

The results confirmed that the currently recommended acreage of 0.5 ha of a mixture of Napier grass with a forage legume (Samanya 1996) will produce additional forage of higher quality than Napier grass alone but cannot sustain an economically producing dairy cow and its calf for a full year. Therefore, establishment of an additional 0.5 ha of a mixture of the drought-tolerant Mulato with a forage legume is recommended for feeding during the dry season, when production of Napier grass monocrop is disadvantaged due to drought, the napier stunt disease and poor agronomic practices.

A second study was conducted comparing the beneficiaries of the drought-tolerant forage technology (0.5 ha Napier + Centro mixture plus 0.5 ha Mulato + Clitoria mixture) with the non-beneficiaries (0.5 ha Napier monocrop) (Table 2). There were no significant ($P>0.05$) differences in land size and number of cattle kept between

Table 2. Socio-economic benefits of integrating Napier grass-Centro and *Brachiaria* cv. Mulato-Clitoria in Napier grass-based farming systems.

Farm characteristics	Beneficiaries (n=24)		Non-beneficiaries (n=24)		F-test	IA[1]
	Mean	SD	Mean	SD		
Land size (ha)	1.7	1.2	1.6	0.9	0.12 NS	
Cattle (number)	1.5	0.5	1.3	0.7	0.03 NS	
Fodder area (ha)	1.1	0.3	0.5	0.3	14.4**	134.1
Feed offered/cow/d (fresh, kg)	55.4	12.3	31.4	7.2	5.7*	76.4
Milk yield (L/d)	10.6	7.2	5.9	3.1	4.3*	79.7
Revenue (US$) from milk yield/cow/yr	676.9	48.2	444	64.1	1.66 NS	52.4

[1]IA: Intervention advantage (%).

the beneficiaries and non-beneficiaries of the interventions but sowing 0.5 ha of each of the grass-legume mixtures improved milk yield and household income by 80 and 52%, respectively, over 0.5 ha Napier grass. The beneficiaries fed 76% more high-quality forage, i.e. the milk yield response was largely due to simply feeding more. Beneficiaries, however, had 120% more land sown to fodder, implying they were not harvesting as much forage per ha (if all harvested forage was fed to cows) or were able to sell fodder to others.

In assessing the overall benefits of this production system, it is important to remember that an extra 0.5 ha was sown to a grass-legume mixture and was no longer available for other agricultural purposes.

Conclusion

Replacing traditional Napier grass forage banks with grass-legume mixtures, including the drought-tolerant *Brachiaria* hybrid cv. Mulato and the deep-rooted legumes Centro and Clitoria, is a promising strategy for year-round feed supply to smallholder dairy cattle in Central and East Africa. The income foregone from the additional area sown to pasture must be taken into consideration in assessing the profitability of this practice.

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Understanding the causes of bush encroachment in Africa: The key to effective management of savanna grasslands

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Keywords: Rangeland degradation, fire, indigenous ecological knowledge, livestock grazing, rainfall variability.

Abstract

The increase in biomass and abundance of woody plant species, often thorny or unpalatable, coupled with the suppression of herbaceous plant cover, is a widely recognized form of rangeland degradation. Bush encroachment therefore has the potential to compromise rural livelihoods in Africa, as many depend on the natural resource base. The causes of bush encroachment are not without debate, but fire, herbivory, nutrient availability and rainfall patterns have been shown to be the key determinants of savanna vegetation structure and composition. In this paper, these determinants are discussed, with particular reference to arid and semi-arid environments of Africa. To improve our current understanding of causes of bush encroachment, an integrated approach, involving ecological and indigenous knowledge systems, is proposed. Only through our knowledge of causes of bush encroachment, both direct and indirect, can better livelihood adjustments be made, or control measures and restoration of savanna ecosystem functioning be realized.

Resumen

Una forma ampliamente reconocida de degradación de pasturas es el incremento de la abundancia de especies de plantas leñosas, a menudo espinosas y no palatables, y de su biomasa, conjuntamente con la pérdida de plantas herbáceas. En África, la invasión por arbustos puede comprometer el sistema de vida rural ya que muchas personas dependen de los recursos naturales básicos. Las causas de la invasión por arbustos no están lo suficientemente claras pero el fuego, los herbívoros, la disponibilidad de nutrientes y el patrón de precipitación han demostrado ser determinantes clave de la estructura y la composición de la vegetación de sabana. En este documento se hace un análisis del impacto de estos determinantes, con especial referencia a los ambientes áridos y semi-áridos de África. Para una mejor comprensión de las causas de la invasión por arbustos se propone un enfoque integrado que involucra sistemas ecológicos y de conocimiento autóctono. Solamente a través del conocimiento, tanto directo como indirecto, de las causas de la invasión por arbustos, será posible hacer los ajustes necesarios para una mejor calidad de vida o tomar las medidas de control y restauración de las funciones del ecosistema de sabanas.

Introduction

Savanna ecosystems are characterized by a continuous layer of herbaceous plants, e.g. grasses, and sparsely populated patches of trees and shrubs. The proliferation of woody plants in savanna ecosystems is known as bush encroachment (van Auken 2009) and an increase of 10% woody cover will lead to a 7% decline in grazing resources in East Africa (Oba et al. 2000). Subsequently, bush encroachment leads to reduced livestock carrying capacity of that particular ecosystem (Ward 2005). This has serious implications for food security, as large areas of arid lands occupied by millions of people are encroached by woody plants, leading to decline in agricultural productivity. For example, it has been indicated that agricultural productivity of 10–20 Mha in South Africa (Ward 2005) and 37 000 km² in Botswana in 1994 (Moleele et al. 2002) has been affected by bush encroachment, thereby threatening the sustainability of livestock production systems and human well-being.

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Bush encroachment has also been shown to have a positive impact on the savanna ecosystem, which is not widely acknowledged. Pastoralists in Africa have indicated that woody plants contribute significantly towards livestock feed, especially during drought periods (Moleele 1998; Kgosikoma et al. 2012a), thereby reducing the cost of supplementary feed. Yet, most grazing policies in Africa do not consider browse plants, when determining grazing capacity of a particular land. In addition, leguminous woody vegetation can improve soil quality through nitrogen fixation and could also contribute significantly towards carbon sequestration. That notwithstanding, there is a consensus between pastoralists and ecologists that the uncontrolled shift from grass-dominated savanna to a bush savanna ecosystem has a negative impact on sustainability of the savanna ecosystem as a whole.

Despite bush encroachment being observed in many grasslands and savannas in Africa and elsewhere, the mechanisms that promote it are not clearly understood (Ward 2005). Several factors, such as overgrazing, fire frequency, soil moisture, nutrients and global warming, have been associated with bush encroachment (van Auken 2009) but it is still controversial how each factor contributes to increased woody plant cover. Probably it will be difficult to attribute a single factor as the sole cause of bush encroachment (van Auken 2009), especially as most environmental factors are spatially correlated (Hernandez-Stefanoni et al. 2011). In this paper, commonly cited causes of bush encroachment are briefly reviewed and an integrated approach proposed for understanding causes of bush encroachment and sustainable management of savanna ecosystems.

Causes of bush encroachment

Suppression of fire

Regular burning suppresses woody plant growth by destroying the shrubs and juvenile trees and thus prevents their development into mature woody plants, which will be resistant to fire and be out of reach for browsers (Mphinyane et al. 2011). However, policy makers in Africa fail to recognize the importance of fire as a management tool in savanna ecosystems and thus prohibit burning of rangelands (Dalle et al. 2006). Subsequently, pastoralists and ecologists argue that lack of regular burning has allowed proliferation of woody vegetation (Kgosikoma et al. 2012a). Therefore, fire should be an integral part of management of savanna ecosystems.

In addition, savanna ecosystems are also overgrazed, such that there is limited fuel load to allow frequent burning at high intensity. Given the important role of fire, it is necessary to establish sustainable burning intervals (Fatunbi et al. 2008) and institutions that will control regular burning of savanna ecosystems. Otherwise, uncontrolled burning could increase pastoralists' vulnerability to impacts of drought and increase release of carbon into the atmosphere. Sustainable use of fire as a management tool therefore requires knowledge of future climatic conditions and the ability to minimize its negative impact, e.g. air pollution and carbon loss.

Rainfall variability

Savanna ecosystems are generally water-limited and subsequently bush encroachment is associated with inter-annual rainfall variability (Angassa and Oba 2007). In arid and semi-arid environments, the woody cover and density tend to increase with increasing mean annual precipitation (Sankaran et al. 2005). At the local scale, unusually high annual rainfall in multi-years promotes an increase in woody vegetation cover; encroacher plants like *Acacia mellifera* require at least 3 years of successive good rainfall to recruit successfully (Joubert et al. 2008). Increased soil moisture availability, particularly when there is limited competition from grasses, allows woody plant seedlings to survive and grow into bush thickets. By contrast drought, through restricted plant growth, seed germination and increased competition for limited water at high shrub densities, leads to death of some plants (Roques et al. 2001) and thus reduces bush encroachment. As a result, bush encroachment is a cyclic natural phenomenon influenced by recruitment and death of encroacher plants in response to rainfall patterns (Wiegand et al. 2006).

Soil properties

Sankaran et al. (2005) demonstrated that woody cover is negatively correlated with soil clay content. Thus, bush encroachment is likely to occur in sandy soil with low clay content as observed in the Kalahari sands of Botswana as illustrated in Figure 1 (Kgosikoma et al. 2012b). A broad-scale analysis of woody cover in African savannas also revealed that woody cover was negatively associated with soil nitrogen and therefore, increased nitrogen deposition may reduce bush encroachment (Sankaran et al. 2008). In a similar study, it was observed that woody cover had a complex and non-linear relationship with total soil phosphorus (Sankaran et al. 2008). On the contrary, other authors have indicated that soil type had no significant impact on shrub dynamics in African savannas (Roques et al. 2001).

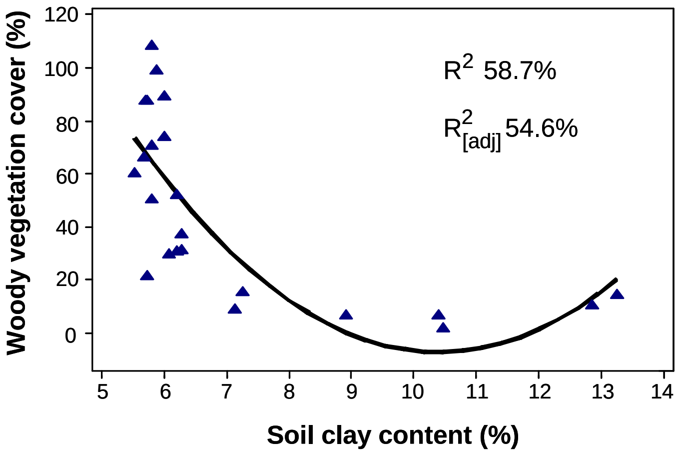

Figure 1. Relationship between woody cover and soil clay content across savanna ecosystems of Botswana (Kgosikoma et al. 2012b).

Overgrazing

In Africa, most rangeland degradation, including bush encroachment, is associated with high cattle density around the boreholes and kraals (van Vegten 1981; Moleele and Perkins 1998). This thinking is supported by the declining density of encroacher plant species with increasing distance from water sources along grazing piospheres. In communal grazing lands of Botswana, the bush encroachment zone has been observed between 0 and 300 m from foci (boreholes), where there is high concentration of grazers (Moleele et al. 2002). The possible explanation is that overgrazing suppresses the dominance of grass species and favors the growth and multiplication of woody species, because they then have increased access to available soil moisture (Skarpe 1990). Grazing also indirectly contributes towards bush encroachment through dispersal of encroacher plants' seeds. Plants like *Dichrostachys cinerea* and *Grewia flava* are highly palatable and are therefore largely consumed by livestock and their seeds are deposited with animal fecal material around boreholes and subsequently recruited in high numbers in these areas. In contrast, other studies have shown that grazing pressure is not significantly related to bush cover (Oba et al. 2000).

Integrated approach needed to understand causes of bush encroachment

Savanna ecosystems are complex and simple models that focus on a single variable are not likely to help us understand causes of bush encroachment, partly because there will be confounding effects of other factors not accounted for in such studies. It is highly likely that the causes of bush encroachment discussed above interact to facilitate the establishment and dominance of bushy vegetation as suggested by van Auken (2009). Therefore, understanding causes of bush encroachment requires an integrated approach that will ensure that both scientific ecological and indigenous ecological knowledge are applied (Sop and Oldeland 2011) as shown in Figure 2. This approach also ensures that strategies adopted to address the problem are economically, culturally and environmentally suitable for the local conditions.

In the African context, there are limited long-term ecological data and the indigenous ecological knowledge on vegetation and other environmental changes accumulated through long-term observation and land use (Allsopp et al. 2007) could complement the scientific knowledge by providing a long-term perspective on vegetation change and underlying causes (Bart 2006). Most rangeland development projects have failed because they focused on addressing the technological aspect, without addressing the socio-economic factors (Squires et al. 1992). Therefore, the use of both scientific and indigenous ecological knowledge ensures that a common goal is set and strategies (policy) adopted to curb bush encroachment also take into consideration the livelihood of that particular community. New grazing policies need to promote transparent decision making that is flexible to changing circumstances, and embraces a diversity of knowledge and values. Given that factors such as rainfall and soil properties are not manipulative, management of bush encroachment needs to focus on regulating grazing pressure and optimum burning intervals.

