

Contribution of intensive silvopastoral systems to animal performance and to adaptation and mitigation of climate change[□]

Contribución de los sistemas silvopastoriles intensivos al desempeño animal y a la adaptación y mitigación al cambio climático

Contribuição dos sistemas silvipastoris intensivos no desempenho dos animais e da adaptação e mitigação às mudanças climáticas

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Summary

According to FAO, world demand for animal products will double in the first half of this century as a result of increasing population and economic growth. During the same period, major changes are expected in world climate. Food security remains one of the highest priority issues in developing Latin American countries, a region where livestock production plays a fundamental role. Agricultural activities seriously threaten natural resources; therefore, it is necessary to ensure that livestock production contributes to satisfy the demand for animal products in a sustainable manner. Intensive silvopastoral systems (ISS) are becoming the technology of choice for Colombian and regional livestock sectors because it can help reduce the seasonality of plants and animal production, and therefore contribute to mitigate and adapt to the effects of climate change. We have recently gained knowledge on the nutritional and productive attributes of these systems. However, in recent years, the low carbon approach acquired importance in animal agriculture, which seeks to primarily promote the adoption of programs running parallel activities aimed at adapting to and mitigating climate change. This review outlines projections on the effects of climate change on the livestock industry, presents concepts on Greenhouse Gas flow and highlights evidence in support of the conclusion that ISS is an interesting option to allow the livestock sector in the region to adapt to climate change and to mitigate some of its effects. The adoption of ISS may help to remove up to 26.6 tons of CO₂ eq/Ha/yr from the atmosphere.

Key words: bovine, GHG, grasslands, livestock, sustainability.

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Resumen

Según la FAO, la demanda mundial de productos de origen animal se duplicará durante la primera mitad de este siglo como resultado del incremento de la población y del crecimiento económico y durante el mismo período se esperan grandes cambios en el clima a nivel mundial. La seguridad alimentaria sigue siendo una de las cuestiones de más alta prioridad en el desarrollo de los países latinoamericanos y la producción ganadera tiene un papel fundamental en muchos de estos países. Todos estos elementos tienen estrecha relación con la enorme presión sobre los recursos naturales, por tanto, es necesario que la producción ganadera se realice de manera sustentable. Los sistemas silvopastoriles intensivos (SSPi) se están convirtiendo en una opción tecnológica de implementación progresiva en la ganadería colombiana y de la región porque pueden reducir la estacionalidad de la producción vegetal y animal; y por lo tanto pueden mitigar los efectos del cambio climático y adaptarse a ellos. En los últimos años se ha avanzado en el conocimiento sobre los atributos nutricionales y productivos de éstos sistemas. Sin embargo, ultimamente empieza a tener importancia el enfoque de agricultura baja en carbono que busca principalmente, adelantar programas de desarrollo donde se ejecuten paralelamente actividades orientadas a la adaptación y a la mitigación del cambio climático. La presente revisión incluye algunas proyecciones sobre los efectos del cambio climático en la ganadería, presenta algunos conceptos sobre el flujo de los gases de efecto invernadero (GEI) en los sistemas ganaderos. Resalta algunas evidencias que permiten afirmar que los SSPi son una opción interesante para que la ganadería de la región se adapte al cambio climático y mitigue algunos de sus efectos, dado que con el establecimiento de SSPi se pueden remover hasta 26,6 ton de CO₂ equivalentes/Ha/año.

Palabras clave: *bovinos, ganadería, GEI, pasturas, sustentabilidad.*

Resumo

Segundo a FAO, a demanda mundial de produtos de origem animal se duplicará durante a primeira metade deste século como resultado do aumento da população e dos recursos económicos; durante o mesmo período se esperam grandes mudanças no clima em todo o mundo. A segurança alimentar continua a ser uma das questões de maior prioridade no desenvolvimento dos países latino-americanos e a produção pecuária tem um papel fundamental em muitos destes. Todos estes elementos têm estreita relação com a enorme pressão sobre os recursos naturais, portanto, é necessário que a produção pecuária seja feita de uma maneira sustentável. Os sistemas silvopastoris intensivos (SSPi) estão se transformando em uma opção tecnológica de implementação progressiva na pecuária colombiana e da região porque podem reduzir a estacionalidade da produção vegetal e animal, portanto, podem mitigar os efeitos das mudanças climáticas e adaptar-se a eles. Nos últimos anos ocorreram avanços no conhecimento sobre os aspectos nutricionais e produtivos destes sistemas. No entanto, recentemente começou a ter importância o enfoque da agricultura com baixa produção de carbono que visa, principalmente, delinear programas de desenvolvimento onde se executem paralelamente atividades destinadas à adaptação e mitigação das mudanças climáticas. Esta revisão apresenta algumas projeções sobre os efeitos das mudanças climáticas na pecuária, apresenta alguns conceitos sobre o fluxo de gases do efeito estufa (GEEs) em sistemas de produção animal. Destaca algumas evidências para apoiar que os SSPi são uma opção interessante para permitir que a pecuária na região se adapte às mudanças climáticas e mitigue alguns dos seus efeitos, pois a adoção dos SSPi pode ajudar a remover até 26,6 tøn. CO₂ eq/Ha/ano a partir da atmosfera.

Palavras chave: *bovino, GEEs, pastagens, pecuária, sustentabilidade.*

Introduction

The impacts of climate change on livestock farming systems have been studied in depth. Several studies have evaluated different scenarios of how changes in the global environment affect the various factors underlying primary production as well as consequences on livestock systems (Steinfeld *et al.*,

2009; Nardone *et al.*, 2010; Thornton *et al.*, 2009; Jones and Thornton, 2009; Seo *et al.*, 2010).

Beef production is mostly carried out outdoors, which constitutes a comparative advantage; as it requires little infrastructure can be conducted in a wide range of climate conditions. However, this also makes the beef industry especially vulnerable not only

to extreme environmental conditions, but also to rapid changes in these conditions (Nardone *et al.*, 2010).

