THE ROLE OF SILVOPASTORAL SYSTEMS IN THE XXI CENTURY

Guilherme Lanna Reis[1*], Ângela Maria Quintão Lana[1], Rogério Martins Maurício[2], Talmir Quinzeiro Neto[1], Guilherme Rocha Moreira[1], Regina Maria Quintão Lana[3], Rodrigo Matta Machado[4], Gustavo Henrique Ferreira Abreu Moreira[1]

ABSTRACT – Inadequate policies and technologies have contributed to the economic, social, and environmental unsustainability of agriculture and livestock production worldwide. Through a review of prior literature, this study analyses the silvopastoral systems (SPS) - an association of trees, forage, and animals - as a tool to attain sustainable animal production in the contexts of increasing populations, crescent demand for food, and environmental impacts. This review covers major SPS advantages, such as environmental services, as well as disadvantages, such as a lack of information and cost of implementation. Recommendations for the adoption of public policies and tools for monitoring environmental impacts are also suggested herein.

Keywords: Deforestation, degradation, environmental impacts, pastures, sustainability.

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RESUMO – Políticas e tecnologias inadequadas têm contribuído para a insustentabilidade econômica, social e ambiental da agropecuária mundial. Por meio de uma profunda revisão da literatura, este estudo analisa os sistemas silvipastoris (SPS) - uma associação de árvores, forrageiras e animais - como uma ferramenta para atingir a produção animal sustentável no contexto de crescimento populacional, demanda crescente por alimentos e impactos ambientais. Esta revisão abrange as principais vantagens do SPS, como os serviços ambientais, e também as desvantagens, como a falta de informação e implementação de custos. Recomendações para a adoção de políticas públicas e instrumentos de monitoramento dos impactos ambientais também são sugeridas.

Palavras-chave: Desmatamento, degradação, impactos ambientais, pastagens, sustentabilidade.

1. INTRODUCTION

In the XXI century, two major concerns have predominated: the environmental consequences of an ever-increasing food supply and the consequences of climate change on food production (Gregory & Ingram, 2000). Furthermore, current agricultural practices have caused more severe environmental impacts (Tilman et al., 2002). In areas of intensive livestock production, the main concerns include nutrient accumulation in the soil, water pollution, and greenhouse gas (GHG) emissions while extensive grazing is also related to deforestation, soil compaction, and desertification (Nicholson et al., 2001). However, in some underdeveloped countries, the livestock sector accounts for 50-80% of Gross Domestic product (GDP) (Neely et al., 2009).

The degradation of land can be limited and recovered through soil conservation methods, the proper management of pastures, and the introduction of silvopastoral systems (SPS) (Steinfeld et al., 2006), an association of trees, forages, and animals.

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[1] Federal University of Minas Gerais, Veterinarian School, Cx.P. 567, 30123-970, Belo Horizonte, MG , Brazil *Corresponding author. Tel.: 5531 34092202 e-mail: guilhermelanna@yahoo.com.br

[2] Federal University of São João Del-Rei (UFSJ), Biosystems Engineering Department, Praça Frei Orlando, 170, Centro, São João del-Rei, Minas Gerais, Brazil

[3] Federal University of Uberlândia, Av. Amazonas, s/n - Bloco 4C, Sala 102, Campus Umuarama, Uberlândia, MG, Brazil

[4] Federal University of Minas Gerais, Institute of Biology Sciences, Cx.P. 567, 30123-970 Belo Horizonte, MG, Brazil

The aim of this review is to assess the role of the SPS in regard to economic, social, and environmental sustainability in the context of the twenty-first century.