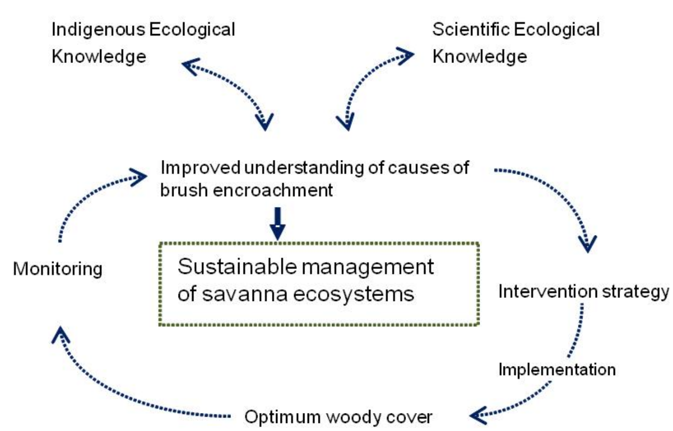

Figure 2. Schematic outline to understanding bush encroachment dynamics.

Conclusion

Bush encroachment is one of the most widespread forms of land degradation in African rangelands and elsewhere. Sadly, its exact causes are still one of the least understood. Rural communities, the majority of whom are dependent on range resources, will have to be assisted to reverse bush encroachment or to adapt accordingly to the new environment. Success in controlling bush encroachment requires improved understanding of underlying causes and an integrated approach provides an opportunity to widen our knowledge on dynamics of bush encroachment. There are few comprehensive studies, e.g. Sankaran et al. (2008), that investigate dynamics of woody vegetation across broad environmental conditions and therefore future research on bush encroachment should include multi-variables.

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Identifying and addressing sustainable pasture and grazing management options for a major economic sector – the north Australian beef industry

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Keywords: Simulation modeling, grazing systems, stocking rate, economics, range condition, beef cattle.

Abstract

Sustainable use of Australia's northern grazing lands is a long-standing issue for management and policy, heightened by projections of increased climatic variability, uncertainty of forage supplies, vegetation complexes and weeds and diseases. Meat & Livestock Australia has supported a large study to explore sustainable grazing management strategies and increase the capacity of the sector to address climate change. Potential options were explored by bio-economic modeling of 'representative' beef enterprises defined by pastoralists and supported by regional research and extension specialists. Typical options include diversification, infrastructure, flexible stocking rates, wet season resting and prescribed fire. Concurrent activities by another team included regional impact assessments and surveys of pastoralists' understanding of and attitudes towards climate change and adaptive capacity. The results have been widely canvassed and a program of on-ground demonstrations of various options implemented. The paper describes the structure of this program and highlights key results indicating considerable scope to address sustainability challenges.

Resumen

El uso sostenible de las pasturas en el norte de Australia, mayormente sabanas arboladas, es un tema de manejo y política de larga data, agudizado por las proyecciones de incremento de la variabilidad climática, la incertidumbre en el suministro de forrajes, lo complejo de la vegetación, las malezas y las enfermedades. Meat & Livestock Australia, una organización de ganaderos australiana, ha apoyado un amplio estudio para explorar estrategias de manejo sostenible y aumentar la capacidad del sector para abordar los efectos del cambio climático. Las opciones potenciales se exploraron mediante el modelamiento bioeconómico de empresas ganaderas 'representativas', definidas por los productores con el apoyo de investigadores y extensionistas regionales. Las opciones típicas incluyen diversificación, infraestructura de las pasturas, carga animal flexible, descanso del pastoreo durante la época de lluvias y quemas controladas. Actividades simultáneas desarrolladas por otro equipo de trabajo incluyeron evaluaciones del impacto regional y encuestas sobre la percepción y actitud de los ganaderos respecto al cambio climático y su capacidad de adaptación. Los resultados han sido ampliamente divulgados y un programa demostrativo de varias opciones fue puesto en marcha. En el documento se describe la estructura de este programa y se resaltan los resultados más importantes los cuales indican un amplio margen para hacer frente a los desafíos de sostenibilidad.

Introduction

The north Australian grazing lands span ~2.3 Mkm^2 and carry ~14 M cattle. Resource heterogeneity, climatic variation and poor grazing management have caused landscape degradation and reduced ecological services (Tothill and Gillies 1993) and much research has been invested in exploring sustainable management practices. In 2009 Meat & Livestock Australia initiated the Northern Grazing Systems (NGS) project, to identify and extend sustainable herd and land management strategies for 9 major bio-regions, involving: (1) scientific reviews

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of past research; (2) regional pastoralist workshops to explore options and define 'representative enterprises' for modeling; (3) bio-economic modeling of the impacts the most promising 'best bet' options have on landscape degradation and production, under current and projected climate regimes; and (4) applied testing and extension of the 'best-bet' options. Concurrent activities included assessments of regional impacts and pastoralists' understanding of and attitudes to climate change and adaptive capacity (Stokes et al. 2012). The bio-economic modeling component explored the production, resource condition and financial implications of northern beef enterprises adopting more promising strategies that were revealed through the science review and pastoralist workshop phases. Simulation of these strategies combined a pasture and animal production model (GRASP) with a dynamic beef herd economic model (ENTERPRISE) calibrated to mimic representative beef enterprises defined by the regional workshops.

Four herd and pasture management strategies were explored in each region: (a) Stocking rates − fixed versus variable stocking rates; (b) Wet season pasture spelling systems − variable paddock rotations, spelling commencement and duration; (c) Prescribed fire for woody vegetation control − fire regimes of varying frequency, starting tree basal area etc.; and (d) Infrastructure − strategic expansion and location of stock waters, fencing etc. The modeling process is illustrated with a comparison of fixed and variable stocking rates strategies in the Fitzroy River region using a hypothetical farm located at Duaringa, Queensland.

Methods

Overall NGS Process

The NGS strategy incorporated the following aspects: (1) Formally review past research conducted across northern Australia to identify central themes and underlying principles that might be applied to management in the regions (McIvor et al. 2010); (2) Present strategies built around these themes at workshops of pastoralists, research and extension specialists in 9 agro-ecological regions, and those of interest listed for further exploration by simulation modeling of a representative beef enterprise defined for each region; (3) Application of bio-economic modeling to the selected strategies of interest; (4) Canvass modeling results at a second series of regional workshops and refine the scenarios where appropriate. The workshop outcomes in conjunction with the initial research review provided insight into further research to fill knowledge gaps or follow through on technical questions raised by the modeling effort; and (5) Conclusions from the workshops and modeling process were used to support on-property confirmation and demonstration trials based on the most promising herd and pasture management strategies for each region.

Bio-Economic Modeling

The modeling method and outcome are illustrated for 1 of the 9 regions, Fitzroy in central Queensland [full details of all regions are presented in Scanlan and McIvor (2010)]. A representative beef enterprise, defined at a workshop in Emerald in April 2009, is characterized as a 10 500 ha property located near Duaringa [23.71^{o} S, 149.67^{o} E; 94 m asl; average annual rainfall (1885–2006) = 704 mm, average annual rainfall (1980–2006) = 613 mm] comprising 15 paddocks of native and sown pastures carrying ~1200 breeding cows and turning off ~600 kg/head slaughter bullocks. Starting paddock condition varies from 'B − good' to 'C − poor and degraded' as rated against a 4-category system (Chilcott et al. 2003).

Pasture yield, annual carrying capacity and animal liveweight gain for the management practices under review are estimated for each paddock using the GRASP pasture simulation model (McKeon et al. 1990). Annual liveweight gain (kg/head/yr) is simulated as a function of forage utilization and growing season length (green days). Land condition impact is assessed through a combination of % perennial grasses in the pasture sward and grass basal area (Scanlan et al. 2011). Projected liveweight gain and stocking rate for each paddock are input to the ENTERPRISE herd economic model (MacLeod and Ash 2001), that allocates the herd across the 15 paddocks. Herd fertility and mortality rates, which underpin the herd population dynamics, are estimated from the liveweight gain projections using regression equations based on herd records from Swans Lagoon Research Station (MacLeod and Ash 2001). ENTERPRISE projects total animal numbers by sex and age class, animal turnoff rates for each year of a simulation trial and a range of profit metrics, including gross margins, net profit and ranges for these measures. Simulations of 25 years were run using climatic data for Duaringa from 1986 to 2010.

Modeling example − fixed versus variable stocking rates

Declining pasture condition is typified by reductions in % palatable perennial grasses, increases in annual grasses and forbs and also the amount of bare ground (McIvor and Orr 1991). Adopting conservative or flexible stocking rates is argued to be critical for sustainable pasture management (McKeon et al. 1990). The example simulation compares a fixed stocking rate strategy with 2 strategies that allow variation in annual stocking rate in response to changing seasonal conditions and associated forage availability. The 'safe' fixed stocking rate is set for each paddock at the assessed long-term safe utilization rate (~20–25%) of standing pasture dry matter at the end of the growing season. The 2 variable strategies are defined as *seasonally responsive* and *constrained variation*. The *seasonally responsive* strategy has a stocking rate in each paddock set each year according to a safe utilization rate of standing dry matter (20–25%) at the end of the growing season and remains unchanged for the following 12 months. The *constrained variation* strategy allows no more than a 10% increase or 20% decrease in stocking rate between individual years subject to annual safe utilization limits and an absolute limit of 20% above or 40% below the stocking rate that is set at the start of the simulation period. Comparisons were made of simulation outputs for each paddock over the 25-year simulation period.

Results

The representative enterprise included 7 land/vegetation types in 15 paddocks, 9 of which were in B condition and 6 in C condition. The GRASP simulation results are presented for one of the 15 paddocks and its constituent land class − a cleared paddock comprising brigalow-blackbutt (*Acacia harpophylla-Eucalyptus cambageana)* vegetation type in B condition at the commencement of the simulation.

Stocking rate

The fixed stocking rate is set in accordance with the safe utilization rate estimated for the average rainfall of the simulation run. The flexible stocking rates fluctuate within the limits defined above. The 2 variable stocking rate strategies decreased the carrying capacity of the paddock by the end of the simulation period (Figure 1). This is largely because of pasture damage caused by holding excessive numbers of stock on pastures when good rainfall years are followed by poor rainfall years (Scanlan and McIvor 2010). The fixed stocking rate by definition did not change over the simulation period.

Pasture condition

The impact of stocking rates on pasture condition as measured by % composition of perennial grasses in the sward is presented in Figure 2. The seasonally adjusted stocking rate strategies can potentially reduce cattle numbers when forage availability is low, and reduce overgrazing risk. However, all 3 strategies overshot animal numbers early in the simulation period, with subsequent decline in % perennials (Figure 1). The more restrictive constrained strategy, unlike the seasonally constrained strategy, prevented sufficient reduction in cattle numbers to stop serious pasture damage, which led to a longer recovery at the end of the simulation (Figure 2).

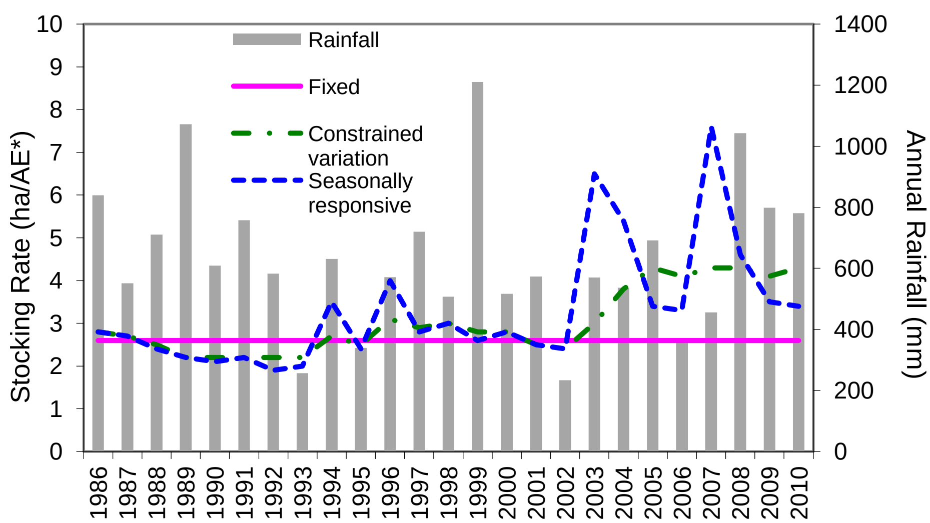

Figure 1. Projections of annual carrying capacity for 3 stocking rate strategies on B condition cleared brigalow-blackbutt pasture, Duaringa (1986–2010). *1 Adult Equivalent (AE) = 455 kg beast.