Livestock production is affected by and depends on meteorological and climate factors. Therefore, climate change can have an enormous impact on production, as some regions struggle with drought, while other regions are forced to deal with floods; some suffer both phenomena within the same year. The impact of these changing conditions requires a proper understanding by scientists and the public alike and transfer of adequate technologies to producers in order to better address climate change response (Steinfeld *et al.*, 2009).

In addition to difficulties related to plagues and diseases, farmers are currently facing abiotic problems. Both producers and agricultural researchers are becoming increasingly aware of the existence of a water stress in agriculture, mostly associated with changes in the distribution and intensity of rainfall and with more frequent reports of hail, frost and snow at high altitudes and prolonged droughts (McDowell, 2008).

It is now clear that there is a strong need to adopt alternative, sustainable livestock production systems that exploit the advantages of integrated management in the biophysical neotropical context, whose natural vocation and mixed forests are being wrongly used as open grazing livestock systems. The silvopastoral-based environmental conversion is a promising alternative to deal with these problems (Murgueitio *et al.*, 2011). Intensive silvopastoral systems (ISS) can play a major role in livestock production, especially in tropical areas where the demand for high quality food is increasing and where extreme events jeopardize existing livestock production systems. This review first will evaluate the possible impacts of climate change on the tropical livestock sector, followed by a discussion on how ISS could be a tool to mitigate these effects.

Impacts of climate change on bovine production

Climate change and variability affect land use and terrestrial ecosystems differently in different parts of the world. This results from the strong interaction between environmental and socioeconomic land use factors, which define the vulnerability and resilience

of each production system (Steinfeld *et al.*, 2009; Jarvis *et al.*, 2010). Unfortunately, most of the current predictions of this phenomenon are qualitative, not quantitative (McDowell, 2008). Therefore, as a recommendation from the IPCC¹, countries must invest resources in modelling and predicting the impacts of climate change on agricultural and livestock production systems for the purpose of taking measures that could mitigate some effects, but above all, permit the adaptation of most systems to the expected changes (IDEAM, 2010; FEDEGAN, 2011).

The vast majority of pastoral livestock systems in the world are completely dependent on the availability of natural resources, and will therefore be affected by increased seasonal and inter-annual climate variability which could lead to reductions in the availability of forage and in animal productivity (Steinfeld *et al.*, 2009; Nardone *et al.*, 2010; Berrang-Ford *et al.*, 2010; Dulal *et al.*, 2011). Global scale modelling indicates that the farming systems that depend on grazing will be more drastically affected, particularly those in Africa, Australia, Central America and South Asia. In these regions, studies predict a loss of up to 50% in the edible biomass that is available to livestock (Nardone *et al.*, 2010).

Climatic variation and extreme events can affect livestock production through different mechanisms that operate directly on the animal or indirectly by reductions in forage availability and/or quality.

Changes in climate will have a significant impact on agricultural production systems, particularly in the Colombian livestock sector. According to the Colombian Cattle Federation (FEDEGAN) and the Ministry of Agriculture and Rural Development (MADR), the rainy season in the late 2010 and early 2011 negatively affected 20% of grazing land. The most affected areas were the Atlantic Coast and Central Colombia, where six million hectares were flooded, thus preventing cattle from grazing. The economic losses for farmers are difficult to estimate, but there are reports of 115,322 animal deaths, the displacement of more than 1.4 million heads of cattle to other regions and damage to 66,158 properties. This was compounded by the scarcity of food for cattle

¹ Intergovernmental Panel on Climate Change.

after the flood subsided due to the slow recovery of the productive capacity of the grasslands (MADR, 2010; FEDEGAN, 2011).

Impacts on animal health

It is expected that global warming will affect animals and humankind, either by direct or indirect effects (Herrero *et al.*, 2009; Nardone *et al.*, 2010). In response to extreme weather events, it is expected that diseases directly related to environmental temperature will change their patterns of occurrence adversely affecting animal health (Herrero *et al.*, 2009; Steinfeld *et al.*, 2009). Possible indirect effects are those related to the ability of animals to adapt to changes in thermal thresholds, changes in rumen microbial populations, the distribution of disease vectors, the resistance of infectious agents and the anticipated shortages of food, water, and the possible increased transmission of foodborne diseases to humans and animals (Herrero *et al.*, 2009; Nardone *et al.*, 2010).

Examples include the changes on the population dynamics of ticks, external parasites that affect cattle production and transmit diseases of economic importance. The variations of weather factors such as ambient temperature and humidity have contributed to the change in the population dynamics of this arthropod (Kivaria, 2010). This has already been reported in Colombia by Bazarusanga *et al.* (2007), who observed high activity and presence of *Rhipicephalus (Boophilus) microplus* nymphs during rainy season at an altitude higher than 1,950 m.a.s.l. and temperatures ranging between 14 and 17 °C. These authors noted that both temperature and precipitation play an important role in the habitat suitability for these ectoparasites. In turn, Benavides *et al.* (2003) reported an overall parasitological prevalence of *Anaplasma marginale* of 34.6% and an overall serological prevalence of 30.8% on farms located at altitudes above 2,400 m.a.s.l. This contrasts with reports from the early 1970s, that considered the upper limit for the distribution of *Boophilus microplus* ticks and the hemoparasites it transmits was 1800 m.a.s.l. (Vizcaino, 1972). This is associated with the fact that the first response of these arthropods to environmental changes are genetic changes in diapause, *i.e.* in the arrest of development stage, which allows the arthropods to mitigate the

otherwise negative effects of seasons with extreme weather occurrences (Emerson *et al.*, 2009).

Impacts on thermal comfort

Animals respond to changes in their environment by adopting different acclimation mechanisms (Fregly and Blatteis, 1996). However, in the face of extreme climate change, they might not adapt completely and therefore their physiological functions will be affected, resulting in diminished animal health and production performance (Blackshaw and Blackshaw, 1994; Nardone *et al.*, 2010; Soussana *et al.*, 2010). The expressions of unacclimated animals are multiple, but the most common include reduced dry matter consumption, increased respiratory rate, changes in water intake and hormonal signals that affect the ability of corporal tissues to respond to environmental stimuli (Fuquay, 1981; Blackshaw and Blackshaw, 1994; Gaughan *et al.*, 2009). These physiological responses contribute to dissipate heat, but reduce animal and system performance and production efficiency as a lower percentage of intake energy can be used for production or growth (Cañas *et al.*, 2003).

