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CHAPTER X

Importance of silvopastoral systems for mitigation of climate change and harnessing of environmental benefits

INTRODUCTION

Forest ecosystems are estimated to absorb up to 3 Pg of carbon (C) annually. In recent years, however, a significant portion has been returned to the atmosphere through deforestation and forest fires. For example, tropical deforestation in the 1980s is estimated to have accounted for up to a quarter of all C emissions stemming from human activities (FAO, 2003). In Central America, more than 9 million ha of primary forest was deforested for expansion of pasture and more than half of this area is degraded (Szott, Ibrahim and Beer, 2000). Pasture degradation leads to a decline of the natural resource base (e.g. decreased biodiversity, soil and water quality); more rapid runoff and hence higher peak flows and sedimentation of rivers; and lower productivity, increased rural poverty and vulnerability and further land-use pressure. It is also related to a significant reduction in soil C stocks and is among one of the main reasons for the large C footprint associated with cattle ranching in Latin America (Ibrahim *et al.*, 2007).

On the other hand, many studies in Latin America conclude that improved grasses and legume pastures can fix similar amounts of C to that of forest systems (Tarre *et al*., 2001; Ibrahim *et al.*, 2007; Amézquita *et al.*, 2008), and that they are associated with increased animal productivity (Ibrahim, 1994). However, the root systems of grasses are generally concentrated in the upper soil layers (0–40 cm depth) and there is little soil-derived C associated with grasses in the deeper soil layers (Nepstad *et al*., 1994). Furthermore, large-scale cultivation of simplified grass monocultures results in agricultural landscapes that are more vulnerable to climate change.

Within this context, CATIE, a regional centre based in Costa Rica, together with other institutions (e.g. CIPAV in Colombia and Nitlapan in Nicaragua[1]), has been promoting complex silvopastoral systems (SPS) in the bioengineering of multifunctional landscapes. In this paper, SPS are defined as *the integration of trees and shrubs in pastures with animals for economic, ecological and social sustainability*. Well-managed SPS can improve overall productivity (Bustamante, Ibrahim and Beer, 1998; Bolívar *et al*., 1999), while sequestering C (López *et al*., 1999; Andrade, 1999; Ibrahim *et al.,* 2007), a potential additional economic benefit for livestock farmers. In these systems, tree roots generally explore deeper soil depths and can contribute to relatively large amounts of sequestered C compared with grass monocultures or forest systems (Ibrahim *et al.,* 2007; Andrade, 2007; Amézquita *et al*., 2008). Results from several studies document the importance of SPS (e.g. pastures with high tree densities or multistrata live fences) for the conservation of biodiversity (Ibrahim *et al*., 2001; Sáenz *et al*., 2007).

The bundling of production activities with the marketing of environmental services could constitute a route to reconverting traditional cattle systems towards ecofriendly systems that integrate silvopastoral and agroforestry systems. This could represent one of the best strategies for poverty alleviation, ecological restoration, C sequestration and conservation of water and biodiversity resources, while ensuring agricultural productivity. This linkage provides the farmer with the option of continuing to produce food, raw materials, and services and at the same time of providing benefits for society and the global environment.

Many observers believe that the clean development mechanism (CDM) offered by the Kyoto Protocol could reduce rural poverty by extending payments to low-income farmers who provide C storage through sustainable land-use systems such as those of agroforestry and silvopasture. Given the vast area of land currently managed as ruminant production systems in Latin America, the potential for climate change mitigation through C sequestration is large. Although implementation of SPS on cattle farms has resulted in significant improvements in livestock productivity (>30 percent) and environmental services are being generated on landscapes dominated by cattle, there is still a lack of capital for investing in SPS, representing a major barrier for adoption of these systems by cattle farmers in Central America

[1] Centro para la investigación en sistemas sostenibles de producción agropecuaria (CIPAV), Instituto de Investigación aplicada y promoción desarrollo local (Nitlapan).

(Alonzo *et al.*, 2001; Chagoya, 2004). Thus, the payment for environmental services for C sequestration in SPS can be an important incentive for ensuring widespread adoption. This paper presents results for C sequestration in pasture and SPS. It also presents lessons learned on payment for environmental services and the impact on C-sequestered and farm-level C budgets, together with an analysis of land-use systems and their value for both C and biodiversity.

CARBON SEQUESTRATION IN PASTURAL AND SILVOPASTORAL SYSTEMS

Interest in managing pastures and SPS to foster C sequestration has increased over the last few years, although there have been mixed results as to the potential of tropical pastures to accumulate soil organic carbon (SOC). Veldkamp (1994) found a net loss of 2–18 percent of C stocks in the top 50 cm of forest equivalent soil after 25 years under pasture in lowland Costa Rica. On the other hand, in a Brazilian study by Neil *et al.* (1997), 11 out of 14 pasture conversion sites studied showed increases in soil C. These pasture sites, each monitored for at least ten years, showed increased C with rates as high as 74.0 g C/m^2/year over 20 years.

The quality of management of tropical pastures is critical to the conclusions drawn about whether the soils under this land use represent a source or a sink of atmospheric C. In well-managed pastures in formerly forested areas, significant amounts of litter (roots and leaf litter) are recycled in the system which result in accumulation of SOC. Studies in Central America showed that SPS with different tree species and configurations stored relatively large amounts of C in relation to secondary and primary forests. In SPS, the amount of C stored in the above-ground tree biomass varied, depending on climatic and soil conditions, species and tree densities as well as the age of trees (Table 18).