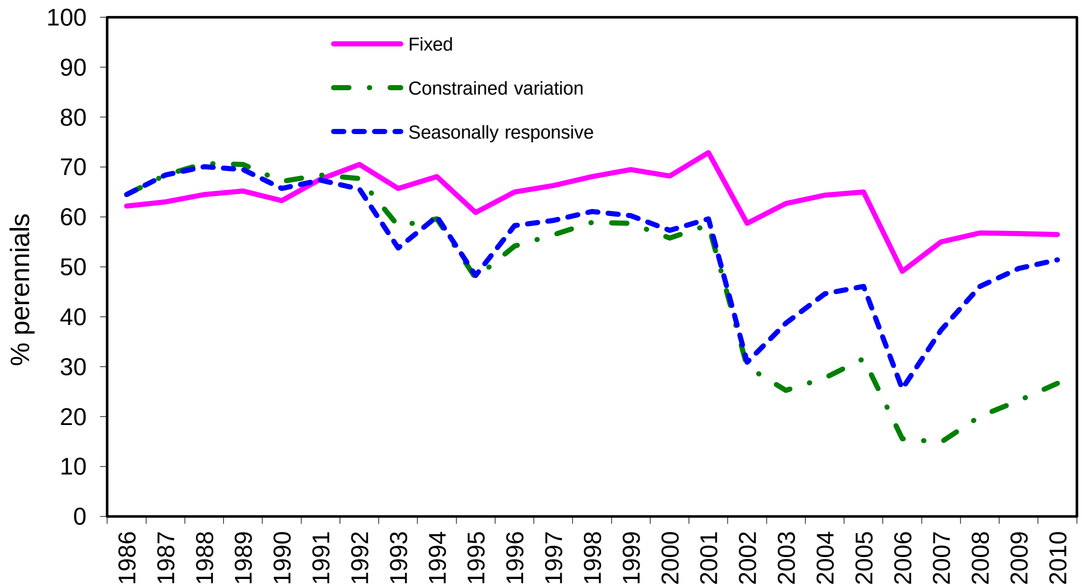

Figure 2. Projections of % perennials for 3 stocking rate strategies on B condition cleared brigalow-blackbutt pasture, Duaringa (1986–2010).

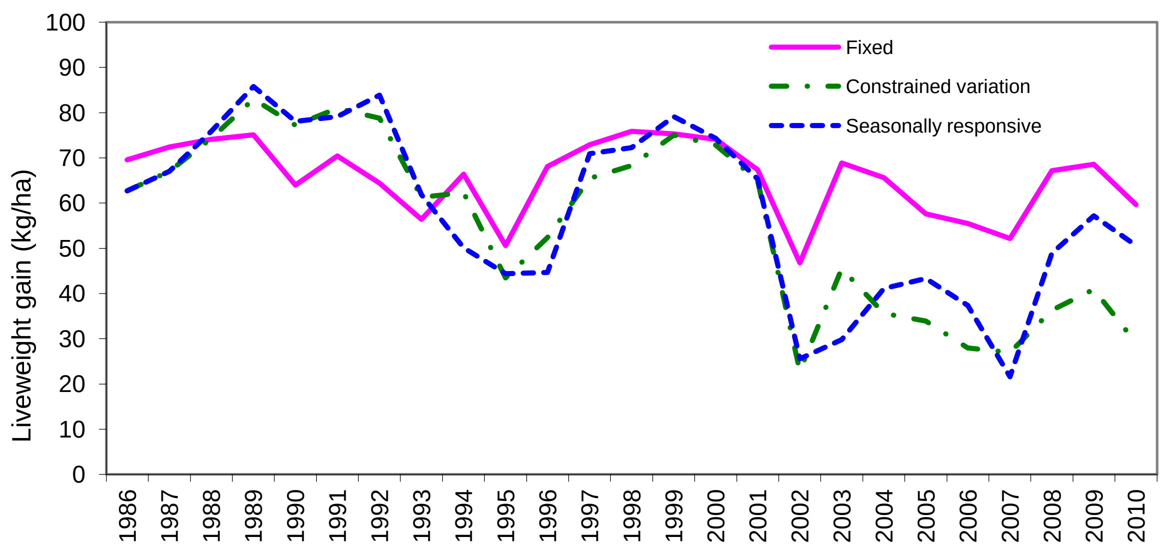

Figure 3. Projections of liveweight gain per hectare for 3 stocking rate strategies on B condition cleared brigalow-blackbutt pasture, Duaringa (1986–2010).

Animal production

The 'safe' fixed stocking rate maintained pasture condition better than the variable strategies, producing higher average liveweight gains per hectare at the end of the period (Figure 3). The variable stocking strategies generally yielded higher gains at the beginning of the simulation, when pasture conditions improved (Figures 2 and 3). The seasonally responsive strategy outperformed the constrained variation strategy as animal numbers were adjusted more rapidly in the face of changing conditions.

Profit

The safe fixed stocking rate strategy produced the highest annual average profit (total revenue minus total costs), followed by seasonally responsive and constrained variation strategies (Table 1). Fixed stocking had the highest minimum profit and the fewest years when profit

Table 1. Estimated annual total profit (AU$) for 3 stocking rate management strategies on the representative Duaringa enterprise (mean values for simulation period 1986–2010).

	Fixed stocking rate	Constrained variation	Seasonally responsive
Average	$204 401	$77 370	$135 536
Minimum	-$64 425	-$183 421	-$313 983
Maximum	$490 670	$346 240	$743 838
Negative years	3	8	11

was negative. As stocking rate flexibility increased, the number of years when annual profit was negative tended to increase.

Discussion

The results are presented to illustrate the utility of the NGS approach. For the Duaringa example, the projected responses for carrying capacity, resource condition, animal production and profitability for the 3 stocking rate options revealed that the 'extremes' of the flexibility strategies were generally the most profitable under the climatic conditions between 1986 and 2010. The results are highly context-dependent and reflect a combination of the stocking rate strategies, land/vegetation types, land condition and climatic conditions at the time of the simulation trial. The results from each of the regional simulations were endorsed at subsequent workshops and the insights for the various strategies, i.e. stocking rates, seasonal resting, prescribed fire, have been incorporated into local extension materials and on-farm demonstrations. The herd and land management strategies have been explored under different climatic sequences in the 9 regions, including under projected climate change, to seek scope for enhanced forecasting to inform management.

Conclusion

The NGS process which includes the simulation of 'representative' grazing enterprises constructed around a process of science review and local pastoralist consensus offers considerable scope for defining sustainable land management practices with both economic potential and high levels of producer ownership. The results presented offer only a limited insight into the full potential of the models to explore management options in detail. The simulation modeling approach offers a useful alternative to trials for screening large numbers of management options and strategies for future application in research or practice.

Acknowledgments

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Forages improve livelihoods of smallholder farmers with beef cattle in South Central Coastal Vietnam

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Abstract

In South Central Coastal Vietnam, on-farm research and farmer experience demonstrated the benefits of growing improved forages as a means of improving the year-round quantity and quality of feed available for smallholder beef cattle production. In Binh Dinh, Phu Yen and Ninh Thuan provinces, 5 new forage species (*Panicum maximum* cv. TD58, *Brachiaria* hybrid cv. Mulato II, *Pennisetum purpureum* cv. VA06, *Paspalum atratum* cv. Terenos and *Stylosanthes guianensis* cv. CIAT 184) were evaluated for yield and crude protein concentration. There was no consistent yield difference between locations for the forage grasses, but in Binh Dinh province *P. maximum* TD58 produced the highest yield. The grasses were comparable in crude protein concentration. Stylo CIAT 184 produced much less forage than the grasses but had a much higher crude protein concentration. All species have potential use, depending on the circumstances and site factors such as fertility, drainage and availability of irrigation. This work was expanded to a total of 45 farmers to gain feedback on farmer experience in growing different forages. The percentage of farmers who "liked" the introduced forages was Mulato II, 92%; TD58, 85%; VA06, 82%; Paspalum, 46%; and Stylo, 36%. By far the most important early socio-economic impact of developing perennial forage plots close to households was an average 50% reduction in the amount of labor and time that farmers spend supplying cut-and-carry forage to their animals. In addition, the growing of forages can meaningfully reduce the grazing pressure on common grazing lands, thereby lowering the potential for environmental degradation.

Resumen

En la región Costa Central del Sur de Vietnam, la investigación en fincas y la experiencia de los productores han demostrado los beneficios de forrajes mejorados para una mayor producción, durante todo el año, de alimento de mejor calidad en fincas de pequeños productores de ganado de carne. En las provincias Binh Dinh, Phu Yen y Ninh Thuan fueron evaluados por producción y concentración de proteína cruda (PC) los cultivares: *Panicum maximum* cv. TD58, *Brachiaria* híbrido cv. Mulato II, *Pennisetum purpureum* cv.VA06, *Paspalum atratum* cv. Terenos y *Stylosanthes guianensis* cv. CIAT 184. No se encontraron diferencias consistentes en la producción de las gramíneas entre localidades; no obstante en la provincia Binh Dinh, *P. maximum* TD58 presentó la más alta producción de forraje. Las gramíneas presentaron concentraciones similares de PC. Stylo CIAT 184 produjo mucho menos forraje que las gramíneas pero su concentración de PC fue mucho más alta. Todas las especies tienen un buen potencial de uso, dependiendo de las condiciones de fertilidad del suelo, el drenaje y las facilidades de riego en cada sitio. El trabajo se extendió a 45 productores con el objeto de obtener retroalimentación respecto a las experiencias en el uso de estos forrajes a nivel de finca. Los porcentajes de aceptación (en paréntesis) de las especies introducidas fueron: Mulato II (92%), TD58 (85%), VA06 (82%), Paspalum (46%) y Stylo (36%). El impacto

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socio-económico inicial más importante de la siembra de parcelas de forrajes perennes cercanas a las viviendas ha sido la reducción en 50% del uso de mano de obra y del tiempo invertido en las labores de corte y acarreo del forraje. Adicionalmente, el cultivo de los forrajes puede reducir de manera significativa la presión de pastoreo sobre áreas de pastoreo comunal y consecuentemente la degradación del ambiente.

Introduction

In Vietnam, beef cattle production has been a traditional and important component of the smallholder farm system, but feeding these livestock has been a major challenge and a labor-intensive activity. Most of the available feed has come from communal land, waste areas on roadsides and around margins of crops, and from crop residues. A combination of supervised grazing and cut-and-carry methods has been and is still used by many smallholder farmers.

Beef production in Vietnam has increased steadily in recent years, from approximately 100 000 t live weight in 2001 to 290 000 t live weight in 2011, in response to a growing demand for beef due to an increasing population, improvements in disposable income and a developing tourism industry. The upward trend is likely to continue, but it will depend upon appropriate Government policies (on land use, credit loans and import tax/regulation), the contribution of the research community to create new technologies and higher quality products, and the efforts of all stakeholders in the beef value chain.

There is a significant opportunity for smallholder crop-livestock farmers in South Central Coastal Vietnam to improve overall household income by changing the balance of their farming systems in favor of beef cattle. However, the availability of labor and competition for traditional feed resources, particularly communal grazing land, are emerging as major impediments to farmers making this change and progressing from cattle keepers to cattle producers. This paper reports on research in South Central Coastal Vietnam, highlighting the socio-economic benefits to smallholder farmers and the environment of introduced forages.

Current beef cattle production system

Smallholder cattle production methods vary across Binh Dinh, Phu Yen and Ninh Thuan, 3 provinces in South Central Coastal Vietnam, according to climatic factors, available resources and production goals. The dominant cow-calf breeding system has relied traditionally on extensive grazing of common lands, especially in Ninh Thuan, where farmers typically have larger herds and limited access to other feed sources. In contrast, in Phu Yen and Binh Dinh provinces, cow-calf farmers typically use a mixture of grazing and stall-fed supplementation, mainly with crop residues such as rice straw, plus some rice bran and other feedstuffs, including cut-and-carry native grass or King grass (*Pennisetum* sp.). Smallholder farmers engaged in fattening male cattle or keeping males for draught work are more likely to rely on intensive stall-feeding of fresh grass, crop residues and concentrates. In a 2009 survey of cattle farmers, 41% of farmers in Binh Dinh and Phu Yen practiced stall-feeding, whereas in Ninh Thuan 94% of farmers utilized grazing (either with or without supplementation) (Parsons et al. 2013).

Development of the beef cattle industry in Vietnam has been constrained by limitations in forage supply and quality. In recent years numerous high-yielding forage species have been imported and evaluated for adaptation, biomass yield and quality across Vietnam (Phan Thi Phan et al. 1999; Truong Tan Khanh 1999), but there is little evidence of their widespread adoption by farmers. Improving feeding options by utilizing locally available feed resources and introducing new forages remains a key strategy for improving beef cattle production (Nguyen Xuan Ba et al. 2010).

Introducing new forages

Between May 2010 and December 2011 in Binh Dinh, Phu Yen and Ninh Thuan, 5 new forage species, *Panicum maximum* cv. TD58 (TD58), *Brachiaria* hybrid cv. Mulato II (Mulato II), *Pennisetum purpureum* cv. VA06 (VA06), *Paspalum atratum* cv. Terenos (Paspalum) and *Stylosanthes guianensis* cv. CIAT 184 (Stylo) were evaluated for yield and feed quality. In each province 4 farms were selected as trial sites (blocks) and planted with the 5 forage species (treatments). Each plot was 5 x 1 m, with 0.5 m between plots. King grass was grown as buffer rows to separate the plots. An identical second set of plots was provided at each farm so farmers could experiment. Each site was managed in a similar manner, with regular inputs of fertilizer plus irrigation in the dry season, to demonstrate potential yields under typical farm conditions. The first harvest was 60 days after establishment, with subsequent harvests at approximately 40-day intervals. Grasses were harvested at a height of 15 cm and Stylo CIAT 184 at 20 cm. The mean daily temperature and mean annual rainfall for Binh Dinh, Phu Yen and Ninh Thuan for the previous 10 years were 27, 26 and 26 ^{o}C and 1710, 1540 and 1160 mm, respectively.

Table 1. Yield and crude protein (CP) concentration of forage species in Binh Dinh, Phu Yen and Ninh Thuan provinces in South Central Coastal Vietnam. Means within columns followed by different letters differ significantly (P<0.05) using Tukey's test.