Several studies indicate that the upper limit of the thermo neutral zone for cattle is 30 °C when relative humidity is less than 80%, and 27 °C when relative humidity is approximately 80% (Fuquay, 1981; Blackshaw and Blackshaw, 1994; Gaughan *et al.*, 2009; SCAHAW, 2001). Temperatures above these thresholds negatively affect animal health and welfare and hence productive performance (Gaughan *et al.*, 2009). For example, animals exposed to temperatures higher than the upper limit of their thermo neutral zone require two to three times more water than when in thermo neutral conditions (Gaughan *et al.*, 2009) and there is evidence that shrubs present in ISS affect the systems' microclimate, favoring the avoidance of heat stress. Ceballos *et al.* (2011) suggest that the lower plant stratum in the system favors heat exchange processes between the animal and the system, allowing heat dissipation and promoting thermal comfort, possibly because the vegetation retains more moisture and lower temperatures than the top tier. However, further studies are needed to associate the effect of variables such as forms of heat transfer, evapotranspiration,

radiation, and wind speed on the ability of animals to thermoregulate.

In this context, the differences between domestic ruminants in their ability to adapt to heat stress are a key criterion for selecting the most suitable animal biotype for production in adverse weather conditions (Steinfeld *et al.*, 2009; Jarvis *et al.*, 2010; Murgueitio, 2011).

Impact on water availability and quality

According to several climate prediction models, there will be changes both in rainfall patterns and amounts on different areas of the world ranging from rainfall reductions in arid regions to precipitation increases in the northern hemisphere and wet areas. Excessive rainfall can lead to reduced water quality and flood risks (Nakicenovic *et al.*, 2000).

Under global warming scenarios, water availability will become the main limiting factor to all livestock systems (CAWMA, 2007; Steinfeld *et al.*, 2009) and will be the second most critical factor to world sustainability, after food access (Janzen, 2011). It is estimated that by 2025, as a result of population growth and increased demand of this vital resource, 64% of the world population will live in locations suffering from water scarcity (Rosegrant *et al.*, 2002).

Sustainable farming systems in the tropics should be based on alternative approaches, far beyond the use of alternative inputs, seeking an integral development of agro ecosystems and low dependence on external inputs. The emphasis should be on planning complex agricultural systems where ecological interactions and synergies between biological components replace external human inputs in order to promote soil fertility, system productivity, crop protection, and water conservation, a resource that began to dwindle dramatically in recent years (Preston and Leng, 2008).

A factor of great importance is that as ambient temperature increases, greater evapotranspiration and water demand by crops and grasslands will be expected. Additionally, increased variability in rainfall patterns and ambient temperatures can

have a negative effect on plant growth and thus affect net primary productivity of the ecosystem (McDowell, 2008).

Impact on Biodiversity

The current rate and magnitude of species extinction far exceed historical rates. The speed and magnitude of climate change associated to increased GHG emissions affect and will continue to affect biodiversity, either directly or in combination with other drivers of change (Millennium Ecosystem Assessment, 2005).

The contribution of changes in land use to emissions of carbon dioxide has recently attracted the attention of both researchers and policymakers. Deforestation and its ties to extensive cattle farming become a critical issue from the climate change perspective, and its negative relationship with biodiversity loss is currently widely accepted (Steinfeld *et al.*, 2009). The priority is to recover and conserve biodiversity, particularly in hot and dry ecosystems where a significant fraction of livestock inventories graze, given the fragility of these ecosystems (Harvey *et al.*, 2008; Murgueitio *et al.*, 2011).

At landscape scale, all forms of agroforestry associated with the conservation and restoration of riparian corridors contribute to generate connectivity both at the farm and regional level and thus significantly promote biodiversity conservation (Harvey *et al.*, 2008; Calle and Piedrahita 2007; Murgueitio *et al.*, 2011).

Impact on animal performance

Animal feeding is almost entirely dependent on grassland forage availability in tropical systems. During the long periods of drought, which occur annually in most agricultural regions, production and forage quality are reduced dramatically. This reduction in forage biomass production is a major cause of the low productivity levels of livestock observed in the tropics. In Colombia this is demonstrated by low growth rates, with animals being weaned at nine months of age at 140 kg, being slaughtered a very late

ages (30 to 42 months) at average weights of 450 kg and 474 kg for steers and bulls respectively, which corresponds to weight gains of 350 grams per day or less (MADR, 2009).

Mechanisms of adaptation and mitigation to climate change in intensive silvopastoral systems

Colombian investment in science and technology, public policy efforts, technical assistance, and training on climate change mitigation have increased recently as demonstrated in various publications, notably the 2019 Strategic Plan of the Colombian Livestock Sector (FEDEGAN, 2006). Among existing projects, special attention should be placed on two such publications financed by the Global Environment Facility (GEF) and the World Bank, which seek the implementation of such acts, the ISS, and other best management practices to achieve a cost-effective reduction of GHG emissions from livestock and to reduce their vulnerability to climate change. The first is the “Integrated Silvopastoral Approaches to Ecosystem Management” project, completed in 2008 and the second is the “Main streaming Biodiversity in Sustainable Cattle Ranching” project, which began implementation in 2011 (Chará *et al.*, 2011).

One of the systems promoted by these institutional strategies is ISS. It provides high fodder shrub densities (more than 10,000/Ha), i.e. the association of the leguminous shrub *Leucaena leucocephala* (Lam.) de Wit. with high biomass producing grasses and native or introduced timber trees, which are grazed under intensive rotational grazing with the use of electric fences and provide a permanent supply of drinking water. Under these conditions, high stocking rates are achieved, with high milk and meat production. These systems increase biodiversity (compared to conventional production systems) and reduce vulnerability to extreme weather changes. In addition, ISS can be a tool to help this sector mitigate and adapt to climate change (Murgueitio *et al.*, 2011).

