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Silvopastoral systems and climate change mitigation in Latin America

Photo 1.
Silvopastoral system of pastures growing in combination with trees that are remnants from previous forest: *Enterolobium cyclocarpum*, a leguminous, nitrogen fixing tree, very commonly used for shade in pastures in the dry forest regions of Latin America. In this picture taken at Rancho La Galeana, Apatzingán, Estado de Michoacán (México), these remnant trees are at relatively low density in the pastures.
Photo F. Uribe T., CIPAV.

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RÉSUMÉ

SYSTÈMES SYLVOPASTORAUX ET ATTÉNUATION DU CHANGEMENT CLIMATIQUE EN AMÉRIQUE LATINE

La production de bétail fait partie de la culture des peuples et est importante pour la nutrition et le bien-être humain. Cependant, le bétail d'élevage conventionnel est une source de gaz à effet de serre (Ges). La séquestration du carbone dans la végétation et les sols peut être améliorée tandis que les émissions de Ges peuvent diminuer avec le pâturage contrôlé, des espèces fourragères appropriées, et l'utilisation de systèmes sylvopastoraux (Sps) combinant arbres, arbustes et pâturages. En outre, les Sps favorisent l'adaptation au changement climatique avec les effets améliorateurs des arbres sur les températures de l'air qui limitent le dessèchement des pâturages et améliorent le bien-être et la productivité des animaux. Plusieurs types de Sps sont très répandus dans les paysages agricoles de l'Amérique latine. Dans les Sps intensifs (Isps), comprenant des banques de fourrage avec des espèces ligneuses plantées à haute densité, les rendements sont supérieurs à l'élevage conventionnel, en raison d'une plus grande densité de bétail et du gain de poids plus élevé des animaux. Les recherches en Colombie, au Nicaragua et au Costa Rica montrent que les Sps ont plus de carbone dans la biomasse aérienne et dans les sols que dans les pâturages dégradés. Dans les Sps, le bois des arbres fruitiers, plantés ou de régénération naturelle, augmente les stocks de carbone et les taux de séquestration. Les espèces arborées locales peuvent être utilisées dans les Sps avec de bons résultats en termes de productivité, de restauration des sols, de séquestration du carbone et de conservation de la biodiversité. L'utilisation de Sps contribue à la séquestration du carbone dans les arbres et dans les sols, tandis que l'établissement des plantations forestières et la conservation des forêts secondaires augmentent la séquestration et le stockage du carbone à l'échelle du paysage. Les Sps et surtout les Isps peuvent contribuer à atténuer le changement climatique car ils peuvent avoir un bilan Ges positif. En Amérique latine, les Isps aux résultats positifs ont été adaptés à des niveaux régionaux. Des mesures incitatives telles que le paiement des services environnementaux ainsi que l'assistance technique peuvent stimuler l'adoption des Sps contribuant ainsi à l'atténuation du changement climatique tout en préservant les moyens de subsistance en milieu rural.

Mots-clés: agroforesterie, séquestration du carbone, cheptel, systèmes sylvopastoraux intensifs, régions tropicales, durabilité.

ABSTRACT

SILVOPASTORAL SYSTEMS AND CLIMATE CHANGE MITIGATION IN LATIN AMERICA

Cattle production is part of people's cultures and is important for human nutrition and welfare. However, conventional cattle ranching is a source of greenhouse gas (GHG) emissions. Carbon sequestration in vegetation and soils can be enhanced and GHG emissions reduced with controlled grazing, appropriate pasture species, and the use of silvopastoral systems (SPS), which combine trees and shrubs with pastures. In addition, SPS contribute to climate change adaptation thanks to the ameliorating effects of trees on air temperatures that dry out pastures, as well as improving animal well-being and productivity. Several types of SPS are commonly found in the agricultural landscapes of Latin America. Intensive SPS (ISPS), where fodder banks are combined with woody species planted at high density, produce better yields than conventional ranching thanks to higher cattle density and better weight gain by the animals. Research in Colombia, Nicaragua and Costa Rica shows that SPS have more carbon in aboveground biomass and in soils than degraded pastures. In SPS, the timber or fruit trees, either planted or from natural forest regeneration, increases carbon stocks and sequestration rates. Native tree species can be used in SPS with good results in terms of productivity, soil restoration, carbon sequestration, and biodiversity conservation. The use of SPS contributes to carbon sequestration in trees and in soils, while establishing forest plantations and conserving secondary forests increase carbon sequestration and storage at the landscape level. SPS and especially ISPS can contribute to climate change mitigation because their net GHG emissions can be negative. In Latin America, successful ISPS are being scaled up to regional levels. Incentives such as Payments for Environmental Services along with technical assistance can stimulate the adoption of SPS, thus contributing to climate change mitigation while preserving rural livelihoods.

Keywords: agroforestry, carbon sequestration, cattle, intensive silvopastoral systems, tropical regions, sustainability.

