Resilient and Sustainable Livestock Systems in the Context of Climate Change in Latin America and the Caribbean

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Abstract

An analysis of the impact of climate change on livestock and livestock production systems, and on the livelihood of livestock producers is presented. Strategies for adaptation of livestock systems to climate change based on the use of local breeds, selection of improved forages, efficient natural resource management and implementation of mixed crop-livestock, and silvopastoral systems are outlined. The co-benefits of adaptation and mitigation strategies are discussed in the context of water use efficiency, biodiversity conservation and use of low carbon emission livestock systems. Policy options to promote technological and institutional innovations for adaptation and mitigation of the effects of climate change on livestock systems are delineated.

Introduction

Global demand for livestock products is expected to double during the first half of this century, in response to growing human population, urbanization, increasing middle class and greater affluence. The Latin American and Caribbean (LAC) region is expected to increase its productivity to respond to global demand for livestock products (Gill and Smith, 2008). In this region, farmers confront the effects of climate change, especially considering that the region has a large proportion of its natural resource base degraded in addition to growing competition for land and water (Zeigler and Truitt, 2014). LAC has about one-third of the world's fresh water resources and more than one-quarter of the world's medium to high potential farmland. However, LAC has already lost an estimated 40 % of its original forests, which are critical to preserving biodiversity and slowing the advance of climate change (Mekonnen *et al*., 2015). Globally, South America suffered the largest net loss of forests between 2000 and 2010, about 4.0 million ha yr^{-1}, decreasing after a peak in the period 2000-2005. The average net loss of forest was 4.2 million ha yr^{-1} in the 1990s; 4.4 million ha yr^{-1} in the period 2000-2005, and 3.6 million ha yr^{-1} in the period 2005-2010. The regional figures reflect at a large extent the developments in Brazil, which accounts for 60 % of the forest area in the region (FAO, 2010). In the period 2000-2010, three of the ten countries with the largest annual net loss of forest area globally are in the LAC region: Brazil with a loss of 2 642 000 ha yr^{-1} or 0.49 %; Bolivia with a loss 290 000 ha yr^{-1} or 0.49 %, and Venezuela with 288,000 ha yr^{-1} or 0.60 % (Mekonnen *et al*., 2015). Wassenaar *et al*. (2007) estimated that, although there are substantial differences among countries in relation to the spatial patterns of deforestation and the substitution trends between land uses, nearly two-thirds of the deforested land will be converted to pasture. Therefore, there is need to implement policies to increase livestock productivity on already cleared lands, so as to reduce the pressure on scarce forest reserves.

Livestock production is under the 'eye of the hurricane' for their contribution to greenhouse gas (GHG) emissions, which amounts to about 14 % of all anthropogenic GHG (Gill and Smith, 2008). Innovative livestock systems are required to adapt to, and mitigate the effects of climate change. Climate change adds to already considerable development challenges and prompt policy makers and international development organizations to promote sustainable and inclusive cropping and livestock systems. Emerging practices that are resilient to climate change, and that help to preserve, sustain, and carefully manage the region's unique biodiversity and habitats, can also deliver benefits to livestock producers, the custodians of these resources for the future. Strategies for sustainable intensification of livestock systems, which involves "producing more outputs with more efficient use of all inputs on a durable basis, while reducing environmental damage and building resilience, natural capital and the flow of environmental services", are key to the adaptation to and mitigation of the effects of climate change.

In this paper we summarize the direct and indirect impacts of climate change on livestock systems and the strategies for technological interventions to develop climate smart livestock systems. In LAC, family farming accounts for 80 % of all farms and occupies 35 % of the land under cultivation, contributes 40 % of production, and generates 64 % of agricultural employment (FAO, 2012). As the majority of family farms are engaged in mixed crop-livestock systems, the co-benefits of improved crop and livestock systems on adaptation to climate change, mitigation of the emission of GHG and the conservation of ecosystem services are also discussed.