Although humans have used leucaena for thousands of years, its commercial use in cattle grazing systems as part of grass-legume associations began nearly 40 years ago in Australia, where there

are currently more than 200,000 hectares of this system (Leucaena Network, 2009). In Colombia, with more than 5,400 ha of Leucaena-based ISS, these systems began two decades ago, and since then they have been considerably modified to include different arrangements of plant strata, with the addition of timber, fruit and palm trees. When the Mainstreaming Biodiversity in Sustainable Cattle Ranching project is completed, approximately 12,000 new hectares of ISS will have been implemented in Colombia (Chará *et al.*, 2011). The use of leucaena SP was restarted five years ago in the Apatzingan Valley, Michoacán (Mexico). Today there are approximately 3,200 hectares already planted and 10,000 new hectares are projected for 14 Mexican states starting in 2012 (Solorio-Sánchez, 2009; Flores and Solorio, 2011).

The scientific and technical evidence that point to ISS as an integral strategy to adapt the Colombian livestock to climate change and mitigate its effects can be conveniently grouped in several categories.

Animal health

ISS promote welfare of grazing animals and contribute to the reduction of parasites and disease vectors (Giraldo *et al.*, 2011). Livestock grazing in open, tree-less grasslands regularly suffer from parasites that thrive and reproduce in wet faeces (Martínez and Lumaret, 2006). In contrast, Giraldo *et al.* (2011) reported that ISS naturally regulates the horn fly (*Haematobia irritans*). They argue that several organisms present in manure are involved in the biological control of flies.

With proper management, ISS vegetation can favor the presence of predators such as birds, ants and entomopathogenic microorganisms like fungi, which are involved in the natural regulation of tick populations (Calle and Piedrahita, 2007; Sáenz, 2007; Giraldo *et al.*, 2011). It has also been reported that permanent forage availability throughout the year, even in regions suffering from prolonged droughts and strong winters, is associated with cattle gaining resistance to internal and external parasites due to improved nutrition and immune response (Giraldo *et al.*, 2011; Murgueitio *et al.*, 2011).

Good farming practices associated with ISS, such as adequate grazing rotation and availability of good quality water, contribute to restore the ecological functionality of various insects (saprophagous, predators, parasitoids, and decomposers) which participate in nutrient recycling and natural regulation of pest insects, all of which is associated with economic benefits for the farmer (Murgueitio *et al.*, 2011).

Ambient temperature and solar radiation

A recommended strategy for mitigating the effects of solar radiation and its influence on animal thermoregulation is incorporating trees and shrubs in pastures (Blackshaw and Blackshaw, 1994; Verchot *et al.*, 2007; Steinfeld *et al.*, 2009). Trees favor the ambient temperature regulation contributing to dissipation of solar radiation. Its benefits include higher dry matter intake and reduced metabolic rate as animals invest less energy dissipating heat (Gaughan *et al.*, 2009; Jarvis *et al.*, 2010).

ISS constitute an interesting option for withstanding critical high ambient temperature periods as compared to systems with free sun exposure, since evapotranspiration is reduced while moisture retention is increased in the system. Rueda *et al.* (2011) found evidence that ISS can mitigate the effects of adverse climatic periods by creating better conditions for plant survival and development as a result of diminishing conditions that cause plant water stress.

In addition, trees in ISS help reduce wind speed and contribute to water preservation and pasture production compared to treeless prairies under similar conditions. This is particularly important in areas with water deficits and marked periods of severe drought, which are the areas where most of the beef cattle are raised in the tropics. The ISS help to reduce the occurrence of extreme temperatures (with differences of up to 13 °C) within the system, increase relative humidity (10-20%), reduce evapotranspiration (1.8 mm/d) and allow greater production of green biomass, which results in more beef and dairy production in regions where traditional farmers are concomitantly experiencing decreased and even negative productivities (Rueda *et al.*, 2011).

In Mexico, ISS average temperatures at peak solar radiations are reduced by 8.6 °C when compared to

traditional systems (Solis *et al.*, 2011). The same authors reported that lower temperatures and higher relative humidity in ISS, while not altering the patterns of animal behavior, were associated with a tendency towards higher dry matter intake.

Water quantity and quality

ISS improve water availability in at least two different ways: a) by improving the soil water-holding capacity and allowing higher water infiltration into deeper soil layers which results in less compacted soil (Vallejo *et al.*, 2010), b) by allowing soil moisture retention as soil is protected from direct solar radiation due to increased vegetation cover (Rueda *et al.*, 2011).

ISS implementation promotes adopting a number of practices that result in improved management of natural resources and protection of riparian forests by reducing the entrance of sediments, nutrients and other pollutants (Chará and Murgueitio, 2005; Chará *et al.*, 2011). Thus, a marked decrease in turbidity, biochemical oxygen demand (BOD) and coliform counts downstream aquatic environments of grazing areas has been reported for ISS (World Bank, 2008). This arises from restricted entry of cattle to riparian strips, allowing restoration of the aquatic ecosystem, as evidenced by the increase in aquatic macro-invertebrates of orders *Ephemeroptera*, *Plecoptera*, and *Trichoptera*, which are indicators of good water quality (Chará *et al.*, 2007).

Silvopastoral systems with leucaena can withstand occasional heavy grazing and serve as a mitigating factor when unexpected or prolonged droughts occur. Being a drought-tolerant species, leucaena is less affected by drought than shallow-rooted grasses and other herbaceous legumes. Leucaena association also has higher efficiency in water use compared with grasslands composed of *Cenchrusciliaris* or native grasses (Dalzell *et al.*, 2006). Leucaena's root system allows using deep water (up to 5 m) and maintaining high quality green leaf production, even in the severely dry summers in Australia (Dalzell *et al.*, 2006).