Species	Binh Dinh		Phu Yen		Ninh Thuan	
	Yield (t DM/ha/yr)	CP (%)	Yield (t DM/ha/yr)	CP (%)	Yield (t DM/ha/yr)	CP (%)
Mulato II	25.7 b	13.7 b	37.3 a	12.4 b	24.4 ab	10.6 b
Paspalum	27.2 b	10.7 b	42.1 a	9.5 b	38.6 a	6.9 d
TD58	40.0 a	12.1 b	50.3 a	10.9 b	33.9 a	9.5 c
VA06	26.4 b	12.1 b	39.4 a	10.3 b	39.0 a	8.3 cd
Stylo	11.5 c	17.5 a	17.0 b	17.9 a	15.8 b	14.7 a
s.e.	1.9	0.75	4.1	0.64	3.6	0.48

Forage yields for all species were relatively high and similar to results from other regions in Vietnam (Table 1). Site factors had a major effect on the total annual yield and relative difference between species for each of the 3 provinces. In Binh Dinh, the greatest yield was obtained from *P. maximum* TD58, but there were no statistically significant differences between the grasses in the other 2 provinces. Stylo CIAT 184 yielded relatively well but much lower than the grasses, but persistence under regular cutting was less than with the grasses. As expected, Stylo CIAT 184 had a greater CP concentration (14.7–17.9%) than the grasses. There was no significant difference between the grasses in CP concentration except in Ninh Thuan province. All grass species were suitable for cultivation, and species selection should be based on factors such as fertility, drainage, availability of irrigation and individual requirements of the cattle feeding system.

On-farm forage development

The on-farm forage trials were led primarily by researchers, with limited farmer involvement. Subsequently, 15 farmers were selected in each province to test a range of 'best-bet' interventions under real farm conditions (Lisson et al. 2010). With guidance from project staff, these farmers concentrated on the introduction and establishment of new forages (both grasses and legumes), improved management practices for existing and new forages, and more effective utilization of other available feed resources. An improved supply of forage was an important first step in the best-bet process, due to its ability to make a rapid impact at farm level, and also to provide a base for the implementation of other cattle management techniques that rely on improved nutrition, such as early weaning. Farmers were provided with seed or tillers of the new forage varieties to establish small nursery areas, then encouraged to expand the area of those that they preferred. Group discussions, workshops and individual household visits were used to assess available resources, plus constraints to and opportunities for increasing the productivity and profitability of each farm. Farms were visited regularly to work through technical issues, provide training in planting, fertilizing, cutting management and feeding, and record qualitative and quantitative data.

By the end of the project, 95% of the best-bet farmers were using the improved forages and 90% had expanded beyond their original planted area. By September 2012, the average area of new forages planted by best-bet farmers was around 200 m^2 in Binh Dinh, 500 m^2 in Phu Yen and 600 m^2 in Ninh Thuan. However, the area of forage grown varied considerably between farmers and between provinces as determined by the availability of land, the aspirations of the individual farmers and the interest and support from extension personnel. Forage preferences differed between farms, and most farmers preferred 2 or 3 species. The percentage of farmers who "liked" each of the introduced cultivars was: Mulato II, 92%; TD58, 85%; VA06, 82%; Paspalum, 46%; and Stylo CIAT 184, 36%. However, these preferences did not necessarily translate into planting by farmers; for example, Stylo CIAT 184 was rarely planted by farmers. Generally farmers with cow-calf systems preferred Mulato II and TD58, because they appeared more palatable and had higher leaf:stem ratios; however, farmers operating fattening systems often preferred VAO6 because it provided bulk to complement concentrate feeding.

Socio-economic impacts of forage development

Apart from improving available fresh forage supply and quality, by far the most important early socio-economic impact of developing perennial forage plots close to households was an average 50% reduction in the amount of labor and time that best-bet farmers now spend supplying cut-and-carry forage compared with the time spent pre-project. For example, a farmer from An Chan commune, Phu Yen reported:

"*I used to graze cattle 6 km from home because the grass in the backyard was not enough for 5 cattle. My wife also had to cut native grass along the dam and rice field, which required 3–4 hours work per day. Now, I have 500 m^2 of forage in my backyard; next year I will expand to 400 m^2 of forage near my maize farm. My wife can reduce cut-and-carry by 2 hours and I can reduce grazing time by 3 hours.*"

The labor saved was used for a range of activities, including crop production, other livestock management, off-farm work, looking after children and grandparents and housework. For instance, the daughter of another farmer at An Chan commune, Phu Yen explained:

"*When my mother had to go grazing cattle, I had to cook the lunch. I sometimes went to school late and spent a part of my learning time on cooking meals. But now, my mother can cook meals for my family because she no longer needs to take the cattle grazing, and I can spend my time learning*."

These stories illustrate that adaptation of technologies often takes farmers in different and divergent directions. Such stories are common throughout Southeast Asia (Connell et al. 2010), and illustrate the potential socio-economic benefits due to cultivation of high-quality forages, especially when grown close to households and cattle housing facilities. Feedback from best-bet farmer interviews indicated that they also benefited from more frequent meetings, the sharing of forage planting material, accessing information on cattle feeding, breeding, markets and prices, and mutual support in techniques of forage and legume planting. Although not all benefits are related directly to new forages, these played an important role in creating the impetus for other improvements.

Environmental impacts

By developing and promoting a system with a more reliable year-round supply of forage, better control of grazing, and a more effective use of local feeds, crop residues and by-products, the risk of environmental damage from overgrazing of common and waste land should decrease. This environmental objective is becoming more critical as the Vietnamese Government is in the process of developing rules for use of forests and other common land, forcing farmers off areas which have previously been freely available. Discussions with farmers have revealed that they see this change as inevitable, that they understand the reasons why cattle are being excluded from grazing in these areas, and that more intensive land use for forage production is desirable.

The sustainable production of viable quantities of feed from introduced forages will require regular inputs of nutrients, especially nitrogen, and irrigation. The timing and rates of fertilizer and manure applications on forage crops, particularly on sandy soils which predominate in the South Central Coastal region, will require careful consideration and management to avoid the risk of nutrient leaching and runoff, with their negative environmental effects.

Conclusions

Increasing population, improvement in disposable income, urbanization, changing dietary preferences and a rapidly developing tourism industry are factors that are driving the demand for animal products in Vietnam. Beef production is well placed to satisfy part of this demand, provided smallholder crop-livestock farmers gain increased access to feeding and management technologies, that can be adapted to the smallholder mixed farming system. Better knowledge about growing, managing and feeding new and existing fresh forages, utilization of crop residues and use of feed supplements will encourage greater intensification of beef cattle production and increase supply of beef to developing markets. Balanced intensification has the potential to improve the livelihoods of smallholder farmers and lessen the risk of ongoing environmental degradation due to uncontrolled grazing and overgrazing of communal land.

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Systematic management of stocking rates improves performance of northern Australian cattle properties in a variable climate

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Keywords: Overgrazing, fixed stocking, flexible stocking, modeling study.

Abstract

The risks for extensive cattle properties in the rangelands of northern Australia arising from high inter-annual rainfall variability are predominantly managed through adjustments in stocking rates (SR). This modeling study compared the performance of SR strategies that varied considerably in the extent that they adjusted SR annually at 3 locations in northern Australia. At all locations, land types and pasture condition states, the SR strategies that achieved the best pasture condition were those that least increased and most decreased SR annually in response to changes in forage availability. At Donors Hill (Qld), these conservative strategies also achieved the highest cattle liveweight gains per hectare (LWG/ha). While conservative strategies produced the highest percent perennial pasture species at Fitzroy Crossing (WA), strategies which allowed larger increases and decreases in SR also performed well, enabling them to also achieve high LWG/ha with little deterioration of pasture condition. A similar trend occurred at Alice Springs (NT), although at this location the strategies with even larger annual increases and decreases in SR achieved relatively high percent perennials and the highest LWG/ha. While systematic management of SR appears to perform better than a constant SR strategy when rainfall variability is high, it is unclear if the magnitude of annual adjustments in SR needs to increase with increasing rainfall variability.

Resumen

En las grandes extensiones de sabanas del norte de Australia los riesgos de la ganadería extensiva por la alta variabilidad interanual de las lluvias son manejados principalmente mediante el ajuste de la carga animal (SR, por su sigla en inglés). Tomando como caso tres localidades del norte de Australia, en este estudio de modelado se compara el desempeño de estrategias de carga animal muy variada y anualmente ajustada. En las 3 localidades, los 2 tipos de tierra y las 3 condiciones de las sabanas, las estrategias de SR que resultaron en las mejores pasturas, fueron las que menos incrementaron y más redujeron la SR como respuesta a los cambios anuales en la disponibilidad de forraje. Con estas estrategias conservacionistas se obtuvo la mayor ganancia de peso vivo/ha en la localidad Donors Hill (Queensland) y el mayor porcentaje de especies perennes en Fitzroy Crossing (Western Australia). En esta última localidad, estrategias que implicaron incrementos y reducciones de la SR más altos, también fueron exitosas y resultaron en altas ganancias de peso vivo/ha con poca degradación de las sabanas. Una tendencia similar se observó en Alice Springs (Northern Territory); aquí, sin embargo, las estrategias que implicaron incrementos y reducciones anuales de la SR aún mayores, resultaron en porcentajes relativamente altos de especies perennes y en ganancias de peso vivo/ha más altas. A pesar de que el manejo sistemático de la SR aparentemente funciona mejor que una estrategia de SR constante cuando las lluvias son altamente variables, no es claro si la magnitud de ajustes anuales de la SR debe ser incrementada cuando la variabilidad de la precipitación aumenta.

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Introduction

Annual forage growth in the north Australian rangelands is predominantly driven by rainfall (McKeon et al. 1990). High annual variability in the supply of forage for livestock has significant implications for pasture condition and cattle productivity, where adjustments in stocking rate (head or adult equivalents per square kilometer) are the main means of managing these risks. Two broad approaches can be used to manage SR: fixed stocking (a constant SR); and flexible stocking (SR varying over time in response to changes in forage supply) (Buxton and Stafford-Smith 1996). A recent review of SR strategies (Scanlan and McIvor 2010) concluded that a constant light SR at close to the long-term carrying capacity appeared to be the most profitable and least-risky strategy, but acknowledged some variation in SR may be required to account for poor seasons and to take advantage of good seasons. The simulation study reported here compared fixed stocking with a number of flexible strategies, which vary greatly in the extent cattle SRs are adjusted annually in response to changes in forage availability.

Methods

The GRASP pasture and animal production model (McKeon et al. 2000) was used to compare the performance of SR strategies at 3 locations: Donors Hill (black soil and tea-tree communities) in the Gulf region of Queensland; Fitzroy Crossing (black soil and spinifex communities) in the Kimberley region of Western Australia; and Alice Springs (alluvial and mulga communities) in the Northern Territory. Mean annual rainfall, the percent coefficient of variation (%CV) for annual rainfall and the Bureau of Meteorology (BOM) index of rainfall variability (BOM 2013) for these locations are shown in Table 1.

Table 1. Mean annual rainfall, %CV for annual rainfall between 1890 and 2010, and BOM rainfall variability index for Donors Hill, Fitzroy Crossing and Alice Springs.

Location	Mean (mm)	%CV	BOM Index
Donors Hill (Queensland – Gulf country)	629	39	1.10
Fitzroy Crossing (Western Australia – Kimberley)	543	36	0.90
Alice Springs (Northern Territory – central Australia)	259	59	1.30

The simulated SR strategies differed in the extent that SR could be adjusted annually in response to the safe utilization of the forage present at the end of the growing season (May). Fixed stocking did not allow any change in SR, while full flexibility changed SR in full proportion to changes in forage availability. A further 54 strategies with intermediate levels of flexibility were simulated. This included 6 core strategies, which set different limits (5, 10, 20, 30, 50 and 70%) to the extent that SR could be increased annually, providing forage availability increased by at least these amounts. Each of these core strategies was simulated with different limits to the extent SR could be decreased annually (5, 10, 20, 30, 40, 50, 60, 70 and 80%), providing forage availability decreased by at least these amounts.

At each location, each strategy was simulated on 2 land types (high and low productivity) with each in 3 initial pasture condition states (excellent, good and poor). Strategies were simulated with the same SR for each combination of land type and pasture condition state. This SR was the fixed SR that maintained the perennial grass content of pastures over the simulation period (Scanlan et al. 2010). Strategies were simulated for 20 different randomly chosen 30-year climate periods, commencing between 1890 and 1981. Climate records were obtained from BOM (SILO 2011). The average percentage perennial grass composition of pastures (percent perennials) and the average cattle liveweight gain per hectare (LWG, kg/ha) achieved for the twenty 30-year climate periods were the values used to compare strategies.

Results

The results of average percent perennials and average LWG/ha achieved by SR strategies are shown for the high productivity land type in good pasture condition at each location. These demonstrate the main findings of this simulation study. The values for percent perennials achieved by the 6 core SR strategies at Donors Hill, Fitzroy Crossing and Alice Springs are shown in Figures 1–3.

The highest values for percent perennials were achieved by strategies that limited annual increases in SR to 5% (Figures 1–3). The percent perennials declined with higher permitted annual increases in SR. For each core strategy, percent perennials increased with higher permitted annual decreases in SR. Consistent with this, the percent perennials achieved by full flexibility was lower than that for the core strategies with high limits for annual decreases in SR. These trends occurred for all land types and pasture condition states at all locations.