Impact of climate change on livestock systems

Climate modeling results indicate that, for the next two decades, a warming of about 0.2 °C per decade is projected for a range of different GHG emission scenarios (IPCC, 2007). With the exception of the Southern Cone, most of South America is forecast to warm more than the global average. Heatwaves are likely to be more frequent and more intense, and the higher temperature in general will tend to favor a longer warm season, possibly leading to extreme events such as hurricanes. In the high Andes, the temperature rise is projected to be greater than the mean values for the region. This means that less water will be stored because snow, ice and glaciers will continue melting. In the Amazon region, which has a large cattle population, the expected higher temperatures are likely to worsen the destructive effects of deforestation and increase the risk of wildfires. In terms of projected precipitation the patterns of probable change point to dry areas becoming dryer and wet areas becoming wetter. Mean annual precipitation is projected to decrease over northern South America near the Caribbean coasts, as well as over large parts of northern Brazil, Chile and Patagonia, and to increase in Colombia, Ecuador, Peru, around the Equator, and in Southeastern South America. Prolonged drought and water scarcity is a significant threat to developing resilient agriculture, already evident in areas such as the Northern region of South America, Northern region of Mexico and the seasonally dry forest areas of Central America and the 'Arco Seco' of Panama. On the other hand, there has been a trend of more frequent extreme events (tropical storms, hurricanes), which together –with increased sea level rise– constitute a threat to the Caribbean islands and coastal regions (IPCC, 2007). A summary of some of the impacts of climate change on livestock and livestock systems in relation to effects on biodiversity, water, feed, livestock and human health is presented in Table 1.

Table 1. Some of the Impacts of Climate Change on Livestock and Livestock Systems (Adapted from Thornton and Herrero, 2008)

Biodiversity	Loss of forest cover due to deforestation for pasture expansion, and forest fires, loss of genetic and cultural diversity and agrobiodiversity as evident in crops and local breeds. A 2.5 °C increase in temperature will have negative impacts on ecosystems such that 20-30 % of all plant and animal species assessed could be a risk of extinction (IPCC, 2007).
Water	Coupled with population growth and economic development, climate change impacts will have a substantial effect on global water availability for agriculture in the future.

Feeds	Climate change and variability will have impact on species niche and composition, and may modify animal diets and productivity.
	• *Changes in the primary productivity of crops, forages and rangeland* Effects depend significantly on location, system and species, but in C_4 species, temperature increases up to 30-35 °C may increase productivity of crops, fodders and pastures (as long as water and nutrients do not significantly limit plant growth). In C_3 plants, temperature has a similar effect but increases in CO_2 levels will have a positive impact on the productivity of these crops. For food-feed crops, harvest indexes will change and so will the quantity of stover and availability of metabolisable energy for dry season feeding. In the semi-arid rangelands where contractions in the growing season are likely, rangeland productivity will decrease.
	• *Changes in species composition*
	As temperature and CO_2 levels change, optimal growth ranges for different species also change, species alter their competition dynamics, and the composition of mixed grasslands changes. Proportion of browse in rangelands will increase in the future as a result of increased growth and competition of browse species due to increased CO_2 levels, but dominance of unpalatable species may exist. Legume species will also benefit from increases in CO_2 and in tropical grasslands, the mix between legumes and grasses could be altered which will affect N fixation.
	• *Quality of plant material* Increased temperatures increase lignification of plant tissues and thus reduces the digestibility and the rates of degradation of plant species. Resultant reduction in livestock production may have impacts on food security and incomes of smallholders. Interactions between primary productivity and quality of grasslands will demand modifications in grazing systems management to attain production objectives.
Livestock (and human health)	Major impacts on vector-borne diseases: expansion of vector populations into cooler areas (higher altitude areas, such as malaria and livestock tick-borne diseases) or into more temperate zones (such as bluetongue disease in northern Europe). Changes in rainfall pattern may also influence expansion of vectors during wetter years, leading to large outbreaks of disease (Rift Valley Fever virus in East Africa). Helminth infections are greatly influenced by changes in temperature and humidity. Climate change may affect trypanotolerance in subhumid zones of West Africa: could lead to loss of this adaptive trait that has developed over millennia and greater disease risk in the future. Effects (via changes in crop, livestock practices) on distribution and impact of malaria in many systems and schistosomiasis and lymphatic filariasis in irrigated systems.

Direct impact of climate change on livestock production and diversity

Drought, floods, pests and disease epidemics may increase as result of climate change. Local and rare breeds thus risk being lost in localized disasters. To secure against such disasters, it is necessary to characterize and preserve animal genetic resources (AnGR) to subsequently build inventories. Information on spatial distribution of breeds and breeding stocks, cryoconservation of genetic material and other measures are valuable tools for genetic recovery in case of disaster (Hoffmann, 2008). These approaches require developing public-private investments for gene banks, especially for the conservation of local breeds.