Biodiversity

ISS implementation has positive effects on biodiversity of ecosystems initially dominated by treeless

pastures. Five years of ISS implementation has increased the number of bird species from 140 to 197, diurnal Lepidoptera from 67 to 130, and terrestrial molluscs from 35 to 81 (Sáenz, 2007; World Bank, 2008).

Farmers are able to identify the recovery of biodiversity after implementing ISS. Thus, producers that implemented silvopastoral arrangements reported a dramatic increase in abundance and diversity of birds (71%), in plant and animal diversity (54%), increased frequency of mammals in their pastures (36%), and more sightings of threatened or rare species (11%) (Calle, 2008; Calle *et al.*, 2009).

Thus, ISS can be easily integrated with other landscape-based strategies such as connectivity corridors to preserve biodiversity and improve environmental services in agricultural landscapes. It is important to remember that many of the remaining unprotected forests of high conservation value are housed within a matrix formed by cattle pastures in monoculture or with a small number of trees (World Bank, 2008; Murgueitio *et al.*, 2011).

Animal productivity

In recent years, successful ISS experiences have been documented in Australia, Mexico, and Colombia, with significantly higher production than conventional extensive systems and similar productivity than that obtained in intensive systems that rely on the use of

high amounts of fertilizers, concentrates, medicines and agrochemicals (Dalzell *et al.*, 2006; González, 2011; Murgueitio *et al.*, 2011).

The high productive response of animals in ISS is due to higher and better distribution of biomass production throughout the year (even in extremely dry conditions), leading to increased stocking capacity (up to 4 times higher than conventional systems) and increased (up to 10 times) meat production per hectare (Table 1).

In addition to improved growth performance, animals fattened in ISS produce competitive meat for demanding markets. Meat quality produced in ISS systems using leucaena can be equated to that of animals fed in feedlots, in terms of slaughtering weight and age, fat thickness and color, meat color, and marbling score (Dalzell *et al.*, 2006; Shelton and Dalzell, 2007). These characteristics are consistent with organically produced meat certified or accredited under the requirements of the European Union and/or Japan. In addition, ISS animals score well in terms of welfare and environmental impact compared with animals raised in feedlots. In the near future this could be an added value for the producer, as consumers are becoming increasingly aware of the origin of the products (Shelton and Dalzell, 2007; Murgueitio *et al.*, 2011).

The results obtained by Corral *et al.* (2011) confirm that the nutrients in in ISS-produced meat is perfectly comparable to that produced in other systems and

Table 1. Production parameters of conventional and ISS farming systems in Australia, Mexico, and Colombia.

System	Country	Parameter			Reference
		Stocking rate (AU/Ha)	Live weight gain (g/an/d)	Meat production, kg/Ha/yr	
Conventional	Australia	1.5	411	225	Dalzell <i>et al.</i> , 2006
	Mexico	1 to 2.5	500	182-456	Solorio-Sánchez <i>et al.</i> , 2011
	Colombia	1.2	130	56.9	Córdoba <i>et al.</i> , 2010
ISS	Australia	3	822	910	Dalzell <i>et al.</i> , 2006
	Mexico	6	900	1,971	Solorio-Sánchez <i>et al.</i> , 2011
	Colombia	3.5 to 4.7	651-790	827-1,341	Córdoba <i>et al.</i> , 2010
		3.5	793-863	1,013 – 1,103	Mahecha <i>et al.</i> , 2011

provides the same amount of protein, and has the advantage of being low in fat.

Increased animal productivity has been also reported in animals other than cattle. Recently, Barros (2011) reported 106 g/sheep/d weight gains in Michoacán (Mexico) for an ISS with 35,000 plants of leucaena/Ha associated with *P. maximum* cv Tanzania.

Biomass production, quality, and forage intake

In general, tropical forage has low nutritional value for ruminants due to low nitrogen (N) content and high levels of fiber, limiting voluntary feed and nutrient intake by animals (Leng, 1990). Furthermore, tropical grasses are characterized by marked seasonal changes in dry matter (DM) content so that in countries like Colombia, during the dry season pastures only reach 30% of rainy season DM production (Cuesta, 2005; Vásquez *et al.*, 2005). In addition, their high cell wall (NDF and ADF) contents are associated with low digestibility and high-energy losses (Barahona and Sánchez, 2005), resulting in increased methane production per kg of meat and milk produced, thus leading to inefficient animal production.

In terms of climate change mitigation, emissions should be differentiated between those that are avoidable, reducible, and compensable. Methane emissions (product of animal physiological processes) are considered reducible emissions as they are directly

affected by diet quality. Therefore, understanding the digestive dynamics of animals grazing on ISS will contribute to the quantification of green house gas (GHG) emissions from these systems.

Diets provided by ISS have high protein levels (15 to 17.5%) with acceptable digestibility (approximately 60%), comparable to the nutritional value of alfalfa. Improved animal production of ISS is partially explained by tannin content in leucaena (Barahona *et al.*, 2003), which protects protein from ruminal degradation, increasing its bypass into the intestine where it is digested (Barahona *et al.*, 2000) (Table 2). It is also explained by their low NDF content, which is associated with greater packing ability in the rumen, higher passage rate, intake, and animal performance (productivity) (Barahona and Sanchez, 2005).

Studies by Bacab-Pérez and Solorio-Sánchez (2011) measuring forage intake of leucaena and *P. maximum* in a ISS established in Tepalcatepec Valley, Michoacán, Mexico (Table 3), show greater results using ISS forage resources. The foraging efficiency observed at Los Huarinches and El Aviador ranches was 68 and 77%, respectively; whereas the traditional system reached only 60% foraging efficiency. Furthermore, the available forage in both ISS ranches was at least 2.6 times higher than that in the traditional ranch (17,290 and 18,851 versus 6,636 kg DM/yr). Table 3 also shows the high selectivity of cattle for leucaena, consuming around 91% of available biomass in both ISS farms.

Table 2. Nutrient content of forage in ISS (values in parentheses correspond to standard deviations).