RESUMEN

SISTEMAS SILVOPASTORILES Y MITIGACIÓN DEL CAMBIO CLIMÁTICO EN AMÉRICA LATINA

La ganadería forma parte importante de la cultura, nutrición y bienestar humano. Sin embargo la ganadería convencional es fuente de gases de efecto invernadero (GEI). La captura de carbono en vegetación y suelos aumenta mientras que las emisiones de GEI disminuyen con el pastoreo controlado, el uso de especies de pasturas adecuadas y los sistemas silvopastoriles (SSP), que son la combinación de árboles o arbustos con pasturas. Los SSP contribuyen a la adaptación al cambio climático por los efectos moderadores de los árboles sobre la temperatura del aire que evitan la desecación de los pastos y mejoran el bienestar y productividad de los animales. En América Latina abundan diversos tipos de SSP. En los SSP intensivos (SSPI), incluyendo bancos forrajeros con especies leñosas plantadas a alta densidad, los rendimientos son superiores a los de la ganadería convencional por la mayor densidad y ganancia en peso de los animales. Investigaciones en Colombia, Nicaragua y Costa Rica demuestran que los SSP acumulan más carbono en biomasa aérea y suelos que las pasturas degradadas. En SSP, árboles frutales o madereros plantados o de regeneración natural aumentan el almacenamiento y captura de carbono. Especies arbóreas nativas en SSP dan buenos resultados en términos de productividad, restauración de suelos, captura de carbono y conservación de la biodiversidad. El uso de SPS contribuye a la captura de carbono en árboles y suelos, mientras que las plantaciones forestales y los bosques secundarios agregan captura y almacenamiento de carbono a nivel de paisaje. Los SPS, y especialmente los SPSi, pueden contribuir a la mitigación del cambio climático con un balance positivo de GEI. En América Latina se están adaptando a escala regional SSPI promisorios. Los incentivos como pagos por servicios ambientales, junto con la asistencia técnica, pueden estimular la adopción de SSP que contribuyan a mitigar el cambio climático y preservar las formas de vida de las poblaciones rurales.

Palabras clave: sistemas agroforestales, captura de carbono, ganadería, sistemas silvopastoriles intensivos, regiones tropicales, sustentabilidad.

Introduction

Pastoral land is an economically important agroecosystem in tropical regions (STEINFELD *et al.*, 2006; MURGUEITIO & IBRAHIM, 2009). Livestock contribute around 12.9% of global calories and 27.9% of protein, and also contribute to crop production through the provision of transport and manure (FAO, 2011). Livestock occupy about 30% of total world land area, and contribute to the livelihoods of people concentrated in rural poor zones, but on the other hand livestock also contribute to about 18% of greenhouse gases (GHG) emissions worldwide (STEINFELD *et al.*, 2006). On a global scale, the livestock sector accounts for 9% of anthropogenic carbon dioxide (CO_2) emissions, mostly derived from land use changes, especially deforestation and expansion of pastures and arable land for feed crops. Livestock are also responsible for emissions of other gases with higher potential to warm the atmosphere: the sector emits 37% of anthropogenic methane, which has 23 times the global warming potential (GWP) of CO_2, and it also emits 65% of anthropogenic nitrous oxide (N_2O) which has 296 times the GWP of CO_2 (STEINFELD *et al.*, 2006).

Photo 2.
Silvopastoral system of *Brachiaria* spp. grass pastures growing in combination with trees that have established through managed succession in the eastern Amazon. In this picture taken at Fazenda Monaliza.Estado de Marañón (Brasil), the regenerating trees are at relatively high density in the pastures (~ › 50 trees per hectare).
Photo R. Martins, UFSJ, Brazil.

In Latin America cattle production systems are responsible for 58 to 70% of total agriculture GHG emissions (SMITH *et al.*, 2007; WORLD BANK, 2010). In tropical regions about 40% of GHG emissions from cattle (mainly CH_4) are from enteric fermentation (STEINFELD *et al.*, 2006). Cattle production systems need to balance trade-offs among resource use, GHG emission, and maintaining and improving human livelihoods, especially among the rural poor (STEINFELD *et al.*, 2006, MURGUEITIO & IBRAHIM, 2009).

Agroforestry systems (AFS), the combination of trees and crops in the same land, including silvopastoral systems (SPS), the combination of trees and pastures/cattle in the same production unit, can help mitigate climate change by increasing carbon sequestration above and belowground, with the additional advantage of increasing productivity in the short and long term, being biodiversity friendly, and bringing social and economic advantages to the farmer (VERCHOT *et al.*, 2007; NAIR *et al.*, 2009). In SPS, temperatures can be 2-5°C lower under the tree canopy compared to temperatures measured outside the tree canopy, depending on the tree traits (MURGUEITIO *et al.*, 2011). Thus, the shade trees in SPS add resilience for adaptation to climate variability.

In this article we review recent evidence from active SPS in tropical regions of Latin America to assess their role in climate change adaptation and mitigation. Different types of SPS are examined as an alternative to improve cattle productivity. We also review evidence on the potential of SPS to mitigate climate change by both sequestering carbon and reducing GHG emissions, and present examples of strategies to stimulate adoption to scale-up SPS in Latin America. The article can assist in decisions on SPS implementation and on policies regarding conversion from conventional ranching to more sustainable cattle production systems which can aid in climate change mitigation and adaptation in rural regions of Latin America and elsewhere.

Silvopastoral systems (SPS) as an alternative to improve cattle productivity

Silvopastoral systems involving the combination of trees with pastures and livestock in settings such as dispersed trees in pastures, tree-alley pasture systems, fodder banks, and pastures with live fences and windbreaks, can provide benefits to farmers by enhancing nutrient cycling, fodder production for animals, and diversification of income (YAMAMOTO *et al.*, 2007; MURGUEITIO & IBRAHIM, 2009; IBRAHIM *et al.*, 2011). The SPS are prominent in the agricultural landscape of tropical and sub-tropical regions of Latin America (SOMARRIBA *et al.*, 2012).

The SPS differ according to level of technology, technical assistance, policies, and the local socioeconomic and cultural settings. The SPS can consist of pastures growing in combination with trees of several different species, ages, and sizes, ranging from older, larger trees left from the original forest, to younger ones that have regenerated naturally or that have been recently planted (YAMAMOTO *et al.*, 2007; MURGUEITIO & IBRAHIM, 2009) (photos 1 and 2).