Relative to the 60% perennial grasses achieved by fixed stocking at each location, the percent perennials achieved by the core strategies was lowest at Donors Hill (Figure 1), moderate at Fitzroy Crossing (Figure 2) and highest at Alice Springs (Figure 3). This is particularly true for the core strategies, which had high permitted annual increases in SR. It can be seen that the percent perennials achieved by these strategies increased

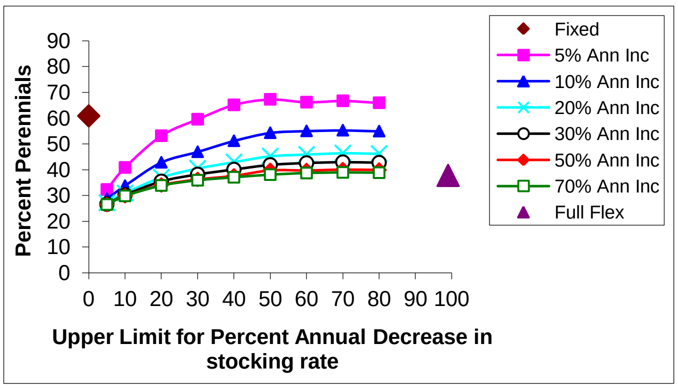

Figure 1. Average percent perennials achieved by SR strategies on black soil at Donors Hill.

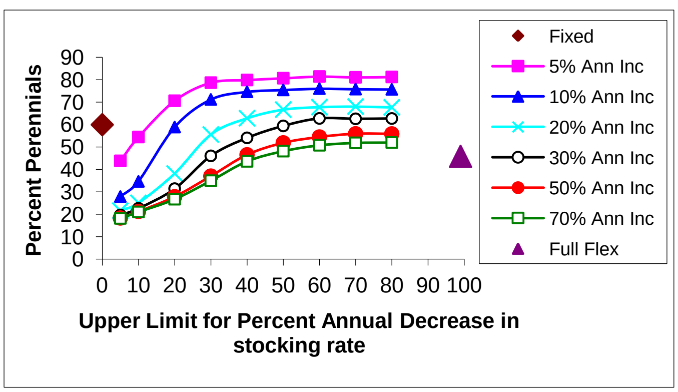

Figure 2. Average percent perennials achieved by SR strategies on black soil at Fitzroy Crossing.

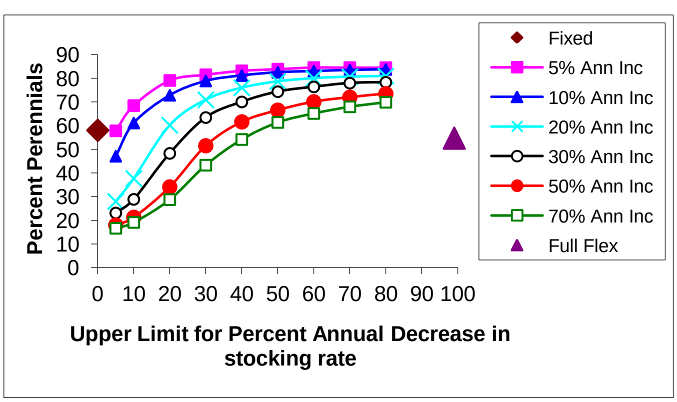

Figure 3. Average percent perennials achieved by SR strategies on alluvial soil at Alice Springs.

at the fastest rate and to the greatest extent as permitted annual decreases in SR rose at Alice Springs (Figure 3), followed by Fitzroy Crossing (Figure 2) and Donors Hill (Figure 1).

Figures 4–6 show the average LWG/ha achieved by the same strategies under the same conditions described above for percent perennials. Again, the benchmark for comparison of the performance of core strategies was the LWG/ha achieved by fixed stocking at each location. At Donors Hill (Figure 4), only the strategies, that limited annual increases in SR to 5% and annual decreases in SR to 30% or more, achieved a LWG/ha that was higher than that achieved by fixed stocking. The LWGs/ha for all other strategies were lower than fixed stocking, and decreased with higher annual increases in SR. As such, fully flexible stocking achieved the lowest LWG/ha of all strategies.

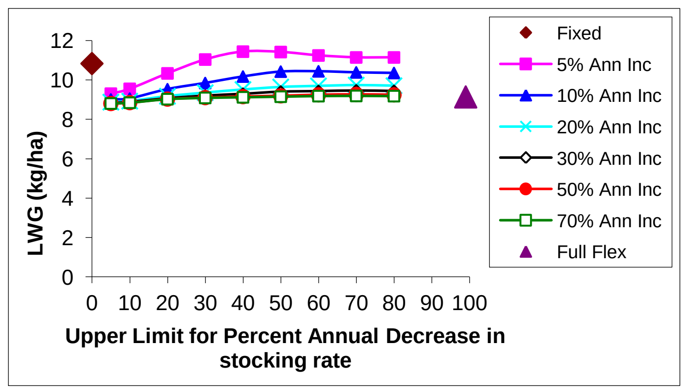

Figure 4. Average LWGs/ha achieved by SR strategies on black soil at Donors Hill.

At Fitzroy Crossing (Figure 5), all 6 core strategies achieved LWGs/ha that were higher than that achieved by fixed stocking, although this often required progressively higher limits to annual decreases in SR.

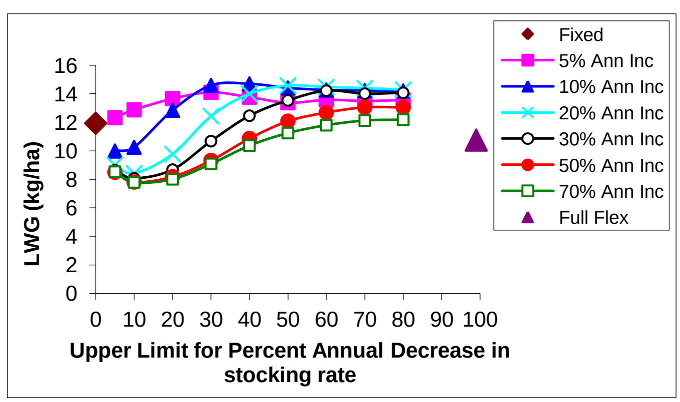

Figure 5. Average LWGs/ha achieved by SR strategies on black soil at Fitzroy Crossing.

This trend continued at Alice Springs (Figure 6), where almost all strategies achieved a higher LWG/ha than fixed stocking. The highest LWG/ha was achieved by the strategy with a 70% limit for annual increases and an 80% limit for annual decreases, and this was only marginally higher than the LWG/ha for full flexibility.

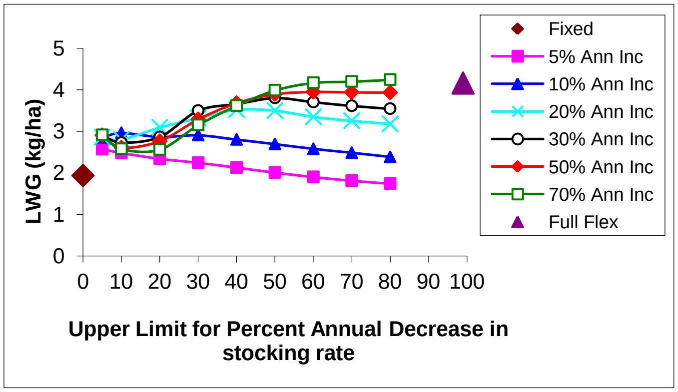

Figure 6. Average LWGs/ha achieved by SR strategies on alluvial soil at Alice Springs.

At Alice Springs, the strategies, which achieved the highest LWGs/ha, had the highest limits for annual increases and decreases in SR. In comparison, the strategies with the lowest limit (5%) to annual increases produced the highest LWG/ha at Donors Hill, while at Fitzroy Crossing the core strategies with 10, 20 and 30% limits to increases in SR achieved the highest LWGs/ha.

Conclusions

In this simulation study, the most consistent trend across locations, land types and pasture condition states was that the highest percent perennials was achieved by strategies, which least increased and most decreased SR annually in response to changes in forage availability. In regions where wet season rainfall is highly variable, this occurs because a SR, that is appropriate at the end of one wet season, is maintained through until the end of the following wet season. For example, if the SR is increased substantially at the end of a high-rainfall wet season, then it is likely that the following wet season will have lower rainfall, resulting in over-grazing and deterioration of pasture condition.

Given the success of this conservative approach to managing SR, it could be expected that the percent perennials achieved by strategies, which allow large increases in SR, would decline as annual rainfall variability increases. However, this does not appear to be the case. Alice Springs has the highest rainfall variance indices (Table 1), yet the strategies that allowed the highest annual increases in SR achieved the highest percent perennials of all locations. Also, strategies which allowed high increases in SR, achieved higher percent perennials at Fitzroy Crossing than at Donors Hill, yet Fitzroy Crossing has lower rainfall variability. It is likely that there are interactions between SR strategies, average annual rainfall and seasonal variation in pasture growth on different land types, which could diminish correlations between the annual rainfall variability and the performance of SR strategies.

At Alice Springs, the highest LWG/ha was achieved by strategies, which allowed the greatest increases and decreases in SRs annually. Only these strategies could increase SR quickly enough to benefit from the occasional short periods of high pasture productivity, and then lower them rapidly to limit pasture degradation. Given that these strategies did not cause major declines in percent perennials (pasture condition) at Alice Springs, the high LWG/ha could be maintained over time. At Donors Hill, these same strategies caused deterioration in pasture condition, and hence the strategies, which most limited (5%) increases in SR annually, achieved the highest LWG/ha. At Fitzroy Crossing, the highest LWG/ha was achieved by strategies with 10, 20 and 30% limits to increases in SR annually, although this was to some extent at the expense of pasture condition. As with percent perennials, the limits to annual adjustments in SR needed to achieve the highest LWG/ha did not appear to be correlated with differences in the rainfall variability of locations.

Acknowledgments

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Lessons from silage adoption studies in Honduras

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Keywords: Dry season, farmer-to-farmer extension, forage conservation, participatory experimentation, tropical forages.

Abstract

To date, silage adoption has been low in the tropics, particularly under smallholder conditions. Innovation and adoption processes of silage technologies were promoted in drought-constrained areas of Honduras using a flexible, site-specific and participatory research and extension approach. A total of about 250 farmers participated in training workshops and field days conducted in 13 locations. Smallholders successfully ensiled maize, sorghum and/or *Pennisetum* spp., mainly in heap and earth silos, while adoption of little bag silage (LBS) was low. LBS proved useful as a demonstration, experimentation and learning tool. A 'silage boom' occurred in 5 locations, where favorable adoption conditions included the presence of demonstration farms and involvement of key innovators, lack of alternative dry season feeds, perceived benefits of silage feeding, a favorable milk market and both extension continuity and intensity. The lack of chopping equipment was the main reason for non-adoption by poor smallholders. The study showed that, when targeting production system needs and farmer demands, silage promotion can lead to significant adoption, including at smallholder level, in the tropics. This experience could contribute to an increase in effectiveness and sustainability of silage extension in similar situations elsewhere.

Resumen

Hasta ahora, la adopción de tecnologías de ensilaje ha sido baja en regiones tropicales, particularmente por pequeños agricultores. Mediante procedimientos de investigación y extensión participativas, flexibles y adaptadas a condiciones locales específicas, se promovieron procesos de innovación y adopción de tecnologías de ensilaje en zonas secas de Honduras. Alrededor de 250 pequeños productores participaron en talleres de capacitación y días de campo implementados en 13 localidades. Como resultado ensilaron con éxito maíz, sorgo y/o *Pennisetum* spp., principalmente en silos de montón y de tierra, mientras que la adopción de ensilaje en pequeñas bolsas (LBS, su sigla en inglés) fue baja. Sin embargo, LBS demostró su utilidad como herramienta de demostración, experimentación y aprendizaje. Un 'boom de ensilaje' se produjo en 5 localidades donde las condiciones de adopción fueron particularmente favorables, incluyendo la presencia de granjas de demostración, la participación de innovadores clave, la falta de alternativas para la alimentación del ganado en la época seca, la percepción de beneficios de la alimentación con ensilaje, un mercado de leche favorable, y un servicio de extensión continuo e intensivo. La falta de máquinas picadoras de forraje fue la razón principal para la no-adopción por parte de los pequeños productores de bajos ingresos. El estudio demostró que cuando los sistemas de producción lo necesitan y los productores lo demandan, la promoción del ensilado puede alcanzar un nivel significativo de adopción también en zonas tropicales, incluyendo los pequeños productores. Esta experiencia puede contribuir a incrementar la eficacia y sostenibilidad de la extensión de tecnologías de ensilaje en situaciones similares en otros lugares.

Introduction

Adoption of silage technologies has been low in the tropics and subtropics, especially by resource-poor smallholders, because of lack of know-how, lack of financial means and insufficient benefits and returns on investment (Mannetje 2000). R&D needs to develop strategies to enhance adoption of forage conservation technologies by the poor. Innovative approaches to forage conservation with technologies such as little bag silage (LBS) can get silage into smallholder farming and livestock systems (Wilkinson et al. 2003).

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This study was embedded in a research project conducted by CIAT (Centro Internacional de Agricultura Tropical) and the Honduran Directorate of Agricultural Science and Technology (Dirección de Ciencia y Tecnología Agropecuaria, DICTA) between 2004 and 2006. Silage making was promoted during farmer training workshops and field days in different drought-constrained areas of Honduras (Reiber et al. 2010). Research objectives of this study were to assess the adoption, potential and constraints of silage, including little bag silage (LBS).

Methods

A total of about 250 farmers participated in training workshops and field days conducted in 13 locations. Two extension strategies were applied: 'promotion of innovation' (PI), characterized by stimulating acceptance and adaptation processes among silage novices, in 7 locations; and 'promotion of adoption' (PA), characterized by scaling-out of site-adapted solutions through farmer-to-farmer promotion, in 6 locations. Furthermore, 3 different extension intensities were distinguished according to the number of training sessions and the presence of a technician to directly support farmers. LBS technology was used as a learning tool to demonstrate silage principles and experiment with adaptable technology components.