Forage	<i>C. plectostachyus</i>	<i>P. maximum</i> cv. Tanzania	<i>L. leucocephala</i>
DM, %	22.36 (1.49)	19.92 (2.05)	21.99 (1.07)
CP, %	8.59 (1.81)	10.07 (2.94)	27.68 (0.73)
NDF, %	69.14 (1.95)	66.78 (1.34)	32.42 (2.19)
AD, %	35.43 (1.54)	35.35 (0.46)	12.30 (0.28)
Lignin, %	5.4	6.3	7.7
Fat, %	1.23	1.24	2.31
Ash, %	9.29 (2.09)	9.97 (2.27)	6.92 (1.58)
NFE, %	11.85	12.02	32.19
Ca, %	0.78 (0.19)	1.08 (0.47)	1.43 (0.66)
P, %	4.04 (6.64)	0.19 (0.08)	0.21 (0.01)
GE MCal/Kg DM	3.629	3.801	4.17

Table 3. Availability, refusal and forage utilization efficiency in several farms in Tepalcatepec Valley, Michoacán, Mexico.

Farm	Forage	Edible forage (kg DM/Ha)	Rejection (kg DM/Ha)	Use (kg DM/Ha)	Use (%)
Los Huarinches	<i>L. leucocephala</i>	8,386	826	7,560	91
	<i>P. maximum</i>	8,904	4,655	4,249	48
	Total	17,290	5,481	11,809	68
El Aviador	<i>L. leucocephala</i>	9,156	826	8,330	91
	<i>P. maximum</i>	9,695	3,542	6,153	63
	Total	18,851	4,368	14,483	77
Conventional	<i>C. plectostachyus</i>	6,636	2,660	3,976	60

Source: Modified from Bacab-Pérez and Solorio-Sánchez (2011).

The high nutrient contents in leucaena (Table 2) should be analyzed in light of its high degradability, as reported by Barros (2011) (Table 4), who observed higher rates of potential *in situ* DM degradability (a + b) of leucaena than in grasses commonly used in monoculture. The high DM degradability of leucaena is corroborated by its high *in vitro* DM digestibility.

Mitigation of environmental effects: reduction of GHG and soil improvement

It is known that N availability is a limiting factor for livestock production. ISS increase animal production by virtue of higher dietary N, increased protein bypass due to lower ruminal protein degradation, greater N transfer to accompanying grasses, and higher N recycling within the system, compared with the traditional system (Dalzell *et al.*, 2006).

Most N fixed by leucaena returns to the ground and is used by the grass (as opposed to monoculture pastures where N availability is very limited), increasing the quantity and quality of forage (Dalzell *et al.*, 2006). Biological nitrogen fixation (BNF) in ISS ranges between 200 and 500 kg N/yr. (Dalzell *et al.*, 2006; Solorio-Sánchez *et al.*, 2009).

When meat production ranges from 827 to 1,341 kg/Ha/yr (Table 1) the N output of the system would be between 16.7 and 27.1 kg N/Ha/yr (assuming 55% carcass yield and the entire carcass is lean tissue with 23% crude protein (CP) and 16% of CP is N). At low BNF estimates, around 172 and 183 kg N/Ha would return to the ground annually. With 500 kg/Ha BNF, approximately 470 kg N/Ha would return to the system annually, with much of this N being available for grass growth. It should be noted that for 20 ton DM/Ha/yr of biomass production, grasslands would have 320 kg N available (assuming 10% CP and 16% N in CP).

Table 4. *In situ* and *in vitro* degradability of *L. leucocephala* and associated grasses in ISS.

Species	<i>in situ</i> DMD parameters (%)				IVDMD (%)
	a	b	C	a+b	
<i>L. leucocephala</i>	21.8 ± 0.96 ^a	51.2 ± 0.99 ^b	0.05 ± 0.002 ^a	72.9 ± 0.40 ^a	63.8 ± 0.3 ^a
<i>P. maximum</i>	12.1 ± 1.38 ^b	55.0 ± 1.90 ^a	0.03 ± 0.002 ^b	67.1 ± 1.50 ^b	59.7 ± 0.3 ^b
<i>C. nlemfuensis</i>	10.3 ± 1.20 ^b	53.0 ± 0.78 ^{ab}	0.03 ± 0.002 ^b	63.3 ± 0.96 ^a	58.4 ± 0.2 ^c
P value	0.0001	0.0091	0.0001	0.0001	0.0001

Source: Barros, 2011.

ISS fix CO₂ in woody stems, leucaena roots, and pasture. The “Integrated Silvopastoral Approaches to Ecosystem Management” project (World Bank, 2008) reports annual C fixation equivalent to 1.5 ton/Ha. Large-scale transition from input-intensive cattle grazing on degraded pastures to environmentally friendly silvopastures could improve soil resilience to degradation and nutrient loss, and sequester large amounts of carbon (4.4 to 22.4 ton CO₂ eq/Ha/yr) (Calle *et al.*, 2012). According to Naranjo *et al.* (2012), ISS remove GHG from the atmosphere in amounts ranging between 8.8 and 26.6 ton CO₂ eq/Ha/yr, alone or associated with timber trees, respectively.

The climate-change adaptation and mitigation mechanisms favoured by ISS are:

1. Capture of CO₂ in the various ISS strata.
2. Soil fertility improvement through all ISS processes.
3. Promotion of good management practices for cattle production by reducing and/or eliminating the use of chemicals such as pesticides, insecticides, and anthelmintics.
4. Reduction of plant and animal production seasonality, making animal production less vulnerable to climate change.
5. Contribution to the preservation of fragile ecosystems and recovery of biodiversity.
6. Reduction of production costs by increased utilization of local resources.
7. Reduction of ruminal methane production.

Overall, ISS implementation should lead to a positive carbon-balance of the production chain due to a more rational use of inputs, competitive improvement, and positive global effects associated with GHG reduction (Ibrahim *et al.*, 2010).