Photo 3.
Silvopastoral system of plantations of timber trees at De Coulon farm in Jardín América, Misiones, NE Argentina, a successful timber/cattle production system. The trees are loblolly pine (*Pinus taeda)*, which are established in combination with a planted pasture where cattle are brought to graze when trees are 2 years old and are not damaged by the cattle. Trees are planted at high density (2,000 stems /ha) and are thinned down to 200/ha final density to ensure good timber production. They are also pruned to improve form. Tree pruning and thinning maintain a good light environment for the grass pastures. Grasses are Pasto jesuita gigante (*Axonopus catarinensis)* which is a native, shade-tolerant grass that has been improved in Brazil, and it has higher productivity and protein content than other grasses such as *Brachiaria* in their farm. Cattle are Bradford (hybrid of Brahman x Hereford) and Brangus (Brahman x Angus), with the rusticity of the Brahman and the beef production and quality of the European breeds. There is electric wire to facilitate rotation of cattle. They are brought to a stable every evening to be fed supplements (sugar cane, salts and minerals). The manure collected from the feedlots is used to prepare compost which they apply to their yerba mate plantations. In these conditions cattle double their weight in about 6 months, and the farm can get a constant influx of income during the year which compensates for the longer time needed for timber to be ready for harvest.
Photo F. Montagnini.

SPS can also consist of plantations of timber trees which are established in combination with pastures grazed by cattle. These SPS can be highly technified and may include hybrid timber trees and improved shade-tolerant grasses (photo 3). In these SPS the trees are generally even-aged, of just one species, and maybe thinned and pruned to improve form and to decrease shade on the pasture (PINAZO *et al*., 2007).

The SPS can also consist of “fodder banks”, which are fodder-producing trees or shrubs planted at very close spacing, with 10,000 or even more stems/hectare, that can be grazed directly by cattle (browsed), or can be harvested to be fed to the cattle. The fodder banks are kept at a low height by harvesting/browsing (photo 4). In seasonally dry ecosystems with alkaline soils the best results have been reported for *Leucaena leucocephala* (Lam.) de Wit. and *Brosimum alicastrum*, while in more humid regions with acid soils the wild sunflower, *Tithonia diversifolia* Hemsl. Gray has proven successful (photo 4) (SHELTON & DALZELL, 2007; MURGUEITIO *et al*., 2011).

In addition to these types of SPS, complementary AFS of living fences and windbreaks can also be part of cattle production farms. Living fences are generally a single line of planted leguminous tree/shrubs whose foliage can be harvested for fodder or browsed directly by the cattle (photos 5 and 6).

Windbreaks, generally composed of one to several rows of timber species, can serve the multiple purposes of ameliorating the environment by decreasing wind speed, decreasing erosion rates, diversifying farm products, and increasing connectivity among fragments of forests in the agricultural landscape (photo 7).

The Intensive Silvopastoral Systems (ISPS) combine several of the types of SPS described above. In the ISPS fodder banks for direct browsing are intercropped with improved pastures to increase the fodder supply, as well as with timber or fruit trees for short- and long-term additional farm income (MURGUEITIO & IBRAHIM, 2009; MURGUEITIO *et al*., 2011) (photos 8 and 9). The trees are generally planted in East-West oriented lines to minimize shading. Shrubs are frequently pruned at a height of 1 m, strict rotation with electric fencing is done and a permanent supply of water for the cattle is guaranteed through water conveyance networks and mobile troughs. This is an innovative technological approach to cattle management that has been practiced successfully in several countries of Latin America such as Argentina, Brazil, Colombia, Mexico, Nicaragua and Panama (MURGUEITIO *et al*., 2011). In Colombia, ISPS have been implemented in several cattle ranching regions ranging in altitude from lowland (Caribbean and Orinoco region), to mid elevation (coffee growing region), and high altitude (Andean region up to 3,000 masl), with annual rainfall as low as 800-2,100 mm/year in the Caribbean region to as high as 3,000 and 5,000 mm/year in the Andean and Orinoco region, respectively (MURGUEITIO *et al*., 2011). This shows the broad adaptability of the ISPS to suit a variety of tropical and subtropical environments and conditions.

An example comparing productivity of SPS with that of conventional cattle management systems is shown here for the dry Caribbean region of Colombia (river Cesar valley and lower Magdalena river valley) where ISPS have been practiced since 2006 (CÓRDOBA *et al.*, 2011). The dry tropical climate, with annual rainfall of 1,200 mm unevenly distributed along the year, results in strong seasonality in cattle production. Soils are Vertisols (US Soil Taxonomy), subject to wind erosion and compaction. Four commercial farms were compared to test pasture systems dedicated to both beef and milk production. In each farm, areas of 20 ha in each system were evaluated during two dry and two wet periods for a total of two years to compare:

- Traditional pasture with the grasses *Bothriochloa pertusa, Dichanthium aristatum* and *Panicum maximum* without trees, no pasture rotation, no artificial watering system for cattle;
- Improved pasture with *Panicum maximum* without trees, rotational pastures, and a network of drinking tanks;
- ISPS with *Leucaena leucocephala* at high density (>10,000 stems/ha) and the grasses *Cynodon plectostachyius*, *Panicum maximum*, associated with mango trees, *Mangifera indica*, rotational pastures with barbed wire and electric ribbons, with grazing periods of 1-2 days and resting periods of 40 days, and an aqueduct that feeds mobile drinking fountains;
- ISPS same as previous but associated with timber trees, *Eucalyptus tereticornis* planted in lines, at a density of 500 trees/ha.