High temperatures increase heat stress and lead to negative effects on performance of animals (Souza, 2002). Although *Bos indicus* animals are generally more heat resistant than *Bos taurus*, their performance is affected by extreme temperatures (Prayaga *et al.*, 2006). High-output breeds originating from temperate regions, such as Holstein cows, are not well adapted to heat stress (Hoffmann, 2008). FAO (2006) provides a broad overview of breed diversity in drylands, which are among the most extreme environments. Most of these breeds are not well characterized, however, their adaptation includes not only heat tolerance, but they also possess an ability to survive, grow and reproduce in the presence of poor seasonal nutrition, parasites and disease.

Indirect impacts of climate change on livestock production and diversity

Ecosystem changes resulting from climate change are relevant for livestock production because of the land dependency of most production systems, and the close interaction of livestock genetic resources with other agricultural biodiversity. Water, feed and forage are the most important inputs for livestock production. Their overall and relative availability may be affected by ecosystem changes, which are accelerated by climate change (IPCC, 2007). Climate change may result in changes in species composition and the proportion of C4 and C3 species in the system, which affects forage availability and quality. In the drylands, prolonged drought and increasing temperatures will favor the dominance of unpalatable trees and shrubs. Increased temperatures are associated with a decrease in forage quality *(e.g.,* digestibility and crude protein) and hence in forage intake (Hoffmann, 2008).

Climate strongly affects agriculture and livestock production through its influence on animal diseases, vectors and pathogens and their habitat. Global warming trends predicted in the 2007 Intergovernmental Panel on Climate Change (IPCC, 2007) Report for South America are likely to change the temporal and geographical distribution of infectious diseases, including those that are vector-borne such as bluetongue, West Nile Fever, vesicular stomatitis and new world screwworm (Pinto *et al*., 2008). Hoffmann *et al*. (2008) list breeds, mainly from developing countries, that were reported to withstand trypanosomiasis, tick burden, tick-borne diseases, internal parasites or foot rot. Many of these are anecdotal evidence rather than scientific studies, and the underlying mechanisms are not well understood. There is, however, a potential for genetic improvement of disease resistance, and commercial breeding programs already include resistance against helminthosis, ticks, mastitis, *E. coli* or scrapie. Breeding has also a role in reducing GHG emissions (Prayaga *et al.,* 2006). In addition to selection to increase production per se, any selection that reduces mortality and increases fertility, longevity and productivity contributes to reducing GHG emissions per unit of livestock output.

Impact on livelihoods

Smallholder and subsistence farmers and pastoralists will suffer complex, localized impacts of climate change, due both to constrained adaptive capacity in many places and to the additional impacts of other climate related processes such as snow-pack decrease and sea level rise (IPCC, 2007). It is already clear that poor livestock keepers are among those whose livelihoods are most vulnerable to climate change. Extensive grazing systems will become less viable in semi-arid areas that become even more warm and dry. Studies in the seasonally dry areas of Central America showed that small cattle farmers generally sell their cattle during prolonged dry season because of feed shortage, thus impacting on their assets base (Campo, 2012). In addition, as pests and diseases move into new areas, the poor who can either not afford or access animal health services are more likely to experience increased morbidity and mortality among their animals. In low lying coastal areas *(e.g.,* Guyana and Suriname), poor livestock keepers facing loss of land to rise in sea levels will find it difficult to locate alternative sites on which to re-establish their livelihoods.

Strategies for developing livestock systems resilient to climate change

Livestock producers have traditionally taken numerous adaptive and environmentally friendly measures to climate variability and uncertainties, such as opportunistic seasonal mobility of animals depending on the availability of forage, or extreme weather conditions such as floods *(e.g.,* coastal areas in the Caribbean), mixed crop-livestock systems and efficient water harvesting. However, human population and economic growth, together with increased demands and consumption of animal products, have rendered these coping mechanisms ineffective. Developing livestock systems that are resilient to climate change will require a holistic approach at a landscape level, involving the implementation of policies and strategies for the conservation of ecosystem services (biodiversity, water and carbon), and climate smart and sustainable practices to increase productivity of livestock systems. Some of the key actions required to develop resilient livestock systems are briefly described below.