Secondary compounds present in most tropical legume forages (tannins, saponins, etc.) may decrease nutrient availability to rumen microbes by fermentation dynamics and inhibition or stimulation of specific microbial populations. Recent research has shown the active role of plant bioactive compounds as

rumen fermentation modulators (Hristov *et al.*, 2013). For example, condensed tannins reduce methane production by 13 to 16% on a DM basis (Waghorn *et al.*, 2002; Woodward *et al.*, 2004; Grainger *et al.*, 2009; Eckard *et al.*, 2010), mainly through a direct toxic effect on methanogens.

Mao *et al.* (2010) recently demonstrated that the saponins present in some plants could reduce ruminal methane production by up to 27% when fed to sheep. Saponins are present in a variety of tropical plants with forage potential such as *Leucaena*, *Tithonia diversifolia*, *Gliricidia sepium* and *Enterolobium cyclocarpum* and are frequently used in SSP (Delgado *et al.*, 2010). For example, feeding *E. cyclocarpum* foliage reduces rumen protozoa (Koenig *et al.*, 2007) and methanogen Archaea. According to Delgado *et al.* (2010), inclusion of increasing levels of *Leucaena* leaves to a single-grass diet reduces ruminal methanogenic bacteria; thus, it is a viable alternative to mitigate methane emissions. In turn, Tan *et al.* (2011) showed effectiveness of leucaena condensed tannin extracts for reducing ruminal methanogenic archaea and protozoa.

E. cyclocarpum ground pods incorporated in the diet (36% of the DM) of hair sheep have resulted in 223 g daily weight gain per head (Moscoso *et al.*, 1995). Likewise, in Mexico, up to 50% DM substitution with *E. cyclocarpum* ground pods for hair sheep resulted in 240 g/head/d weight gain, similar to that with grain-based diets (Esquivel-Mimenza *et al.*, 2010). To some extent, this productivity is due to methane-production reduction and, thus, to increased metabolizable energy absorption in the form of VFA², as well as greater efficiency of ruminal microbial protein synthesis and increased supply of microbial protein to the small intestine.

Milk and meat quality

Consumers are increasingly aware of the benefits of products that contribute to their health and welfare, and this could act as a driver to position food products in the market, especially those deemed to improve human health, animal welfare and care of the ecosystem

² Volatile fatty acids.

(Thornton, 2010). Existing low-carbon agriculture initiatives (Norce, 2012) include this perspective when they encourage the adoption of practices aimed at adapting and mitigating climate change.

It remains unclear if unsaturated fatty acid concentration—including conjugated linoleic acid isomers (CLA)—in milk and meat of ruminants may be modified by grazing on ISS. *Leucaena* foliage has significant amounts of condensed tannins (Barahona et al., 2003). Recently, Vasta et al. (2009) were able to alter the concentration of rumenic acid (C18:2) in grazing sheep that received *Schinopsis lorentzii* (Quebracho) condensed tannins in their diet. The mechanism of action is related with the ability of tannins for reducing ruminal biohydrogenation of unsaturated fatty acids (Shingfield et al., 2010). Likewise, Vasta et al. (2012) succeeded in modifying the pattern of unsaturated fatty acids in sheep. It is also possible to increase unsaturated fatty acids concentration in cow's milk by feeding various types of oils (Hristov et al., 2011). In Colombia, Mahecha et al. (2008) were able to modify milk fat secretion in cows. They increased its content of polyunsaturated fatty acids and conjugated linoleic acid (CLA), turning ISS milk into a functional food. These nutritional principles may give ISS the possibility of increasing the value of animal products and eventually generate greater economic benefits for the farmer.

Promotion of ISS for the Colombian livestock sector

Adoption of ISS in Colombia is currently driven by FEDEGAN in partnership with other institutions through the “Mainstreaming Biodiversity in Sustainable Cattle Ranching” project, which is present in five regions of the country and is supported by GEF. The project promotes sustainable intensification of production in response to climate change, providing support for farmers in areas such as public policies, incentives and technologies aimed at promoting sustainable use of natural resources and improving productive efficiency (Chará et al., 2011).

Additionally, the Colombian Ministry of Agriculture and Rural Developments (MADR) and the Fund for Agricultural Financing (FINAGRO) approved a Rural

Capitalization Incentive (RCI), which allows farmers access to loans for establishing ISS. It includes a 40% reduction in the cost of the loan by meeting specific tree-planting densities (FINAGRO, 2011). The silvopastoral RCI provides a 40% subsidy on total costs when farmers establish up to 99 hectares, and 30% if they establish more than 100 hectares of ISS associated to timber trees. Currently, the incentive is \$500 usd/Ha for ISS with over 7,000 shrubs/Ha and about \$800 usd for ISS with at least 5,000 bushes and 500 timber trees/Ha (i.e. 10 fodder trees per one timber tree) (Murgueitio et al., 2011). Additionally, a Technical Assistance Incentive (TAI) aimed to the development of productive projects that include any farming activity is currently available. The TAI covers up to 80% of the technical support costs of for a period not exceeding three years. This is another important tool for promoting ISS.

Herd productivity and stocking rates (AU/Ha) can be increased by implementing ISS, thereby generating more income throughout the year and recovering the investment in short periods of time. The main difficulty of ISS is the high establishment costs when compared monoculture pastures. For this reason, analysis of ISS implementation costs is important in order to provide support to interested farmers.

Implementation costs

Recently, Solarte et al. (2011) compared implementation costs of ISS associated with timber versus monoculture pasture (star grass *Cynodon* sp.). They found that implementing a hectare of each costs \$3,251 usd and \$2,336 usd, respectively.

Investment costs are higher for ISS (\$915 usd/hectare) compared to monoculture pastures, but ISS economic returns are higher: \$384 usd/Ha for beef systems, and \$409 usd/Ha for beef-dairy (dual-purpose) farms compared to annual returns of monoculture (\$289 usd and \$328 usd for beef and dairy, respectively). In addition, revenues projected for the twelfth year for timber sales reach \$14,105 usd/Ha.