Carbon fixation rates of SPS varied between 1.0 and 5.0 tonnes C/ha/year (Table 19), depending again on the climate and soil conditions, pasture type, tree species, tree density and age. The amount of C fixed in SPS is influenced by tree and/or shrub species, density and spatial distribution of trees and shade tolerance of herbaceous species (Nyberg and Hogberg, 1995; Jackson and Ash, 1998). On the slopes of the Ecuadorean Andes, total soil C increased from 7.9 percent under open *Setaria sphacelata* pasture to 11.4 percent beneath the canopies of *Inga* spp. but no differences were observed under *Psidium guajava.* Soils under *Inga* contained an additional 20 Mg C/ha in the upper 15 cm compared with open pasture (Rhoades, Eckert and Coleman, 1998).

PAYMENT FOR ENVIRONMENTAL SERVICES AND THE IMPACT ON FARM-LEVEL CARBON BUDGETS: LESSONS LEARNED

There is considerable evidence demonstrating that SPS result in improved production efficiency of cattle farms, C sequestration and conservation of biodiversity and water in landscapes dominated by cattle (Rios *et al*., 2007). However, high costs for labour and the establishment of intensive SPS (for example, fodder banks and multistrata SPS) are among the major reasons for their poor adoption (Alonzo *et al*., 2001; Dagang and Nair, 2003). In a Global Environmental Facility (GEF) funded project, CATIE worked with FAO, Nitlapan (Nicaragua), CIPAV (Colombia) and the World Bank to evaluate the impacts of payment for environmental services (PES) on adoption of SPS.

The project developed an ecological index that ranked land-use systems in terms of their value for C sequestration. This was used as a proxy for PES to the farmers (Murgueitio *et al*., 2003.). The project developed a baseline of land uses for each farm and farms were monitored on a yearly basis to evaluate land-use changes. Payments were made on the achievement of incremental ecological points. The project monitored water, biodiversity and C sequestration on replicated and representative land uses in each pilot area. The results of the project were published in several papers (Ibrahim *et al*., 2007; Ríos *et al*., 2007; Sáenz *et al*., 2007; Tobar and Ibrahim, 2010). Over the four years of the project, PES resulted in an increase (22.5 percent) in the area of SPS (high and low tree densities), live fences (simple and multistrata fences) and a small percentage increase in the area of fodder banks and forest (Table 20). In Costa Rica, PES was given to 104 farmers with a total area of 3 002 ha. The adoption of SPS and, to some extent, forest systems resulted in a significant increase in the amount of C sequestered (>90 percent) with an estimated annual sequestration rate of 1.1 tonnes CO_2eq/ha (Table 20). Farms of different poverty levels in Matiguás, Nicaragua were monitored to evaluate socio-economic impacts of PES and the results showed that there were significant improvements in milk yields, leading to higher family gross income per capita, which was associated with the adoption of improved fodder technologies for feeding cattle (Table 21).

Since ruminant systems have been in the spotlight for their contribution to emissions of greenhouse gases (GHGs) and global warming (FAO, 2006), the project carried out an analysis of the impacts of PES on emission of GHGs using a life-cycle analysis (LCA), and on the C budgets or balance (sequestration in land-use systems versus emissions) of cattle farms. The results showed that farms with SPS had lower emissions of GHGs converted in CO_2eq, compared with conventional management systems (extensive grazing, use of supplements) (Figures 21 and 22). Other farms with SPS sequestered more C in the land-use systems than was emitted (Figure 23), indicating that there are good opportunities for certification of livestock farms with SPS for C neutral products, and an opportunity for obtaining added value of farm products.

In terms of GHG, the use of leguminous-based pasture systems can offset the use of nitrogen (N) fertilizers for sustaining pasture yields, thus contributing to a reduction in the emissions of nitrous oxide (N_2O). Feeding better-quality forages results in a reduction of methane (CH_4) during rumen fermentation. Dairy farms that had a higher tree cover and used fewer external inputs (e.g. concentrates and N fertilizers) had better overall C budgets (e.g. fewer emissions of GHGs), compared with those farms that had lower tree cover and used more external inputs (Mora, 2001).

Biodiversity indicators of land-use change were used to develop a biodiversity index for each change and to analyse the relationship between C sequestration and biodiversity for each land use. Grass monoculture pastures with low tree density had a relatively high value for C but a low value for biodiversity conservation, whereas SPS with high tree density had relatively high levels of C and biodiversity value when compared with forest systems. These results indicate the importance of fostering SPS for harnessing environmental services (Figure 24).

CONCLUSIONS

Silvopastoral systems hold enormous promise for addressing multiple issues facing livestock farmers in Latin America. Well-managed SPS increase soil and biomass C, biological diversity, and water capture and storage while directly increasing the livelihoods of cattle producers through improved livestock production. Obstacles to scaling up these systems tend to centre upon lack of financial capital or lack of labour associated with establishing complex agroforestry systems. The use of PES in Costa Rica and elsewhere has prompted greater uptake of SPS, leading to lower GHG emissions from livestock-based systems, improved income levels and the stewarding of multiple environmental services.

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