Research methods comprised surveys based on structured questionnaires, participatory experimentation with and evaluation of LBS, and organoleptic evaluation of silage fermentation quality. Farms were classified according to their herd size into small (1−20 head of cattle; 64 farmers), medium (21−50 head; 69 farmers), large (51−100 head; 58 farmers) and very large (>100 head; 31 farmers). A further grouping was made into silage adopters (farmers who made silage at least once and intended to re-use/repeat the practice), non-adopters, potential adopters (farmers who reliably intended to adopt) and rejecters (farmers who made silage at least once but decided to reject it). Data analysis included descriptive statistics and non-parametric tests.

Results

Continuous silage promotion can lead to significant adoption

As a result of the training and promotion activities, silage was adopted by 53% of participants, of which 20, 26, 36 and 18% were from small, medium, large and very large farms, respectively. Depending on the research location, the strategy 'promotion of innovation' (PI) resulted in total adoption rates of 0−29%, with an average of 19%. Adoption increases ranged from -5% to 24% between 2003/04 and 2006/07, with an average increase of about 9%. In contrast, 'promotion of adoption' (PA) resulted in total adoption of 13−79%, with an average of 57%. Adoption increases ranged from -40% to 57% between 2003/04 and 2006/07, with an average increase of about 31%. The difference in total adoption between the strategies was significant ($P<0.05$). With respect to extension intensity, adoption increases were 12.5, 10.4 and 32.7% for low, medium and high extension intensity, respectively.

In the area of Yoro, where silage was promoted under strategy PA and high intensity in 4 locations, the total number of adopters increased from 11 farmers in 2002/03 to 102 farmers in 2006/07. The proportions of all livestock keepers making silage reached 23% in Yoro, 36% in Yorito, 41% in Sulaco and 37% in Victoria. The proportion of small-scale farmers making silage increased from 0% in 2003 to 16% in 2006/07. Lack of feed during the dry season, the presence of key silage adopters who experienced a positive effect of silage (mainly from maize and sorghum) on livestock production, improved milk market conditions, motivated farmer groups, experienced and trained extension staff and continuous silage promotion were identified as contributing to the dissemination of silage technology in the area. In contrast, less adoption occurred where one or more of the above-mentioned conditions was not met (Reiber et al. 2010).

Increasing use of sorghum and Pennisetum *spp. ensiled in heap silos by smallholder silage novices*

While in 2004 silage was made almost exclusively from maize, 3 years later about 49% of the silage adopters ensiled at least 2 different crops, with an increasing share of sorghum: 66% ensiled maize, 61% sorghum, 20% cut-and-carry grasses (*Pennisetum* spp. 'King Grass' or 'Camerún'), 6% sugarcane, 4% *Brachiaria brizantha* cv. Toledo and 4% cowpea (*Vigna unguiculata*). Small-scale farmers ensiled relatively more cut-and-carry grass than larger-scale farmers.

In 2007, the average area per farm dedicated to silage production was 2.3 ha, with 1.7, 2.3, 2.7 and 3.0 ha for small, medium, large and very large farms, respectively. The average areas of maize, sorghum and cut-and-carry grasses for silage were 1.2, 1.0 and 0.1 ha, respectively. Small, medium and very large farms dedicated a larger area to sorghum than to maize, whereas on large farms the area of maize was more than twice the area of sorghum. Maize and sorghum silage were generally of high quality and preferred to silages of other forages (Reiber et al. 2010).

The share of adopted low-cost silos, such as heap and earth silos, increased with decreasing farm size, whereas the share of cost-intensive bunker silos decreased (Figure 1). However, this did not hold for very large farms, where more heap silos were used than bunker silos. Preferences for specific silo types differed with the location (Figure 2).

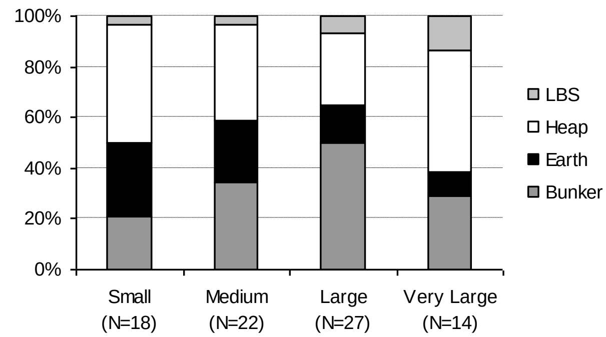

Figure 1. Silo types used by farm size categories.

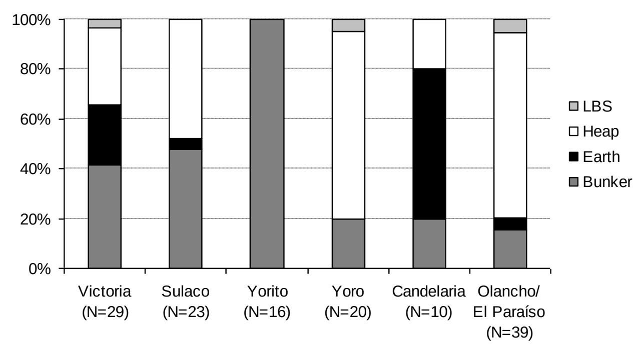

Figure 2. Adoption of silo types in the different locations.

Heap silos, the most adopted silo type (41%), were mainly used by silage novices in Yoro, Olancho and Jamastrán (El Paraíso) and were considered as 'silo for the poor'.

LBS and its potential as a demonstration, experimentation and learning tool

Little bag silage was adopted by only about 5% of farmers. Main drawbacks were lack of suitable plastic material in rural areas and high aerobic-spoilage losses, due to perforation of plastic by rodents. Some advantages of heap silage over bag silage were less risk of aerobic-spoilage losses, lower cost per unit of silage, and no need to invest in storage facilities (Reiber et al. 2010). The most suitable LBS material was a tubular bag with a plastic thickness of 152 µm (caliber 6). The use of a mould (i.e. a plastic barrel) during bag silage preparation was shown to make compaction easier, while protecting the plastic bag from tearing and puncturing. The bag is placed inside a vertically cut barrel, which is kept shut, e.g. with ropes, during compaction and subsequently opened to remove the bag.

Participatory experimentation with and evaluation of LBS revealed that molasses as an additive in wilted grass silage (T4) proved more effective for the reduction of pH than other additives (T5 and T6) (Table 1). Farmers' assessments of smell and their preference ranking were higher for all silages with additives than for those without, irrespective of DM content. Farmers learned that: (1) short wilting and the addition of sugar-containing additives, especially molasses, improve fermentation quality of grass silage; and (2) wilted silages, although presenting a better smell, were more prone to increased spoilage losses (Reiber et al. 2009).

Table 1. Participatory group experimentation with differently treated LBS of *Brachiaria brizantha* cv. Toledo.

Treatment	Bags (no.)	pH		Spoilage losses (%)		Smell	Preference
		Value	s.e.	Range (average)	s.e.	(1-5)[1]	ranking
T1: unwilted, without additive	3	4.4[bc2]	0.03	0-10 (5)	3	2	6
T2: unwilted, with 6% molasses	4	4.5[bc]	0.07	0-7 (4)	2	4	3
T3: wilted, without additive	2	6.0[3]	0.75	0-100 (50)	35	3	5
T4: wilted, with 6% molasses	4	3.9[a]	0.04	0-80 (32)	20	4	2
T5: wilted, with 20% sugar cane	4	4.7[c]	0.07	0-15 (5)	4	4	1
T6: wilted, with 6% sugar water	4	4.2[b]	0.73	10-100 (40)	21	3-4	4

[1]1 = rotten, strong; 2 = bad; 3 = acceptable; 4 = good; 5 = very good.
[2]Values with different superscripts are different (P<0.05).
[3]T3 was excluded from test of significance between groups due to low number of bags and high spoilage losses.

Considering perceived benefits and farmer criteria for silage adoption and rejection

Farmers perceived multiple benefits from silage, such as an average 50% milk yield increase, improved body condition, fertility and health of cows, increased feed security, reduced risk of production losses, lower labor requirements during the dry season, and a positive effect on pasture recuperation and production because of reduced grazing pressure (Reiber et al. 2010).

The most frequently mentioned reason for adoption was the lack of dry season feed and the subsequent risk of livestock production losses (29%). Further motivating factors were neighboring farmers, who had already adopted and promoted the use of silage (15%), and an innovative extensionist, who himself was a prototype farmer and provided technical assistance (12%). The most frequently mentioned reasons for non-adoption of silage-making by smallholders were 'non-availability of a chopper' (46%) and 'lack of money coupled with high costs' (25%).

Discussion

A limitation in silage production is the lack of experience and sufficient understanding of silage-making principles, not only by farmers but also by extensionists (Froemert 1991). This becomes especially important when forages low in DM and water-soluble carbohydrates are to be ensiled. Using LBS technology as a demonstration and learning tool proved effective for teaching basic technological principles such as chopping, proper compaction and sealing within the course of a one-day farmer training or field day ('learning by doing') and for demonstrating the impact of various silage-processing practices (e.g. wilting, silage additives) on silage quality. As experienced during this study, the use of LBS as an introductory silage system led to adaptations and adoption of earth, heap and bunker silos in several cases.

Besides the requirements of quality plastic bags, proper compaction and air-tight sealing, silage bags need to be protected from animals and direct sunlight to ensure success. Rats and mice were also reported as problems by Lane (2000). Therefore, some form of protection is recommended, either within an existing store, or in a specialized building, e.g. on stilts (Lane 2000). An inexpensive and handy storage alternative is to bury the bags in a pre-dug trench as described by Otieno et al. (1990); this would assist in maintaining anaerobic conditions, compaction and lower temperatures.

The main constraint to silage adoption for resource-poor smallholders, i.e. lack of a chopper, could be overcome by its cooperative purchase, administration and use (Wilkins 2005). In his review of reasons for non-adoption of silage making in countries such as Pakistan, India and Thailand, Mannetje (2000) pointed out that cost, trouble and effort of silage making did not provide adequate returns and benefits, and concluded that technology of any kind will be adopted only if it can be part of production systems that generate income. In this study, farmers experienced an increase in milk yields as a result of feeding high quality silage, mainly from maize and sorghum, to crossbred cows.

The successful and sustained use of silage may require more time and effort than are allocated in most development projects and programs. Farmer motivation and participatory technology experimentation, evaluation and development are particularly important in areas where silage is less known. Thereby, farmer constraints and objectives should be linked to the purposes and objectives of silage making. Establishing the basis for wider silage adoption (i.e. identifying and training leader farmers) may last 2 years. Development projects should not stop at this stage but should scale-out adapted and efficient silage technologies through demonstrations and exchange of experiences using an integrated and participatory approach involving smallholders as well as larger-scale farmers.

Conclusion

The study showed that promotion of silage, including LBS, can lead to significant adoption in environments where: (1) seasonal lack of feed in drought-prone areas (that is, with more than 4.5 dry months) causes great production losses (e.g. reduced milk production); and (2) organized and motivated farmers with market-oriented dairy production exist or are emerging. LBS proved useful and could play an important role in participatory research and extension activities, as a demonstration, experimentation and learning tool that can be used to train basic technological principles and to get small-scale silage novices started with a low-risk technology. This experience could contribute to an increase in effectiveness and sustainability of silage extension in similar situations elsewhere.

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Grasslands in India: Problems and perspectives for sustaining livestock and rural livelihoods

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Keywords: Grazing land, pastoralism, nomadic pastoralism, grazing resources, mixed farming.

Abstract

In India, grazing-based livestock husbandry plays an important role in the rural economy as around 50% of animals depend on grazing. Pasturelands over an area of 12 Mha constitute the main grazing resources that are available. Temperate/alpine pastures are spread across elevations higher than 2000 m in the Eastern and Western Himalayas including the Jammu & Kashmir, Himachal Pradesh, Uttarakhand, West Bengal, Arunachal Pradesh and Sikkim states. Nearly 30 pastoral communities in hilly or arid/semi-arid regions in northern and western parts of India, as well as 20 in temperate/hilly regions, depend on grazing-based livestock production. Due to overgrazing coupled with poor management and care, these grazing lands have deteriorated to a large extent and need amelioration or rehabilitation. Appropriate technologies have been developed, refined and tested in various research and academic institutions. These technologies need to be implemented on a large scale in different parts of the country for augmenting forage resources, enhancing livestock production and sustaining livelihood options in an eco-friendly manner.

Resumen

En la India, la ganadería basada en pastizales juega un importante papel en la economía rural, ya que el 50% de los animales depende del pastoreo. Las áreas de pastoreo abarcan 12 Mha y constituyen el principal recurso para la ganadería. Los pastizales de zonas templadas/alpinas se encuentran a alturas >2000 m.s.n.m. en las regiones este y oeste del Himalaya, incluyendo los Estados de Jammu & Kashmir, Himachal Pradesh, Uttarakhand, West Bengal, Arunachal Pradesh y Sikkim. Aproximadamente 30 comunidades de pastores en regiones de ladera o zonas áridas/semi-áridas en el norte y oeste de India, y 20 en zonas templadas y/o topografía pendiente dependen de la ganadería basada en pastoreo. Debido al sobrepastoreo acompañado de mal manejo, los pastizales se han degradado y requieren prácticas de rehabilitación. En varias instituciones de investigación se han desarrollado y probado tecnologías apropiadas que deben ser implementadas a gran escala en varias regiones del país, con el objeto de aumentar, en forma amigable con el medio ambiente, los recursos forrajeros para mayor producción pecuaria y mejor calidad de vida de las comunidades rurales.