Photo 4.
SPS of a fodder bank of *Tithonia diversifolia* (Asteraceae) planted at very close spacing, in countour lines across the slope at El Cortijo farm in Quindio, Colombia. They are grazed directly by cattle (browsed), or they are harvested to be fed to their Holstein dairy cattle. Tithonia (botón de oro, mirasol) is commonly known as the tree marigold, Mexican sunflower, Japanese sunflower or Nitobe chrysanthemum. It is native to eastern Mexico and Central America but has a nearly pantropical distribution as an introduced species. Depending on the area it may be either annual or perennial, 2-3 m in height with upright and sometimes ligneous stalks in the form of woody shrubs. Its high nutrient content makes it excellent fodder, and the foliage is also used for preparing compost. It is also used in landscaping to form hedges and barriers that prevent erosion, repel noxious pests and are aesthethically pleasant.
Photo F. Montagnini.

Productivity parameters were all superior in the two ISPS with fruit or timber trees (table I). Cattle density increased from 1.2/hectare in the traditional system to up to 4.7 in the ISPS with timber trees, with beef production increasing from 130 kg/ha/year in the conventional system to up to 1,341 in the ISPS with timber trees, as a consequence of larger cattle density and higher weight gain by the animals. In the same systems, volume of milk produced was 1,150 liters/ha in the traditional system and 5,552 in the ISPS thanks to higher cattle density. Higher milk production was also associated with higher content of fat, protein and solids in the milk which are important parameters for the milk processing industry (CÓRDOBA *et al.*, 2011). In the commercial farms under study the cattle breeds had not been genetically selected, the animals bred naturally, milking was done manually and cows did not get feed supplements. Probably improved management in the factors just mentioned could result in even higher productivity. Nevertheless, this comparison shows the benefits of ISPS as result of both higher cattle density and conditions leading to increased cattle productivity.

Carbon sequestration in SPS

Recent reports of vegetation (above and belowground) carbon sequestration potential of SPS worldwide ranged from 1.1 to 6.55 Mg/ha/yr depending on geographic location and on the SPS age, design and management (NAIR *et al.*, 2009). Table II shows C stocks and C sequestration in trees and soils for several locations in tropical and sub-tropical regions of Latin America. The SPS of pastures with planted trees show a range of tree C stock of 0.31-91.8 Mg/ha, and SPS of pastures with natural trees show tree C stocks of 2.43-74 Mg/ha. Calculated C sequestration values are 0.08-4.59 Mg/ha/year for the pastures with planted trees, and 0.49-4.93 Mg/ha/year for the pastures with natural trees. This reflects the heterogeneity of the SSP, which differ in their design, species, and site conditions. However some trends become evident: for example, the SPS of *Pinus taeda* planted at high density depict the highest values of C stock at 20 years of age. The data of these SPS from Misiones, Argentina, demonstrate the high potential of selected and well managed timber tree species to attain high biomass and volume in subtropical regions (PINAZO *et al.*, 2007).

Table I.
Cattle density and productivity under traditional, improved, and ISPS with fruit and timber trees in the dry Caribbean region of Colombia. See text for full explanation of pasture systems (CÓRDOBA *et al.*, 2011).

Region	Pasture system	Cattle density (No. animals/ha)	Cattle weight gain (g/day)	Beef productivity (kg/ha/year)
Lower Magdalena	Traditional	1.2	296.0	129.6
Lower Magdalena	Improved pasture	3.6	453.8	596.2
River Cesar Valley	ISPS with fruit trees	3.5	651.3	827.3
River Cesar Valley	ISPS with timber trees	4.7	790.2	1341.2

Table II.
Tree carbon stock, carbon accumulation rates and soil carbon stocks in silvopastoral systems of tropical and subtropical locations in Latin America.

Location	Type of SPS	Tree species	Tree density (#/ha)	Age (years)	Tree C stock (Mg/ha)	C accum. Rate (Mg/ha/yr)	Soil C Stock (Mg /ha)	Soil depth (cm)	Sources
Maturin, Venezuela	Planted trees in pastures	*Gliricidia sepium, Leucaena leucocephala*	3333	2	0.31	0.16	13.2	10	ARIAS *et al.* (1997)
Misiones, Argentina	Planted trees in pastures	*Pinus taeda*	857	20	91.8	4.59	59	30	PINAZO *et al.* (2007)
Misiones, Argentina	Planted trees in pastures	*Pinus taeda*	420	20	51.5	2.58	59.5	30	PINAZO *et al.* (2007)
Veracruz, Mexico	Planted trees in pastures	*Acacia pennatula, Erythrina americana*	125	5	3.29	0.66	59.7	30	TORRES RIVERA *et al.* (2010)
Yaracuy, Venezuela	Planted trees in pastures	*Leucaena leucocephala*	1861	5	0.42	0.08	58.2	100	MESSA ARBOLEDA (2009)
Rio La Vieja, Colombia	Pastures with trees	Native forest species	83	ND	13.65	ND	140.3	30	ARIAS GIRALDO *et al.* (2009)
Rio La Vieja, Colombia	Pastures with trees	*Maclura tinctoria*	15-20	ND	28.07	ND	140.3	30	ARIAS GIRALDO *et al.* (2009)
Rio La Vieja, Colombia	Pastures with trees	*Samanea saman*	15-20	ND	24.56	ND	140.3	30	ARIAS GIRALDO *et al.* (2009)
Rio La Vieja, Colombia	Pastures with trees	*Erythrina poeppigiana*	15-20	ND	24.17	ND	140.3	30	ARIAS GIRALDO *et al.* (2009)
Chiapas, Mexico	Pastures with trees	Native forest species	ND	15	74	4.93	68	30	SOTO-PINTO *et al.* (2010)
Ucayali, Peru	Pastures with trees	Native forest species	ND	ND	19.2	ND	37	30	REALU II (2012)
Yaracuy, Venezuela	Pastures with trees	Native forest species	122	ND	18.1	ND	77.5	100	MESSA ARBOLEDA (2009)

ND: no data available.