Genetic improvement for adaptation to climate change

Climate change will affect the products and services provided by agricultural biodiversity, but this biodiversity has not yet been properly integrated in adaptation and mitigation strategies to climate change, and its role for the resilience of food systems must still be addressed (FAO and Bioversity, 2008). Research should focus on improving livestock capacity to cope with climate change through the identification and improvement of local breeds adapted to available feed resources and tolerant to heat and/or cold and health stress. In LAC there are good examples showing that local breeds *(e.g.* Carora dairy breed in Venezuela and milking 'Creole' in Nicaragua) are commonly used in grassland-based pastoral and small-scale mixed crop-livestock systems, where they deliver a wide range of products and services for the local community, with low to medium external inputs. The spread of commercial breeds in LAC is due to their perceived economic competitiveness, and has, in some countries, indirectly increased the risk of extinction of local less productive breeds. Facing the complex challenges of climate, ecological, economic and social change, the question is how animal genetic resources can adapt and continue to contribute to food security and resilience of rural livelihoods (Hoffmann, 2008). The integration of local breeds in breeding programs will be important in selection based on traits related to tolerance to heat stress and to disease and parasites, as well as on efficiency in the use of forage based feeds to increase productivity.

Managing diversity of forages to adapt to climate change

Selection and management of improved grasses and legumes that are more adapted to climate stress conditions *(e.g.* drought and waterlogging) will be critical for resilient livestock systems. For wet conditions improved grasses *(Panicum spp*, *Brachiaria spp)* and legumes that are more tolerant to water logged conditions have been selected (Rao *et al*., 2014). There is a tendency for prolonged drought conditions in areas of importance for cattle production such as the Dry Corridor of Central America, Northern region of Mexico, Northeastern region of Brazil, and El Chaco of Paraguay, Bolivia and Argentina. In the sub-humid regions, improved grass species *(Brachiaria spp* and *Panicum spp)* that are more drought tolerant have been selected, but they cannot withstand prolonged drought as evident from the El Niño effect. Ospina *et al*. (2012) found that native *Paspalum* pastures in a sub-humid zone of Nicaragua has more stable yields than improved grass pastures with *Brachiaria brizantha*. This study demonstrated the importance of selecting native herbaceous legumes and grasses for climate resilient forage systems.

With longer dry seasons, the integration of forage trees and shrubs that are more drought tolerant and of relatively high nutritive value will become more important as an adaptation strategy for overcoming feed shortage in the dry season. A large number of forage trees and shrubs with traits for drought tolerance, dry matter production, and of nutritional quality have been selected and validated on small and medium size livestock farms in LAC (Ibrahim *et al*., 2001b; Pérez *et al*., 2012; Lombo *et al*., 2013). For example, *Prosopis* has been a flag genus for the arid and semi-arid regions, and *Brosimum alicastrum* that thrives well on heavy alkaline soils, has been managed for its forage value in seasonally dry areas of Mexico, Belize and Guatemala, and species such as *Gliricidia sepium*, *Guazuma ulmilifolia* and *Leucaena spp* have been traditionally managed for dry season feeding in sub-humid regions of Mesoamerica.

In a recent study conducted to evaluate growth responses of forage trees in a seasonally dry area in Nicaragua, Lombo *et al*. (2013) found that regrowth capacities of *Pithecellobium dulce* and *Cordia dentata* were higher than those of *Guazuma ulmilifolia*, *Albizia saman*, *Gliricidia sepium*, and *Albizia niopoides,* being 260.5, 147.8, 69.3, 54.0, 24.3 and 17.3 regrowths/tree, respectively. Higher regrowth capacity was associated to a higher number of leaves per regrowth, which is an adaptation mechanism to dry conditions. The use of these traits is promising in the selection of drought tolerant species.

The use of forage trees and shrubs for feeding livestock generally results in increased productivity of milk and meat (Ibrahim *et al*., 2001ab; Pérez *et al*., 2012; Villanueva *et al*., 2012). For example, in a seasonally dry region in Costa Rica, dual purpose cows fed on a diet of *Cratylia argentea* and sugar cane produced daily 6.1 l of milk, this yield being similar in amount and quality of milk produced by cows supplemented poultry litter and higher than milk yields obtained with cows grazing *Hyparrhenia rufa* pastures (Ibrahim *et al*., 2001a). In LAC there are large efficiency gaps in milk and beef production on small and medium size farms, and it is recommended to prioritize research on the use of the concept of plant traits and functional diversity, to identify mixture of forage species that will enhance feed efficiency conversion, and to achieve increased and stable productivity, reducing emissions of enteric methane and carbon footprint of livestock products.

Mixed crop-livestock systems for adaptation to climate change

Production systems that combine livestock and cash crops at farm level are considered to be an effective way to sustainably intensify agricultural systems and for adaptation and mitigation to climate change. Such systems offer opportunities to generate additional income and environmental sustainability through diversification of marketable products, higher resilience to climate and other shocks and enhanced ecosystem services such as from carbon sequestration and reduction of GHG emissions, higher biodiversity, and improved water and nutrient management (Ryschawy *et al.*, 2014).