Introduction

In India, agriculture is characterized by the traditional predominance of a mixed farming system, a well-knit combination of crop production and livestock rearing. Livestock rearing is a major source of income providing employment and livelihoods for rural families. Livestock production is the backbone of Indian agriculture, contributing 4% to national GDP and providing a source of employment and the ultimate livelihood for 70% of the population in rural areas.

India's livestock sector is one of the largest in the world, with a livestock population around 623 M, which is expected to grow at a rate of 0.55% in the coming years. India has 56.7% of the world's buffaloes, 12.5% of the cattle, 20.4% of the small ruminants, 2.4% of the camels, 1.4% of the equines, 1.5% of the pigs and 3.1% of the poultry. The livestock population, over the years, has shown a steady growth on 2 broad fronts, namely: (i) in the number of stall-fed bovine livestock, including buffaloes and crossbred cows, owned mainly by people with arable land and resources to grow or procure green fodder; and (ii) in the number of small ruminants like goats and sheep, surviving mainly by free grazing the available pasture lands and tree foliage (Anon. 2011).

This latter category is the topic of this paper. Uncontrolled grazing is the basis of grazing systems of resource-

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poor households, landless pastoralists, nomadic and semi-nomadic tribes and marginal farmers. Between 84 and 100% of poor households gather food, fuel, fodder and fiber items from the 'common property grazing resources' (CPRs). These landless farmers graze their animals on, as well as collect fodder from, the CPRs. In this paper we describe work to: survey and update the distribution of the main grassland types of India; define the current grazing methods; summarize the overall state of the grassland-livestock systems; and propose action to rehabilitate grassland areas.

Methods

A reconnaissance survey of the grasslands of India was conducted from 1954 to 1962, revealing 5 major ecosystems based on vegetation composition and distribution, primarily governed by climatic factors, latitude, elevation, topography and seasonal patterns of soil moisture (Dabadghao and Shankaranarayan 1973). The 5 types were: *Sehima* - *Dichanthium* grasslands; *Dichanthium* - *Cenchrus* - *Lasiurus* grasslands; *Phragmites* - *Saccharum* - *Imperata* grasslands; *Themeda* - *Arundinella* grasslands; and temperate/alpine grasslands.

Several previous studies and reports (Shankarnarayan and Shankar 1984; Singh et al. 1997; Pandeya 2000; Tambe and Rawat 2009) were used to draw conclusions for this paper. In recent studies (Singh et al. 2009; 2011), the monitoring and mapping of grasslands of the Himalayan region (Himachal Pradesh, Sikkim, Jammu and Kashmir states) during 2007−12 with modern tools and techniques, viz. GIS, RS, GPS and FSGT, were used in conjunction with ground-truthing to assess the extent of grasslands and their productivity.

Grassland areas

Hill region

In Himachal Pradesh (IRSP6L3 2008[1]), grasslands occur on 16.5% of the total area, occupying 15.3, 21.6, 18.0 and 15.3% of geo-climatic zones 1 (Low hill subtropical), 2 (Mid-hill subhumid), 3 (Mid-hill temperate wet) and 4 (High hill temperate), respectively. Forage production from high hills was recorded as 4.0 t/ha/yr (fresh weight) and 1.1 t/ha/yr (dry matter), with an average crude protein concentration of 11.3% (Singh et al. 2009).

In Jammu and Kashmir (IRSP6L3 2009 and 2010 data), 4.3% of the total geographical area was under productive grasslands, whereas the area of other grazing lands, including scrub and other unpalatable swards, was 9.8% of the total. The areas under productive grasslands in Jammu, Kashmir and Ladakh were 3.5, 13.2 and 5.8%, respectively.

In Sikkim, the area under alpine pastures in the High hill zone was 7.4% of total geographical area, whereas it was 6.8% in the Mid-hill zone. About 36.5% of the total pasturelands (14.1% of the total area) were in various stages of degradation. About 44.6% of pasturelands at different elevations and slopes in the Mid-hill zone were susceptible to soil erosion/depletion and/or landslides.

Temperate/alpine and subalpine meadows

The Indian Himalaya system comprises various mountain ranges which run parallel to each other, and contains a tremendous diversity in ecology, terrain, elevation, climate, resource availability, ethnicity, agricultural activities, flora and fauna. Steep topography, prolonged and severe cold winters, shallow soils and lack of irrigation etc., have limited the choice of agricultural activities, with livestock rearing being one of the most important occupations in the region. The temperate/alpine pastures are spread across elevations higher than 2000 m in the Eastern and Western Himalayas including Jammu and Kashmir, Himachal Pradesh, Uttarakhand, West Bengal, Arunachal Pradesh and Sikkim states. The alpine and subalpine meadows suffer from general degradation, with an increasing incidence of unpalatable species and erosion due to overgrazing. These grasslands and pastures, besides being a major source of forage for livestock, provide habitat for a large variety of wild animals and birds, and for endangered species of plants, many of which have an ethnobotanic value.

Tropical and subtropical grasslands

These are found mainly from high rainfall areas (Western Ghats) to arid/semi-arid areas including the Terai and Gangetic plains. These areas are subjected to heavy grazing, which has resulted in their general degradation and very low productivity. Ecologically they belong to the mid-successional/subclimax type of grasslands.

Grassland management

Nomadic pastoralism, a traditional form of human-livestock-grassland interaction, is still predominant in the drylands of western India, the Deccan Plateau, and in the mountainous reaches of the Himalayas. Nearly 200 castes are engaged in pastoral nomadism. They represent endogamous (discrete) social units, and specialize in the breeding of traditional animal sub-types, including buffaloes, sheep, goats, camels, cattle, donkeys and yaks (Tables 1 and 2).

[1]IRSP6L3 2008 = Indian Remote Sensing Satellite P6, Linear Imaging Self Scanning Band 3, Year 2008

Table 1. Some important pastoralist communities in the Himalayan region of India (Sharma et al. 2003).

Pastoral community	Area	Predominant livestock species
Bakarwal	Jammu and Kashmir	mainly goats
Bhotia	Uttarakhand, Garhwal, Kumaon − upper regions	sheep, goats and cattle
Bhutia	North Sikkim	sheep, goats and cattle
Changpa	Jammu and Kashmir, mainly in Zanskar	yaks
Gaddi	Himachal Pradesh, Jammu and Kashmir	sheep and goats
Kinnaura	Kinnaur − Himachal Pradesh	sheep and goats
Gujjar	Jammu and Kashmir, Rajasthan, Himachal Pradesh	buffaloes, some cattle
Monpa	Tawang, West Kemeng of Arunachal Pradesh	yaks and cattle
Van Gujar	Uttarakhand, Uttar Pradesh	buffaloes

Table 2. Some important pastoral communities in Western India (Sharma et al. 2003).

Pastoral community	Area	Predominant livestock species
Bharwad	Gujarat	sheep, goats and cattle
Charan	Gir forest region of Gujarat	cattle
Dhangar	Maharashtra, Karnataka and Madhya Pradesh	sheep
Gavli	Gujarat, Goa, Karnataka and Maharashtra	cattle
Gayri	southern Rajasthan (Mewar)	sheep
Ghosi	Bihar, Rajasthan and Uttar Pradesh	cattle
Golla	Andhra Pradesh and Maharashtra	cattle
Jath	Kutch region of Gujarat	cattle, occasionally camels
Mer	Saurashtra region of Gujarat	camels, some cattle
Rath	western Rajasthan (Ganganagar, Bikaner)	cattle (mainly of Rathi breed)
Rebari/Raika	Rajasthan and Gujarat	camels, cattle and goats
Sindhi Sipahi or Sindhi Musalman	Marwar and Jaisalmer	mainly camels, also cattle and sheep

These pastoral groups are concentrated in certain regions such as the semi-arid and arid Thar desert region, salty marshy lands of Kutch, and the alpine and subalpine zones in the Himalayas. In mountainous areas, nomadic grazing descends in winter to the lower slopes and in summer it progresses up the hills to get the maximum benefit from the good pastures that regenerate after the snow melts. In plateaus, plains and desert areas, the pastoralists move according to the alternation of the monsoon and dry seasons, in response to the availability of forage resources, including tree fodder. Usually in the dry season, they move to the coastal tracts, and leave when the rains come.

The grazing lands are degrading due to management neglect and have been invaded by unpalatable, alien species like *Lantana*, *Eupatorium*, *Parthenium*, *Prosopis juliflora* and others, severely affecting grassland productivity. The once robust village-level traditional institutions, that ensured the sustainable management of grasslands, have broken down and there is no responsible agency to look after the management issues (Anon. 2011). Neglect, poor maintenance and overgrazing have resulted in most of the grazing resources declining to a poor, degraded condition. In semi-arid areas, the carrying capacity is currently less than 1.0 adult cattle unit (ACU)/ha, whereas in the arid areas, it is 0.2−0.5 ACU/ha.

Many of the ecologically important, sensitive pasture lands, viz. Shola grasslands of Nilgiris; Sewan grasslands of Bikaner, Jodhpur and Jaisalmer; semi-arid grasslands of Deccan; Rollapadu grasslands in the semi-arid tracts of Andhra Pradesh; Banni grasslands of Gujarat; and Alpine grasslands of Sikkim and Western Himalaya, have already deteriorated to a large extent.

Issues for consideration to revitalize grasslands

Several factors, including the involvement of multi-stakeholders, a lack of participation of pastoral people in decision-making and in Government initiatives, overgrazing, and a lack of sufficient extension resources have hampered the revitalization of grasslands or CPRs. Some of the following points require attention, in order to achieve the rehabilitation of grazing lands, which are a source of livelihood for a large population**:**

- A national policy, involving various stakeholders, needs to be formulated and implemented for the targeted rehabilitation and development of the country's grazing resources (natural and cultivated).
- There is need to coordinate various research, educational and extension projects on fodder and pasture development for the CPR areas.
- Ecologically sensitive grasslands need to be mapped and appropriate amelioration models/protocols developed, given priority and implemented.
- Fodder conservation strategies need to be explored and implemented to control numbers of grazing animals, meet the fodder requirement targets for use during periods of low productivity, and prevent overgrazing.
- In the arid and semi-arid zones, the adoption of silvopastoral practices could be considered.
- In specific subregions, a network of nurseries and seed banks is needed for the rejuvenation of CPRs and grasslands.
- The rejuvenation of degraded grasslands will require the best strategies for transferring technologies developed in institutes to the field situation, using participative methods that consult with and educate the pastoralists.

Conclusion

A lot of significant work has been done and technologies have been developed and tested with the active support of Government agencies and researchers. More emphasis is required in a coordinated manner involving multiple stakeholders to implement processes and activities to rehabilitate grasslands. It is hoped that this paper will help to create international awareness and development of suitable eco-friendly technologies for grassland rehabilitation and sustainable livelihoods of communities.

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Improving smallholder livelihoods: Dairy production in Tanzania

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Keywords: Small-scale dairy farmer, Nronga Women Dairy Cooperative, Hai district, zero-grazing dairy, milk marketing, biogas.

Abstract

Tanzania is primarily an agro-based economy, characterized by subsistence agricultural production that employs more than 80% of the population and contributes up to 45% of the GDP (2005). This country is endowed with a cattle population of 21.3 M, composed mainly of indigenous Zebu breeds and about 680 000 improved dairy animals. About 70% of the milk produced comes from the traditional sector (indigenous cattle) kept in rural areas, while the remaining 30% comes from improved cattle, mainly kept by smallholder producers. In Northern Tanzania and particularly in Hai district of Kilimanjaro Region, some dairy farmers organize themselves into small producer groups for the purpose of milk collecting, marketing and general promotion of the dairy sector in their community. Nronga Women Dairy Cooperative Society (NWDCS) Limited is one of such organizations dedicated to improve the well-being of the Nronga village community through promoting small-scale dairy farming and its flow-on benefits. Milk flows out of the village, and services for investment and dairy production flow into the village, ensuring a sustainable financial circulation necessary for poverty reduction, rural development and better life for the rural community. In 2001 NWDCS introduced a school milk feeding program that has attracted Australian donors since 2005. Guided by Global Development Group, a multi-faceted project, integrating micro-enterprises, business, education and child health/nutrition, was proposed and initiated by building a dairy plant in Hai District headquarters, the Boma plant. In March 2013, the Australian High Commission to East Africa approved Direct Aid Program funding of AUD 30 000 towards the NWDCS - Biogas Pilot Project in Tanzania, which included the renovation of zero-grazing cow shade units, the construction of 6-m^3 biodigester plants on each farm, and encouragement of the use of bioslurry for pasture production and home gardens.