Other species of planted trees in pastures (*Leucaena leucocephala, Gliricidia sepium, Erythrina americana, Acacia pennatula*) show lower values due to their younger age (2 to 5 years old). These species are used for fodder, being either harvested or browsed by the cattle, therefore their standing biomass, composed principally by branches and foliage, remains low. Due to their design and management, fodder banks cannot attain high values of C stock, therefore it is highly recommended to include other trees, especially timber or fruit species which can attain higher values of C sequestration rates and stock. Among the SPS of pastures with natural trees some had high values of C stock, again depending on species, age and density (ARIAS GIRALDO *et al*., 2009; SOTO PINTO *et al*., 2010) (table II).

Ranges of values of soil C stocks (SCS) were similar in magnitude to those of tree C stocks, stressing the importance of this C pool in carbon mitigation projects. At 30 cm depth, which is the depth the IPCC (2006) recommends for soil C monitoring, soil C stocks ranged from 37.0 to 59.7 Mg/ha for both types of SPS considered together (table II). Many projects however sample soils to 1 m depth since in SPS deep tree roots maybe enhancing C flux at deeper soil layers. At 100 cm depth SCS ranged from 54.3 to 140.3 Mg/ha (table II).

As suggested by the data presented above, the type of pasture system, species, management and site are most important factors determining the mitigation capacity of cattle production farms.

Using native trees in SPS

As seen from the examples presented so far, SPS can have important functions in improving cattle farm productivity and sustainability while serving climate change mitigation goals. In addition to increasing on-site productivity, the higher complexity of SPS relative to grass monoculture systems has important benefits for biodiversity (GIRALDO *et al*., 2011; MURGUEITIO & IBRAHIM, 2009) (photo 10). The biodiversity benefit of SPS depends on the system components and management, with larger biodiversity in the more complex systems including several tree and shrub systems, such as in the SPS of natural regenerating trees in pastures, than in the fodder banks or planted timber trees in pastures.

Photo 5.
Living fence of *Gliricidia sepium* (balo, matarratón, gliricidia) a leguminous tree of fodder value, which can be browsed directly by cattle, and can also be harvested for fodder to supply food for cattle when biomass and nutritional value of grasses declines during the dry season. Farm located in Provincia de Azuero (Panama).
Photo E. Murgueitio R.

Photo 6.
Cow browsing foliage of *Gliricidia sepium*. Finca belongs to Oscar Forto, and is located in Valle de Otoro (Honduras).
Photo E. Murgueitio.

Photo 7.
Windbreaks, which can be composed of one to several rows of planted trees, generally of timber value, can also be part of cattle production farms, serving to ameliorate the microenvironemt, increasing farm diversification of products, and contributing to landscape connectivity.
Cordia gerascanthus (Móncoro), a native tree of high timber value, planted as windbreak at a farm located in Departamento del Cesar, Colombia.
Photo L. Hernando Solarte, CIPAV.

Using native species as part of SPS confers several advantages to biodiversity conservation (MONTAGNINI & FINNEY, 2011; MURGUEITIO *et al.*, 2011). An important pool of knowledge has recently developed on native trees and their adaptability to several land use types including AFS and SPS. More than 130 neotropical species have been screened by various national projects and several have shown good growth and survival in degraded areas (CALLE *et al.*, 2012, citing HALL *et al.*, 2011; VAN BRUEGEL *et al.*, 2011).

For example, results from projects designed to recover degraded pasture in the Caribbean lowlands of Costa Rica showed that native tree species had good productivity and high rates of C sequestration both in aboveground biomass and soils. Among 9 native tree species examined at 15-16 years of age, *Vochysia guatemalensis, Vochysia ferruginea, Terminalia amazonia, Hieronyma alchorneoides* and *Dypterix oleifera* grew well and had rates of aboveground C accumulation ranging from 16.5 to 58.5 Mg C/ha and soil C stocks of 30 to 51 Mg C/ha at 0-15 cm depth, depending on the species. These trees are commonly planted in the region as they are preferred by farmers for their high quality timber (MONTAGNINI, 2011).

In other research in seasonally dry lowlands of Costa Rica, indigenous tree species of nitrogen fixing trees, *Pithecellobium saman, Diphysa robinioides* and *Dalbergia retusa* were associated with fast growing pasture species (*Brachiaria brizantha*) and grazed for 4 or 5 days with 1-2 month intervals between grazing. The total C in above + below ground phytomass (TSOC) was 12.5 Mg C/ha in the SPS while in treeless control pastures dominated by *Hyparrhenia rufa* it was about one third of this value with 3.5 Mg C/ha (ANDRADE *et al.*, 2008). As seen, several native tree species can be used in SPS with good results in terms of productivity, restorative effects on soils and C sequestration capacity above and belowground.

Table III.
Estimate methane (CH_4) emissions (kg/animal/day) according to different feeding systems. Emissions can be 15-18% higher in the dry season due to lower nutritional quality of fodder. The IPCC defines 3 ranges of fodder digestibility: 45-55% low, 55-75% medium, 75-85% high nutritional quality (mostly from food supplements).