ISS provide good financial returns, regardless of the system size. Return on Investment (ROI) fluctuates between 13 to 28% for dairy farms. For beef ISS farms, ROI is 12 to 27% without timber

tress, and over 22% for farms having 500 timber/Ha (FEDEGAN-CIPAV, 2010). Additionally, Murgueitio *et al.* (2009) found that ROI of ISS increases from 12 to 19.4% when ISS planting area increases from 5 to 15 hectares.

Table 5 shows financial analysis for dual-purpose and beef production systems under ISS. These values were obtained from a profitability assessment carried out in the Michoacán tropics (annual precipitation: 600 to 1,000 mm, average temperature: 29 °C, altitude: 0 to 1,200 m.a.s.l) (González and Solorio, 2011).

Shelton and Dalzell (2007) reported that leucaena-grass pastures are the most productive, profitable, and sustainable beef production systems in northern Australia. The benefits of using leucaena-pasture systems include an increase in animal production/Ha (up to 4 times) due to a combination of greater weight gain, increased stocking rates and longevity of pastures (up to 30 to 40 yr). Those researchers reported that steers grazing on *Cenchrusciliaris*, *Chlorisgayana* and *P. maximum* in central Queensland pastures gained only 140 to 190 kg/yr; while grazing on pastures with leucaena gained 250 to 300 kg/yr. Using irrigation, leucaena can increase meat production 3

to 6 times, reaching up to 1,000 to 1,500 kg/Ha/yr (Petty *et al.*, 1994).

Reviewing results from 15 experiments, Jones and Bunch (1995) found that 8 of them reported increases of more than 70% in weight gain of animals with access to leucaena pastures compared to animals consuming only pasture, either native or improved.

Diversification of production and associated practices in ISS that can improve the economy of small farmers include the following.

Seed production

Leucaena seed production is highly variable depending on climate, soil, seeding, and management conditions. Leucaena seeds are currently sold in small-scale stores in Colombia at \$15 usd to \$22 usd/kg. Taking the average seed production, which amounts to 481 kg seed/Ha/yr, and multiplying it by the lowest price in the seed market (that of associative projects, or \$10 usd/kg of seed), generates an additional annual gross income of \$4,809 usd/Ha for the producer. It should be noted that leucaena seed is harvested in the dry season, when cattle price is low and such low income can generate financial crises, especially in farms located in dry regions.

Table 5. Financial analysis for dual-purpose and fattening production systems under ISS.

Parameter	System	Farm classification by productivity		
		Low (15%)	Medium (63%)	Good (22%)
<u>Dual purpose</u>				
Benefit: Cost	Conventional	<1, slight loss	Break-even point	1.1 average
ROI	Conventional		Less than 5%, 11% max.	
	ISS	15.0	20.2	25.3
Stocking rate (AU/Ha)	Conventional		1.0 a 2.5	
	ISS	5.5	6.9	8.3
Payback; years	ISS	7.0	5.0	4.0
<u>Fattening</u>				
Benefit: Cost		1.2	1.2	1.3
ROI	ISS	8.8	10.3	11.9
Payback; years		14.0	10.0	8.0

Decreased cost of mineral supplementation

Mineral salt intake decreases in ISS farms located in tropical dry forests due to better mineral balance of fodder. In a study conducted at El Porvenir farm, where mineral intake by cattle was measured and results were used to formulate a specific salt, annual savings of approximately \$5,600 usd were obtained (herd size: 470 animals; savings: \$12 usd/head/yr).

Lifetime of the system

SPS with more than 20 years in full production and well-documented, thorough research have been reported in several regions of Colombia and other countries. According to Jones and Bunch (1995), leucaena is one of the few types of tropical forage that can survive and remain productive for periods of more than 30 years under regular grazing in Australia. The same authors investigated the mortality of plants in a leucaena system after 40 years of grazing, finding that 74% of the original plants still remained. Commercial systems also show similar longevity and high productivity, with 25 years of continuous grazing being a common report.

Fencing

Use of fixed and mobile electric fencing is a standard recommendation for ISS, which reduces the demand of wood for posts between 60 and 90%. It must be remembered that wood posts in Colombia are usually obtained from forest remnants that remain in relative conservation.

Efficient management of water resources

Another relevant aspect of ISS is the permanent availability of fresh and good quality water for livestock. According to Murgueitio *et al.* (2011), it is essential to have a permanent supply of good quality drinking water for the animals in any livestock system, preventing them from entering water bodies like rivers, streams, wetlands and springs. This encourages farmers to improve the quality of water resources. It is necessary to implement water conveyance networks in grazing areas and install fixed or mobile drinkers

depending on the group size and rotation systems. Drinkers should be strategically located to prevent animals from walking long distances, which decreases productivity due to increased energy expenditure, and increases pasture trampling.

Animal health

ISS help to reduce internal parasite load by 40% due to disruption of parasite life cycles, which is obtained by grazing rotations and the effects of secondary metabolites present in leucaena. Presence of external parasites such as horn flies is minimized over time due to the fast degradation of cattle manure where insects breed. Rapid degradation of excreta in ISS obeys to increased presence of dung beetles, earthworms and other organisms. This helps to reduce production costs and lowers pesticide usage that affects human health and ecosystems and can compromise product safety. Additionally, ISS can help to reduce tick populations by increasing the presence of natural predators (birds and ants) and the biological control performed by some fungi.

Conclusion

ISS can increase animal productivity profitability. ISS has been associated with four-fold increases in meat production per hectare, compared to traditional systems around the world. This is associated with higher protein content (14.3 vs. 10.0%) and lower content of neutral detergent fiber (58.4 vs. 66.8%) compared to traditional grazing diets, respectively. In turn, this leads to greater DM degradability compared to traditional grass-only pastures.

Finally, research suggests that ISS can contribute to GHG mitigation. From the perspective of mitigating climate change, efforts should be made to determine differences between avoidable, reducible, and compensable emissions within each farming system. In addition, ISS can contribute naturally to intensification of livestock production in a sustainable manner as it increases land productivity and allow conservation of forests and biological corridors of local and global importance.

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