Soil quality improvement results from application of livestock manure and use of crop-grassland rotations. Increased landscape heterogeneity through the integration of grasslands within diversified crop rotations enhance biological regulation and improve soil water holding capacities. In terms of nutrient cycling, there has been advance in research to identify strains of *Rhizobium* for leguminous crops that increase N fixation, in mixed cropping systems. For example, in Brazil, soybean *(Glycine max)* is an important component of mixed crop-livestock farms. The soybean-*Bradyrhizobium* mix might be considered as the "perfect symbiosis", adapted to a variety of soil and climatic conditions, reaching rates of 300 kg of N ha^{-1}, in addition to about 30 kg N ha^{-1} left over for the following crop, which in mixed crop-livestock-forest system is often maize or *Brachiaria spp*. Considering the prices of nitrogen fertilizers in Brazil, this "leftover" implies an economy of about US$ 30 ha^{-1}, besides the mitigation of 135 kg CO_2eq, considering a ratio of 4.5 kg of CO_2 eq per kg of N-fertilizer (Hungria and Boddey, 2015). Other studies with mixed crop-livestock-forest systems in Brazil showed that pasture carrying capacity increased from 0.5 animal units (AU, 450 kg LW) ha^{-1} under degraded condition to 2.5 AU ha^{-1} with mixed crop livestock systems. Carcass production was 43% higher with mixed crop-livestock-forest system. The C-footprint for 1 kg of carcass was reduced by approximately 45 % (Alves *et al.*, 2015). The results on mixed crop-livestock-forest systems demonstrate that these systems have adaptation and mitigation to climate change benefits as well as economic and environmental benefits. However, there is a need to extend our understanding of the complex interactions of mixed systems, in order to scale up these systems effectively and develop systems that are economically and environmentally sustainable in the long term.

Silvopastoral systems for improved productivity and resilience

Silvopastoral systems involve the integration of woody perennials (shrubs and trees) with animal and pasture components, and are classified based on the structure and functional role of trees in these systems (Cajas-Giron and Sinclair, 2001; Ibrahim *et al.*, 2001 b; Ibrahim *et al.*, 2015). The interactions between components in these systems depend on the spatial arrangements and/or configuration and diversity of trees in the pastures. Silvopastoral systems have the potential to reduce the impact of livestock on the environment in the long term, and enhance both livestock productivity and resilience of livestock production to climate change. Livestock farmers have traditionally integrated trees and shrub species in their farming systems, and have empirical knowledge of the functional traits of these species, their use value for forage, shade, eco-system services and timber (Mosquera *et al*., 2012; Ibrahim *et al*., 2015). The importance of trees and shrubs in livestock systems has increased in the sub-humid, and semi-arid and arid regions where there is water deficit. In Central America, landscapes dominated with cattle are characterized by relatively high richness and moderate tree density in pastures, ranging from 72 to 107 species and 10 to 33 trees ha^{-1} respectively (Esquivel *et al.,* 2011; Harvey *et al*., 2011).

Trees in silvopastoral systems have multiple functions. Managing shade trees in pastures will become more important with projected increase of temperatures that is correlated with heat stress of animals. Several studies in Central America indicate that temperatures under tree canopy were 2 -7 °C lower than those measured outside tree canopy, and differences were associated to the functional traits of the species in terms of their phenology and leaf arrangements (Villanueva *et al*., 2012 ;García and Ibrahim, 2013). The benefits of shade trees in pastures were demonstrated in a study conducted in the humid tropics of Costa Rica, in which Jersey cows grazing with access to shade trees had lower respiratory rates and increased forage intake and milk production compared to those grazing in pastures without shade trees (Table 2).

Table 2. Effect of Shade Trees on Respiratory Rate and Milk Production of Jersey Cows Grazing *Cynodon nemfluensis Pastures* in the Humid Tropics of Costa Rica.

Treatment	Respiratory rate, no./min	Milk production, kg/cow/day
Cows grazing pastures without shade trees.	11.37	80
Cows grazing pastures with shade trees.	12.48	65

Source: Souza (2002)

Due to tendency of increased temperatures and prolonged drought conditions in seasonally dry areas of Central America, farmers have been increasing the density of shade trees in pastures to manage heat stress of animals (Mosquera *et al*., 2012; Ibrahim *et al*., 2015). Further research is needed to evaluate the interactions between breeds of livestock and shade trees in pastures, and their effect in controlling heat stress, as well as on the efficiencies in the use of feed and water, and synergies with biodiversity conservation.