Type of pasture	*IVDMD (%)	**CP (%)	CH_4 (Kg/animal/day)	Reference
Hyparrhenia rufa (Native pasture)	45	5.5	0.38	HOLMANN, 1994
Brachiaria brizantha (Improved pasture)	54	10	0.196	JIMÉNEZ, 2007
B brizantha + Leucaena leucocephala	58	13.5	0.174	JIMÉNEZ, 2007

*IVDMD = *in vitro* dry matter digestibility.
**% CP= crude protein.

Mitigation of Greenhouse gases (GHG) emissions in silvopastoral systems

One possible approach to decrease contributions of cattle production to GHG consists of reducing GHG emissions by feeding cattle with forage of high digestibility. For example, as shown in table III, leguminous fodder that contains condensed tannins (*Lotus* spp., *Leucaena leucocephala* and others) can decrease methane emissions by 12-15%, with improvement of cattle productivity (BARAHONA *et al.*, 2003) (table III).

Likewise, experiences in Australia have shown that feeding leucaena, *Leucaena leucocephala,* can reduce emission of CH_4 /kg of dry matter consumed by livestock up to 30%, while in Colombia in ISPS with leucaena annual CH_4 emission per animal decreased by 38% (NARANJO *et al.*, 2012). It has been argued that including nitrogen fixing species in cattle production systems can increase nitrous oxide emission; however calculations of GHG balances shave shown that the N_2O emitted by the nitrogen fixing species is compensated by greater GHG capture in aerial biomass and soil (NARANJO *et al.*, 2012).

The second approach for mitigation of emissions consists of planning and managing cattle ranching systems to sequester carbon. In combination, both approaches are expected to lead to "Carbon neutral systems" which are defined as land uses that can reduce emissions or sequester carbon and show environmental integrity according to national or international standards (MURGUEITIO & IBRAHIM, 2009). In this sense, SPS can provide a good combination of economic production, poverty reduction, recovery of degraded areas and environmental services, particularly C sequestration. Silvopastoral systems can have important C sequestration benefits in at least two ways:

- by increasing direct C sequestration through the addition of the tree and shrub components, as well as in the soil;
- by reducing the need to clear more forests as lands that are used for SPS can be productive for longer time than if used in conventional ranching (YAMAMOTO *et al.*, 2007).

In recent research in Colombia, Nicaragua and Costa Rica, above and below ground carbon stocks were studied in several land uses in agricultural landscapes including degraded pastures, improved pastures, secondary forests and tree plantations (IBRAHIM *et al.*, 2007). Soils were sampled to 1m depth to measure bulk density and soil organic carbon (SOC). Carbon in tree biomass was calculated with allometric equations using measured diameter at breast height of trees in subplots (IBRAHIM *et al.*, 2007). In Costa Rica, degraded pastures had the lowest SOC (22 Mg C/ha). The other land uses did not show statistically significant differences, with 96 Mg/ha in tree plantations and 140 Mg/ha in improved pastures without trees. Teak plantations and secondary forests had the highest aboveground biomass C (about 90 Mg/ha). The secondary forest was the land use with more carbon stored (both in soil and trees) in Costa Rica and Nicaragua; in Colombia, it was the riparian forest. Overall results from the three regions of study showed that degraded pasture was the land use with less carbon compared to improved pastures with trees, and with the forest systems. The authors concluded that there are good opportunities for C-sequestration in agricultural landscapes dominated by cattle by conserving and adding trees in the landscape in the form of SPS, tree plantations and riparian forests (IBRAHIM *et al.*, 2007).

In a further comparison of C sequestration and fluxes in biomass and soils among degraded pastures, SPS of pastures with low and high tree density, fodder banks, as well as tree plantations and secondary forests located in dry and wet regions of Costa Rica, the SPS showed the largest values for aboveground biomass and soil C. The improved pastures without trees had large values of soil C, but very low or negligible values for aboveground biomass C (table IV).

Table IV.
Carbon stock and aerial biomass in trees (Mg/ha) measured in sub-humid tropical forest (Guanacaste, Costa Rica) and in tropical wet forest (Pocora, Costa Rica) (AMÉZQUITA *et al.*, 2008; TOBAR *et al.*, 2010).

Land use	Mean age of land use (years)	Carbon in Soil	Carbon in aerial biomass	Total carbon (C)
Guanacaste, Costa Rica (sub-humid tropical forest)				
Degraded pastures	8	60.2	0.3	60.5
Forage banks of woody species	4	70.0	6.9	76.8
Improved pastures with high tree density	4.5	76.3	30.8	107.1
Forage banks of grasses	6.5	86.2	26.3	112.5
Forest plantations	‹15	91.0	51.4	142.4
Secondary forests	›25	86.8	91.9	178.7
Pocora, Costa Rica (wet tropical forest)				
Degraded pastures	›70	107.9	ND	107.9
Brachiaria brizantha	›19	153	ND	153
B. brizantha + Arachis pintoi	16	186.8	ND	186.8
Silvopastoral system (*Acacia mangium + Panicum maximum*)	15	160.9	12.8	173.7
Secondary forests	›25	141.3	174.2	315.5