Resumen

La economía de Tanzania se basa principalmente en la agricultura, caracterizada por sistemas de producción de subsistencia que emplean más del 80% de la población. En 2005 estos sistemas contribuyeron con más del 45% del PIB. El país tiene una población de 21.3 M vacunos, compuesta principalmente por razas cebuínas autóctonas, y aproximadamente 680 000 vacunos lecheros mejorados. El 70% de la leche se produce en el sector tradicional rural con animales autóctonos, mientras que el restante 30% proviene de animales de razas mejoradas mantenidos por pequeños productores. En el norte de Tanzania y particularmente en el distrito Hai de la región Kilimanjaro, algunos productores de leche se han organizado en grupos pequeños con el propósito de recolectar la leche producida, comercializarla y, en general, promocionar el sector lechero dentro de su comunidad. Una de estas organizaciones es la Cooperativa Lechera de Mujeres de Nronga (NWDCS Ltd., por su sigla en inglés), dedicada a mejorar el bienestar de la comunidad a través de la promoción de explotaciones lecheras a pequeña escala y su flujo de beneficios. La leche producida es enviada fuera de la comunidad y en cambio regresan servicios para la inversión y la producción lechera; de esta forma se asegura un flujo monetario sostenible que es necesario para la reducción de la pobreza, el desarrollo rural y un mejor nivel de vida de la comunidad rural. En 2001 la NWDCS estableció un programa de suministro de leche a las escuelas, que desde 2005 ha atraído a donantes australianos. Con la

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orientación del Global Development Group, una ONG australiana, se propuso un proyecto multifacético que integra micro-empresarios, negocios, educación, nutrición y salud infantil; este proyecto se inició con la construcción de una planta procesadora de leche en Boma, la cabecera del distrito Hai. En Marzo 2013, la Australian High Commission to East Africa aprobó una partida de su Direct Aid Program por AU$30 000 para la NWDCS, destinada al proyecto de una planta piloto de biogás, que incluye la renovación de unidades cubiertas para vacas lecheras en confinamiento, la construcción de biodigestores de 6 m^3 en cada finca y la promoción del uso de biolodo para fertilización de plantas forrajeras y huertos familiares.

Introduction

Tanzania is primarily an agro-based economy, characterized by subsistence agricultural production. Despite its subsistence nature, the agricultural sector employs more than 80% of the population and contributes up to 45% of GDP (2005). The livestock sector contributes 30% of agricultural GDP, which includes contributions of 40% by beef production, 30% by milk production and 30% by poultry and small stock production (ASR 2008).

Tanzania has a cattle population of 21.3 M (ASR 2008), ranking third in Africa after Ethiopia and Sudan. The Tanzanian cattle population is composed mainly of indigenous Zebu breeds and about 680 000 improved dairy animals. Livestock-keeping offers a livelihood to 1.3 M men and women, who raise their animals on the semi-arid plains and highlands of Tanzania. The cattle herd has been increasing at 2.1% per annum, which is still short of the targeted growth from 2.7% in 2000 to 9% by 2010, set by the National Strategy for Economic Growth and Poverty Reduction, known by its Swahili acronym as MKUKUTA.

Tanzania's dairy industry is meager; estimated milk production is 1650 ML (2011). About 70% of the milk produced comes from the traditional sector (indigenous cattle) kept in rural areas, while the remaining 30% comes from improved cattle, mainly kept by smallholder producers. Per capita consumption of milk is estimated to be 42 L/annum (2011). Around 10% of the small-scale dairy farmers are found in Northern Zone and Southern Highlands, where rainfall is high, climate is temperate and disease vectors are minimal. Hai District, in the Northern zone with 49 225 households and 38 280 dairy cattle on the southern slopes of Mount Kilimanjaro, practices intensive dairy production with improved dairy cattle breeds. Most households own from 1 to 3 animals and milk production exceeds family requirements; the surplus milk is sold to meet financial obligations of the family. Average daily milk yields per milking cow range from 7 to 12 L. There are 12 small-scale dairy farmer groups in the district, collecting on average 4550 L of milk daily.

This case study focuses on one of the groups, the Nronga Women Dairy Cooperative Society Limited. The paper describes the structure and operation of the cooperative, discusses some of the main challenges and constraints, outlines Australian assistance programs and points towards some lessons for the future.

Case study

The Nronga Women Dairy Cooperative Society Limited (NWDCS, registered as KLR 476) is an organization of dairy farmers, whose main purpose is to improve the well-being of the Nronga village community through promoting small-scale dairy farming and its flow-on benefits. For the Wachagga tribe on the southern slopes of Mount Kilimanjaro, milk production is considered a traditional chore/role for women, so women in Nronga were the originators of the organization that now serves the whole community. The cooperative's services to the Nronga community include:

- Buying milk from all dairy farmers in the village;
- Promoting milk consumption through school milk nutrition programs;
- Offering saving and credit facilities to the community (by way of a village community bank);
- Providing artificial insemination of dairy cows, also for neighboring villages; and
- Promoting slow-combustion wood stoves in an effort to reduce environmental impact.

The Nronga village is situated in Machame Division, Hai District, located on the mountainous area of the slopes of Mount Kilimanjaro. It has 659 households with a population of 2181 inhabitants, and a population density of 860 people per km^2 (2011). An international heritage area, the Kilimanjaro Forest to the north of the village, is the source of 2 major rivers, the Semira and Kikavu, located to the east and west of the village, respectively. These rivers converge to the south of the village, with deep valleys isolating Nronga from the neighboring villages. Animal fodder, firewood and building materials were collected from riverside and heritage forests until recently, when the government restricted the exploitation of these natural resources. Hence, the community is left with very narrow options on the alternative sources of basic materials, particularly firewood.

NWDCS was formed in March 1988 as a model producer-based organization to promote dairy production through effective milk marketing. Its formation was assisted by FAO, DANIDA and the Tanzania Ministry of Livestock Development. NWDCS started with 75 members by collecting daily about 200 L of milk from its members and selling the milk untreated to food shops in Moshi town, as they had no milk coolers, processing machine or office. The members milked their cows just after midnight and sent the milk to collection points, where a vehicle would collect it in cans, drive to Moshi and sell it in bulk to food stores before dawn. While this procedure was cumbersome, tedious and actually painful to women, who traditionally own the milk, it was necessary to minimize losses from milk going sour. Elected leaders recorded the details and were responsible for fortnightly payments in an open area in Nronga primary school playing grounds. Today, NWDCS has 402 members and collects daily between 800 and 900 L of milk from Nronga village and the neighboring villages of Foo, Shari and Kyeeri. Evening and morning milk is collected and cooled in electric-powered cooling tanks before processing or selling unpasteurized to wholesalers or consumers in urban areas of Kilimanjaro and Arusha Regions. Milk is disposed of in the following products: 36% fresh whole milk, 36% skimmed cultured milk, 24% whole cultured milk in packets (500 ml for ordinary market and 200 ml for school distribution), 4% pasteurized butter and 1% yogurt. These products are produced manually using local facilities and limited skills to produce market-competitive products.

Hence, NWDCS benefits the Nronga village community, dairy farmers in Hai District and Tanzania at large. The main benefits are:

- Dairy productivity has been enhanced in the Nronga village as well as in the neighboring villages. Nronga village and neighboring village dairy farmers have a clearly defined milk market and consumers and traders have a reliable milk supply.
- The cooperative has made a business out of dairying, which was once considered a subsistence activity. As milk flows out of the village, services for investment and dairy production flow into the village, ensuring a sustainable cash flow necessary for poverty reduction, rural development and a better life for the rural community. The NWDCS initiative's business has fostered a Saving and Credit Cooperative Society (SACCOS) and a Village Community Bank (VICOBA) in Nronga village.
- In their endeavor to increase future per capita milk consumption in Northern Tanzania, in 2001 NWDCS introduced a school milk feeding program. Currently 6 schools (3 in Kilimanjaro Region and 3 in Arusha Region) with a total of 4717 pupils are fed milk, usually twice a week, on a cost-sharing basis: the parents contribute Tsh 150 (150 Tanzanian shillings) and the Tanzania Dairy Board (TDB, which receives Australian donor funds) also contributes Tsh 150 per 200 ml packet fed to the pupils. NWDCS donates milk to a total of 540 orphan pupils in the same schools. This school milk feeding program has improved health and academic performance of pupils, improved enrolments and attendance, and enhanced the morale of teachers.
- About 650 farmers are self-employed through dairy farming and supply of milk to NWDCS. The lowest supplier earns Tsh 70 000 per month from milk sales, more than the Tanzanian minimal wage for rural workers, while the highest supplier earns about Tsh 450 000 per month, a middle-class employee salary. Moreover the NWDCS has indirectly created employment opportunities for traders, vendors and suppliers of dairy farming inputs in and around Kilimanjaro and Arusha Regions.
- Other benefits of NWDCS include public awareness creation, women empowerment, promotion of the dairy subsector nationwide, and the model for dairy development in Tanzania.
- Through NWDCS it has been possible to introduce other appropriate technologies to the community, such as energy-saving firewood stoves and the use of biogas from zero-grazed cattle waste, to conserve forest resources.
- Nronga village is one of the most developed villages in Tanzania. It has a good source of income to pay for social needs, such as good housing and school fees. Enrolment in primary school is 100%, while 85% of primary school graduates join secondary schools and 10% join vocational colleges. About 45% of high school graduates join universities. The village has 12 university professors and other high-level personnel working on various projects and their involvement has been attributed to the impact of the NWDCS.

Challenges and constraints

Market competition

As the number of dairy groups and processors increases, competition in the market increases as well. Lowering the price is not a good option in order to remain viable; satisfying the customer may be a better choice. Improved product quality, better packaging, product diversification and promotion of the products etc. need to be priorities. Resources to take these steps are the main constraints. NWDCS needs better technology, skills, funds for machinery, buildings, organization and legal frame work, facilities to ensure quality is maintained, to mention but a few, in order to be competitive.

Location and inadequate infrastructure

The NWDCS factory is not centrally located to the market for its products. The land on which the facility is located has limited scope for expansion. The terrain for transportation is difficult. It is located in the rural area, where utilities like electric power, water and telephone are unreliable. In order to expand processing facilities, NWDCS will soon have no choice but to transfer to a location with enough land and relatively reliable utilities, where workers' housing can easily be provided.

NWDCS is a pioneer in the dairy business in the Hai district. Other milk collecting groups would like NWDCS to grow further in order to be able to receive milk from them. However, NWDCS's capacity for receiving milk is already over-stretched. These other groups are ready to supply Nronga with milk, provided they position their processing plant in the lowland area, where it will be easily accessed, rather than in the undulating terrain of the Hai District on the slopes of Mount Kilimanjaro.

Technology and training

Dairy farming productivity in the Hai District as a whole is below its potential. The effective training of farmers, extension agents and other key players in development of the subsector is paramount. If milk production is to increase in quality and quantity, the milk collection system must be made efficient and the dairy products compatible with customer needs. A training center specifically for these purposes must be in place.

Packaging materials

The school milk program is a tool to boost future per capita milk consumption and ultimately expand the market for milk and milk products. The immediate benefit of the program is remarkable (as mentioned earlier) and the cooperative would like to expand to more schools and reach more pupils and orphans for development of the Tanzanian economy and well-being of its people. However, the production of more school milk pouches is the main constraint. An automatic packing machine is required to make the many extra pouches that will be needed by the schools.

Investment plan and profitability

In the past profitability of NWDCS has been suboptimal. For sustainability and development of the cooperative and dairy sector in the Hai District at large, the NWDCS has to make a profit or at least break even. A good investment plan is therefore essential.

Undeveloped distribution network

In rural areas, disposal of excess milk is difficult to organize. In Tanzania there are few milk collecting centers, mostly organized through donor-funded projects. In Hai district, there are 12 centers owned and managed by producer groups. However, most of these centers have no skilled manpower, facilities and proper equipment to manage collection of this perishable food resource.

Australian support

School milk project

In 2007, 3 Australian private donors learnt about the NWDCS initiative to feed school children with milk and kindly decided to partner with the cooperative by providing funds to increase the number of children and schools receiving milk on subsidy. A refrigerated van was also donated to distribute milk to distant schools.

Of late the donors are contributing towards building a second dairy factory in the District capital town (Boma - Hai) to enable NWDCS to make more milk packets and reach more schools in a sustainable way. The dairy factory and the donors have agreed that 10% of the milk collected for processing will go towards the school milk program.

The 3 Australian donors requested Global Development Group (GDG), an Australian charity organization carrying out humanitarian projects with approved partners and providing aid to relieve poverty in a tangible way, to provide a governance role and assist in the areas of planning, monitoring and evaluation, as well as compliance, risk management and auditing to ensure that this project is carried out to Australian aid requirements.

The Biogas and Zero-Grazing Dairy Projects

Through a local contact in Tanzania using participatory methodologies, GDG identified the need for and suitability of a local biogas program to complement plans for adopting zero-grazing dairy methods that would provide wider community benefit. Biogas is the use of livestock waste to produce renewable energy in a climate-friendly and resource-efficient way. The Australian High Commission to East Africa approved in Mach 2013 Direct Aid Program funding of AUD30 000 towards the NWDCS - Biogas Pilot Project in Nronga.

The features of this project include: renovation of 17 zero-grazing cow shade units; construction of 6-m^3 biodigester plants on each participating farm; and encouragement of the use of bioslurry for pasture production and home gardens.

The expected direct benefits from the production and use of biogas to the Nronga community include:

- Environmental sanitation through biodigestion.
- Biogas as an alternative fuel has the potential to reduce illegal logging in the international heritage-listed Kilimanjaro Forest.
- Appropriate zero-grazing cow sheds have positive impacts on animal well-being and productivity.
- Bioslurry enhances pasture production and home gardening.

Other expected benefits are: Cash saving; increased milk production; reduced women work load; cleaner food preparation environment; family happiness and peace; home sanitation; less pneumonia and ocular illnesses; NWDCS's image enhanced; and the youths are attracted to stay with the rural community.

Conclusions

The formation and development of the NWDCS has been pivotal to the well-being of the dairy industry, farmers, villages and school children in Tanzania. Development organizations as well as policy makers commend this model of rural formation for stimulating and spearheading improvement of living standards in rural communities. NWDCS is a living example of a successful primary cooperative society that addresses its community needs.

References

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