Importance of silvopastoral systems in soil improvement and water conservation

Many studies have demonstrated the importance of trees and shrubs in enhancing nutrient cycling and improving water conservation and availability, which is important to sustain productive and resilient systems (Ibrahim *et al*., 2001b; Casals *et al*., 2013). The integration of trees in silvopastoral systems generally increases soil organic matter and the concentration of N and P, depending on the tree species. In a study conducted with native tree species *Albizia saman*, *Enterolobium cyclocarpum*, *Tabebuia rosea* and *Guazuma ulmifolia* managed in traditional silvopastoral systems in the sub-humid tropics of Nicaragua, Casals *et al*. (2013) found that soil organic C and N, available P and extractable K+ and Ca++ were higher under the tree canopy than under paired open grassland, but there were differences between species in soil fertility variables. In relation to water use, farmers have integrated a diversity of tree species in their systems with differences in drought tolerance strategies such that some trees are capable of exploring water in deeper soil depths (Olivero, 2011; Bucheli *et al*., 2013). Water use efficiency of grasses was higher in silvopastoral compared to grass monoculture, but there are interactions between grass and native tree species in terms of water use which should be considered in system design and management (Andrade, 2007).

Importance of dispersed trees in pastures as dry season feed

Farmers maintain a mixture of tree species in pastures depending on their value and functional roles. Many species are retained to provide multiple functions, for example trees commonly found in pastures such as *Enterlobium cyclocarpum*, *Guazuma ulmifolia*, *Pithcellobium saman* and *Prosopis sp* are important for providing high value edible fruits for animals, while also providing shade and ecosystem services (Esquivel *et al*., 2011). Fruits of *Enterlobium* and *Pithcellobium* had *in vitro* dry matter digestibility of 68 to 73 % and crude protein of 19 to 23 %, which was significantly higher than those measured of the grass species (35 % and 4 %, respectively) at the time of fruit drop in the dry season (Esquivel *et al*., 2011). In addition, these species produced fruit in the middle and towards the end of the dry season when there is a critical need for feed supply. With increasing frequency of prolonged drought, participatory research should focus on designing silvopastoral systems with composition and density of tree species based on different scenarios of climate change and the impacts on forage supply, heat stress of animals and ecosystem functions.

Multiple benefits of climate smart livestock systems

The strategies to adapt livestock systems to climate change discussed above are considered win-win options, as they increase productivity while reducing GHG emissions as a co-benefit that enhances ecosystem services and contributes to mitigation of the effects of climate change.

Improving livestock water productivity

Agriculture, in particular livestock production, has drawn attention for the inefficient use of water to produce crop and livestock commodities. Mekonnen *et al.* (2015) found that the total water footprint (WF) of national production in LAC in the period 1996-2005 was 1162 billion m^3 yr^{-1}, of which 87 % is green water, 5 % blue water and 8 % grey water. Crop production contributed 71 % of this total, followed by grazing (23 %), domestic water supply (4 %), industrial production (2 %) and animal water supply (1 %). Efficient use of the existing agricultural land and associated green water resources is therefore crucial to increase total production. Among the agricultural export products, cotton has the highest return per unit of water used (0.58 US$ m^{-3}), followed by livestock products (0.20 US$ m^{-3}), sugarcane and coffee (0.15 US$ m^{-3} each). Soybeans have a very modest economic revenue of 0.12 US$ m^{-3}.

Livestock water productivity (LWP) is the ratio of the net beneficial animal products and services, produced to the water depleted in producing them. Strategic feed sourcing, conserving water and enhancing animal productivity provide multiple options for increasing LWP (Oweis and Peden, 2008). Increasing LWP can be achieved by maximizing the value of animal products and services produced with available feed that is produced where transpiration is high and other forms of water depletion are low. The establishment of silvopastoral systems and fodder banks on sloping land was associated with reduced run off rates and increased infiltration rates of water (Table 3), and this should enhance the efficiency of use of water for forage production (Ríos *et al*., 2007). There is need for further research to understand the interactions between components in the system to increase the efficiency of use of green water and to reduce the water foot print of livestock systems.

Table 3. Superficial Runoff and Infiltration of Water Measured in Different Land Use Systems in the Sub-Humid Tropics of Nicaragua and Costa Rica.