Photo 8.
Highly productive intensive SPS in finca "El Hatico" near Cali, Colombia. This ISPS are established by planting high densities of the nitrogen-fixing shrub *Leucaena leucocephala* in association with improved grasses. In a 2 year old system and at high density (60,000 planted shrubs/ha, 1.30 m between lines) the *Leucaena* may fix up to 300 kg N/ha/yr (SHELTON & DALZELL, 2007). N-fixing species provide protein-rich fodder and due to higher N availability the grasses maintain their productivity and do not require expensive urea fertilizers. Cattle feed on the vigorous pastures and the shrub foliage, and the system is sturdy enough to allow direct browsing on a regular rotation. Grass species in the picture are *Panicum maximum* (Guinea grass) var. Tanzania, and *Cynodon plectostachyius* (African star grass). The system also has about 50-70 trees per hectare of several species with a predominance of *Prosopis juliflora*. There are 4.5 animals /ha. At that cattle density there can be about 9 tons/ha/yr of manure addition to the soils (MOLINA *et al.*, 2009). The cattle are of Lucerna breed, a cross between the European Holstein and Shorthorn breeds of high beef and milk productivity, and the criollo (local) Hartón del Valle breed to add rusticity. On average the foliage of the trees decreases air temperature by 2-3°C, and even by 6°C during the hottest days in comparison with open areas thus providing comfort to the animals and increasing their productivity.
Photo F. Montagnini.

In Colombia, NARANJO *et al.* (2012) calculated GHG balances in ISPS of *Leucaena leucocephala* alone, ISPS associated with timber trees, and in two baseline scenarios of degraded and improved pastures, using IPCC protocols. According to the calculations, the degraded and improved pastures were both net emitters with 3.2 and 3.3 tons CO_2e per ha per year respectively, while ISPS removed GHG with an average value of 8.8 CO_2e per ha per year (NARANJO *et al.*, 2012). When the ISPS included timber trees as part of their design their GHG mitigation capacity reached up to 26.6 ton CO_2e per ha per year. The authors concluded that the ISPS is a technology that can contribute to mitigate climate change due to its production capacity (both plant biomass and animal productivity) that enables this system to have a positive GHG balance.

Scaling up SPS to regional levels

Cattle production systems are part of local cultures and are also an important component in subsistence economies of small and medium sized landholders. Therefore in spite of controversial issues concerning their impacts on ecosystems many pasture systems will continue to be important parts of rural landscapes. As shown with the examples described, SPS can serve to offset emissions from the system itself and even from outside the system, and due to their productive and environmental functions they are being promoted in several countries in Latin America. However, a true change in the paradigm of tropical cattle ranching requires that adoption of SPS happens at a relevant scale. Scaling-up has been defined as bringing more benefits to more people, more quickly and more lastingly (MURGUEITIO *et al.*, 2011; CALLE *et al.*, 2013). In the case of SPS, the first step to scale up the transformation of cattle-based forms of land use is a cultural and intellectual shift by farmers, scientists, educators and politicians. This change requires a combination of scientific and technological innovation, policy and economic and market incentives at all scales (CALLE *et al.*, 2012; CALLE *et al.*, 2013).

In Colombia, the strategy for scaling-up SPS has combined five elements:

As shown, different types of SPS have different capacity for mitigation of GHG emissions depending on their capacity to both decrease GHG and to sequester C. Current research at CATIE (Centro Agronómico Tropical de Investigación y Enseñanza, Tropical Agriculture Research and Higher Education Center) in the Pacific region of Costa Rica has shown that livestock farms can mitigate between 2.2 to 10.6 tons of CO_2e[1] per ha per year by the incorporation of SPS that have potential for carbon sequestration in biomass and soils (IBRAHIM *et al.*, 2010). The use of SPS contributes to carbon sequestration in both trees and in soils, while establishing forest plantations and conserving secondary forests add carbon sequestration and storage at the landscape level (GAMMA, 2010).

[1] CO_{2e} is a metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential (GWP) (WIGHTMAN, 2007).

- Pilot farms: participatory research conducted in cattle farms to optimize SPS designs and management;
- Capacity building: training and outreach activities to spread the principles of SPS among farmers, researchers, technicians, politicians and decision makers;
- Pilot Projects: to explore the role of different incentives such as Payment for Environmental Services (PES), technical assistance, soft loans and bonus prices, in spreading SPS;
- Influencing the livestock sector, farmer organizations and the public policy agenda using the success of the SPS experiences;
- Large scale projects applying the lessons learned in pilot projects to mainstream SPS in order to achieve landscape-scale benefits, enhance climate change adaptation and mitigation and open access for SPS products to green markets (CALLE *et al.*, 2013).

Photo 9.
Some consider *Leucaena* as an invasive species, however in the ISPS the *Leucaena* trees are pruned to keep them at 1.5-2m height so as to allow browsing by cattle, thus they do not produce seed and do not become invasive (CALLE *et al.*, 2011; SHELTON & DALZELL, 2007). The riparian forest bordering this pasture has rich natural regeneration of woody species, and no *Leucaena* seedlings or shrubs can be observed in the understory.
Photo F. Montagnini.

Tools for promoting adoption of SPS: incentives and financial instruments

If the function of SPS on climate change mitigation is expected to be significant at the landscape, regional and national levels, adoption of the systems has to be ensured through proper promotion. Although SPS can provide significant benefits, lack of capital and high cost of establishment and management represent the two most important barriers to the adoption of these systems (CALLE *et al.*, 2009; CALLE *et al.*, 2013). Even though the investment can be recovered in a relatively short period (3-4 years), most farmers, technicians and banks have not assimilated this relatively new thinking about cattle-ranching. Nevertheless, Latin American cattle ranchers must quickly adapt to a changing climate and to the challenges of recent free-trade agreements that will demand producing high-quality beef and dairy products, at a lower cost and adhering to rigorous environmental standards (CALLE *et al.*, 2013). Therefore, incentives and financial instruments are needed to promote the large-scale adoption of SPS.

Subsidies provided by specific projects, or government programs of Payments for Environmental Services (PES) are instrumental in promoting adoption (IBRAHIM *et al.*, 2011; MONTAGNINI & FINNEY, 2011). In Colombia, Costa Rica and Nicaragua PES programs were recently used effectively to promote SPS (PAGIOLA *et al.*, 2007; IBRAHIM *et al.*, 2011). In Colombia, FEDEGAN, Federación Colombiana de Ganaderos (National Federation of Cattle Ranchers) through a World Bank funded project: “Mainstreaming Biodiversity into Sustainable Cattle Ranching” is promoting the adoption of environmentally-friendly SPS, to improve natural resource management, enhance the provision of environmental services (biodiversity, carbon, and water), and raise productivity in participating farms throughout the country. An important component of this project is increasing landscape connectivity and reducing land degradation on participating cattle ranching farms through differentiated Payments for Environmental Services (PES) schemes (WORLD BANK, 2010; MURGUEITIO *et al.*, 2011; CALLE *et al.*, 2012).

In Costa Rica the governmental PES Program includes AFS and SPS among the land uses that can receive PES. Farmers receive US$1.30 per tree, with 350-3,500 trees allowed in each contract, and 40-625 trees/ha depending on the type of AFS (MONTAGNINI & FINNEY, 2011). In Costa Rica, the GAMMA Program at CATIE is currently developing SPS that can be carbon-neutral in compliance with Costa Rica’s goal to become the first country to be carbon neutral by 2021. The Costa Rican Ministry of Agriculture has launched a program on climate change and agriculture and is currently working with the private sector, for example CORFORGA (Corporation of beef cattle farmers), and Dos Pinos (a large milk cooperative). The goal of this program is to develop incentive mechanisms to promote the transition of traditional cattle farms to carbon-neutral cattle farms, and to open out markets for their products. To achieve this goal, the farmers need to increase tree cover in their farms, which contributes to enhance carbon fixation and stock (in biomass and soil). Farmers are also encouraged to improve overall

Photo 10.
Another advantage of the SPS is that shrubs, timber and fruit trees and palms attract biodiversity. Some of the birds and insects that can be found in the SPS have important ecological functions in terms of seed dispersal, and some provide other benefits such as controlling pests and diseases of cattle. In the picture, two Guacamayas (*Ara macao*, an endangered, emblematic species in Colombia) are seen perching in the canopy of a saman tree (*Samanea saman* (Jacq.) Merrill), also known as *Albizzia saman* (Jacq.) F.v. Mueller, and *Pithecellobium saman* (Jacq. Benth.). The saman is a nitrogen fixing species, with many uses such as timber, fuelwood, medicinal, and ornamental. It is an important tree component of silvopastoral systems in dry tropical forest regions. *Samanea saman* belongs to the mimosoid subfamily of the Fabaceae family, and is native to the Neotropics, with a range extending from Mexico to Peru and Brazil. It can reach very large dimensions when growing in relatively open woodlands or savannas and is an emblematic tree in many Latin American countries such as Colombia, Venezuela, and Costa Rica. Common names include saman, rain tree and monkeypod.
Photo C. Pineda.

farm management through the use of vermicompost, biogas, silage, improved pastures, and forest protection. These management options contribute to reduce GHG emissions, to climate change adaptation and to improvements in productivity (GAMMA, 2010). Within the framework of cooperation between the US and Costa Rica, CATIE is providing technical support to the EC-LEDS (Enhancing Capacity for Low Emission Development) project to strengthen the private sector to develop low emission cattle production systems.

Likewise, projects in Nicaragua are providing incentives to favor adoption of SPS, building upon successful experiences to scale them up in the country. For example, the CAMBio project (Mercados Centro Americanos para la Biodiversidad, Central American Markets for Biodiversity) funded by GEF promotes SPS with emphasis on native species and provides economic incentives to farmers with credits and technical assistance (RAMÍREZ, 2010). CAMBio incorporates environmental incentives into local financial policies, for example with the use of the Fondo de Desarrollo Local (FDL) (Local Development Fund), which is the main micro-finance entity in Nicaragua with a broad action in the rural sector (RAMÍREZ, 2010).

As seen from these examples, several strategies have been advanced as tools for promoting adoption of SPS, including financial incentives and payments for ecosystem services. Other tools include specialized technical assistance, innovation awards for farmers, and market preferences (CALLE *et al.*, 2012). Different incentives can be used at different scales, with the understanding that they may present both advantages and constraints in their broad application. Subsidies such as PES and technical assistance are instrumental to stimulate adoption of SPS as these systems often require the use of new techniques, including planting new tree, shrub and other fodder species, as well as using breeds of cattle better adapted to local conditions.

Conclusions

Silvopastoral systems (SPS), and more especially Intensive Silvopastoral Systems (ISPS) have shown a capacity for livestock production higher than that of conventional systems. Biomass production throughout the year, even in the dry season, allows a greater transformation of cattle feed into beef and milk with cattle stocking densities almost four times higher, and beef yields higher than those in conventional, extensive systems. SPS show an ability to adapt to climate change due to the ameliorating effects of trees and shrubs on air temperatures that contribute to enhancing animal comfort and productivity. In addition, the experiences shown here demonstrate that if well planned and managed, SPS can be effective carbon sinks, leading to carbon neutral systems and thus helping to achieve mitigation goals of individual farmers, regions and countries. Up-scaling of projects that promote the adoption of SPS is already ongoing in Colombia, Costa Rica, and Nicaragua, and many ISPS are already being practiced successfully elsewhere in Latin America.

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