System	Runoff (%)			Infiltration (cm/hr)		
	Costa Rica	Nicaragua	Mean	Costa Rica	Nicaragua	Mean
Overgrazed natural pasture.	28.00	48.00	38.00	0.07	0.03	0.05
Improved pasture with tres.	14.00	16.00	15.00	0.75	0.46	0.61
Young secondary forest.	7.00	10.50	8.75	0.23	0.81	0.52
Forage bank.	4.00	4.36	4.18	3.54	0.96	2.25

Source: Ríos *et al.* (2007)

Contribution of climate smart practices to biodiversity conservation

The conversion of natural ecosystems into grazing lands and cropland are currently the main reasons for biodiversity loss and ecosystem degradation in LAC. In addition to on-site benefits, the higher complexity of silvopastoral systems relative to grass monoculture systems has important benefits for biodiversity conservation (Tobar *et al.,* 2007; Harvey *et al*., 2011). Pasture lands converted to silvopastoral systems sustain relatively high productivity over time and can reduce the pressure to clear forest for pasture expansion (Ibrahim *et al.,* 2010). Many studies demonstrate that high tree density and multi-strata live fences are involved in the conservation of biodiversity especially because of their importance in functional and structural connectivity (Table 4).

Table 4. Abundance and Richness of Birds, Butterflies and Dung Beetles in Silvopastoral and Forest Land Use in Different Zones.

Taxa	Zone	Land use	Secondary Forest	Pasture with high tree density	Pasture with low tree density	Live fence	Source
Birds	Tropical Dry Forest	Abundance	70	80	62	70	Cárdenas *et al.* (2003)
		Richness	20	25	17	21	
		Abundance	60	33	25	31	Harvey *et al.* (2005)
		Richness	18	15	8	10	
	Subtropical Forest	Abundance	26	32	22	20	Enríquez (2007)
		Richness	13	13	10	8	
Butterflies	Tropical Dry Forest	Abundance	10	11	20	9	Harvey *et al.* (2005)
		Richness	4	6	6	5	
	Subropical Forest	Abundance	132	132	104	88	Tobar *et al.* (2007)
		Richness	21	14	10	17	
Dung Beetles	Tropical Dry Forest	Abundance	303	270	220	304	Harvey *et al.* (2005)
		Richness	23	24	20	24	
	Subropical Forest	Abundance	452		241	865	Harvey *et al.* (2008)
		Richness	26		10	17	

Low emission carbon livestock systems

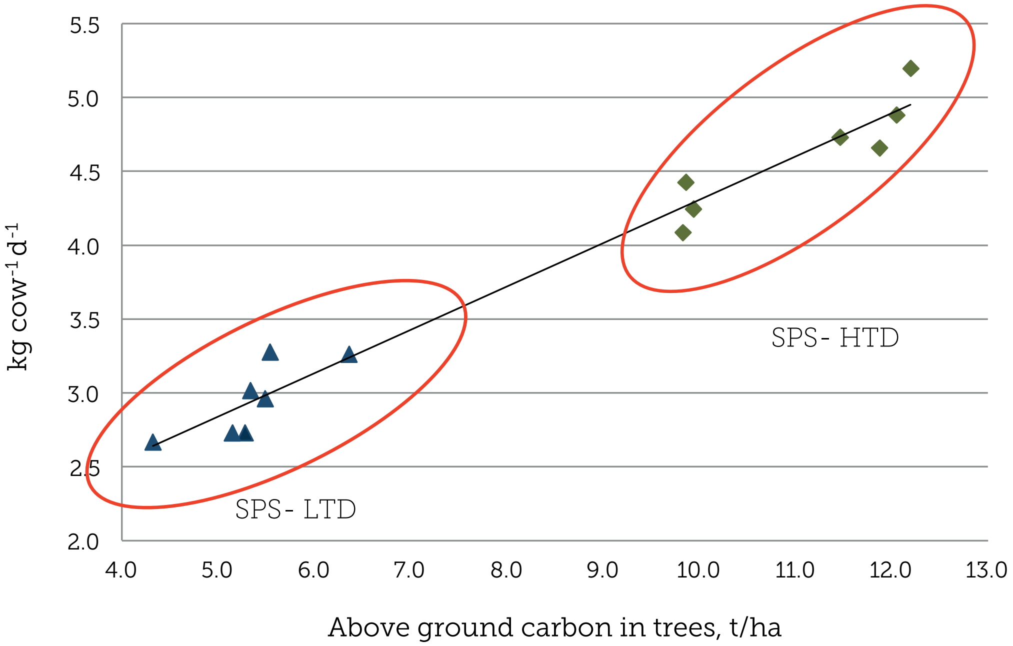
Livestock account for an important share of the global emissions of GHG leading to negative impacts on climate change (Gill and Smith, 2008). Feeding ruminants on diets of improved quality increased livestock productivity and reduced emissions of enteric methane per kg of milk or meat produced (Waghorn and Clark 2005; Mara *et al*., 2008). In New Zeland, Waghorn and Clark (2005) found that feeding growing lambs on a diet of rye grass, that had 10.0 MJ kg^{-1} dry matter and on a diet of white clover that had 12.0 MJ kg^{-1} dry matter, led to liveweight gains of 100 and 300 g d^{-1}, and CH_4 emissions of 330 g kg^{-1} gain and 100 g kg^{-1} gain, respectively. These results demonstrate that improved feeding technologies lead to productivity gains and lower GHG emissions per unit milk or meat; especially considering that enteric methane account for close to 40 % of the total emissions of ruminants. Furthermore, improved pasture, mixed crop-livestock and silvopastoral systems have an important role in carbon removal (or sequestration). Perennial agricultural systems of improved silvopastoral systems often contain greater soil organic carbon and above ground carbon in the vegetation than grass monoculture pastures (Table 5).

Table 5. Carbon in Soil and Vegetation of Pasture and Silvopastoral Systems in the Sub-Humid and Humid Tropics of Costa Rica.

Ecosystem	System	Soil Carbon, t/ha	Vegetation, t/ha	Total C, t/ha	References
Dry tropics of Costa Rica	*Brachiaria brizantha* + Trees	44.2	43.1	87.3	Andrade *et al*. (2008)
	Hyparrhenia rufa + Trees	42.0	39.4	81.4	
Humid tropics of Costa Rica	*Brachiaria brizantha*	150	3	153	Amézquita *et al*. (2008)
	Brachiaria brizantha + *Eucalyptus deglupta*	160.9	12.8	173.7	
	Brachiaria brizantha + *Arachis pintoi* + dispersal trees	178.5	8.3	186.8	
Sub-humid tropics of Costa Rica	Degraded pasture	21.6	5	26.6	Ibrahim *et al*. (2007)
	Brachiaria brizantha	114.4	2.7	117.1	Ibrahim *et al*. (2007)
	Brachiaria brizantha + dispersed trees	118	12	130	Ibrahim *et al*. (2007)

The removals of carbon in improved pasture and mixed crop systems is important to offset emissions of livestock systems and to develop low emission carbon or carbon neutral livestock products. In addition, Ibrahim *et al*. (2011) found that there was a high correlation between the amount of carbon and biodiversity index of different land use systems such as silvopastoral systems. High tree densities had relatively high correlation values with biodiversity and carbon compared to other agricultural land use practices. In another study on silvopastoral systems, Chuncho *et al*. (2012) found that relatively high milk yields and above ground carbon stored in trees when compared with low tree density silvopastoral systems. These results demonstrate that is possible to increase productivity, while contributing to mitigation of the effects of climate change (Figure 1).

Figure 1. Relationship between milk yields per cow and the amount of above ground carbon stored trees in low tree density (LTD) and high tree density silvopastoral systems (SPS), in sub-humid tropics of Nicaragua.



Conclusions

The projections of future climate indicate that variations in temperatures and rainfall patterns will have significant effects on livestock systems and livelihoods of the rural communities that depend on this activity. Changes in climate will affect forage availability and quality, prevalence of pest and diseases and parasites, and physiological responses of animals. Selection of improved breeds and climate smart management practices increase productivity of livestock systems, while providing ecosystem services and mitigating emissions of GHG. Policies should be promoted to enhance the adoption of these practices through:

a. Strengthening research and rural extension services to promote innovation based on adaptation to and mitigation of the effects of climate change.
b. Providing incentives for diversification of livelihoods as a strategy for managing climate risk, including incentives for mixed crop-livestock systems, and for investing in technologies for water harvesting and conservation of forage.
c. Providing incentives for conservation of ecosystem services (biodiversity, carbon and water), and for integrated pasture and silvopastoral management systems.
d. Developing flexible management systems based on projections of climate change and establishing carrying capacities based on forage availability, and to reduce the ecological footprint.
e. Establishing early warning systems for livestock systems at different scales that considers forecasting and crisis preparedness.
f. Building capacities of farmers and rural extension workers to make decisions on restocking and destocking options and policies that allow livestock producers to sell their stock during drought or flood conditions, as a strategy to reduce losses and damage to farm assets.
g. Developing public private partnerships for managing risk such weather-based index insurance linked to measurable climate change events such as extreme heat, low rainfall and vegetation.

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