2. GLOBAL CONTEXT

2.1. Population increase and demand for food and resources

The global population of six billion people increases approximately 1.3%, or 73 million people, yearly. This figure is predicted to reach 7.5 billion in 2020 and 9.4 billion in 2050 (Lal, 2001). By 2020, 98% of this increase is estimated to occur in developing countries, mainly in urban areas (Sanchez, 2000). Likewise, food demand is predicted to double by 2050 (Tilman et al., 2002). In the period from 1998 to 2030, the GDP per capita is expected to increase by 2.6% yearly, which would consequently increase the daily food demand from 2,803 to 3,050 kcal per capita (which is above the minimum of 1,700-2,000 kcal per person per day to prevent malnutrition). In the same light, the annual meat consumption will increase from 36 to 45 kg per person, confirming the fact that the population's diet tends to include more livestock products. It is estimated that, by 2030, food production will meet this demand. However, this indicates that the agricultural area will have expanded by 8%, mainly producing negative effects on tropical forests in developing countries (Eickhout et al., 2006). On the other hand, the increase in food demand provides an opportunity to alleviate poverty, especially when considering that small-scale producers are responsible for 50% of the global production of meat and milk supplies (Nicholson et al., 2001).

Animals convert byproducts into food which is appropriate for human consumption. These byproducts represent approximately 33% to 50% of the rations consumed by intensive systems. The biological protein value of livestock products is up to 1.4 times greater than that of vegetables. Ruminants demand less human-edible feed than do monogastrics as the conversion of grain fed per unit of meat is approximately 0.3 for cattle, whereas it is 1.6 for poultry and 1.8 for swine (Nicholson et al., 2001).

Although food production is enough to meet demand, around 20% of the world's population lives on less than US$1.00/day, and 850 million people are socially marginalized because they do not have access to land, employment, food, nor adequate water supply (Bennett, 2000). In this context, the world's poor, along with other agents, such as misery, have improperly exploited natural resources and have contributed to the degradation of potential agricultural areas (Paris & Paris, 1996).

2.2. Environmental impacts

Although in the last 35 years new technology has been able to overcome losses in productivity caused by environmental impacts in a high demand context, the consequences of intensive agriculture, such as soil degradation, water pollution, and loss of biodiversity, have become even more prevalent (Harris & Kennedy, 1999).

2.2.1. Deforestation

Globally, the annual deforestation rates are approximately 13 million of hectares (Schwendenmann & Pendall, 2006). In the Brazilian Amazon, macroeconomic policies encouraged migration to the outer limits of forests through colonization projects or subsidies for investments in the region leading to deforestation. Other factors have also contributed to deforestation, such as the attempt to secure land titles, poverty, low soil fertility and, consequently, insufficient productivity (Carpentier et al., 2000).

Cattle have been considered a major player in tropical deforestation. Generally, the roads opened by logging companies to extract valuable hardwoods are used by farmers to replace the forest with agriculture activities (Nicholson et al., 2001). The extensive grazing areas are frequently burned to clear away tress, plants, and weeds. Fertilizers, due to their high local cost, are rarely used to maintain pasture fertility. Therefore, the pasture deteriorates within approximately 5-15 years of use (Asner el al., 2004). Overgrazing also compromises soil fertility. As the forage losses vigor and productivity, the soil becomes even more exposed and more compact. Then, water infiltration in the soil diminishes, leading to erosion and the compromising of water courses. Over time, deforestation reduces the number of local benefits.

2.2.2. Climate change

Climate change is strongly related to food safety, poverty reduction, and environmental conservation (Sanchez, 2000). The largest proportion of C emissions results from the burning of fossil fuels and the deforestation of tropical rainforests (Albrecht & Kandji, 2003). The Amazon region covers nearly 700 million ha, mostly located within the borders of Brazil, whose annual rate of deforestation ranges from 1.1 to 2.9 million ha. About 70% of the cleared area becomes grazing areas (Cerri et al., 2004). However the Savanna is the Brazilian ecosystem that is the most affected by agricultural expansion, losing 3.4 million ha annually. The biomass of native vegetation under the soil can actually overwhelm the aerial biomass in an attempt to adapt and overcome droughts and effects from slashing and burning. Nevertheless, the native vegetation has been replaced by monocultures, such as soybean, which do not have the same C sink capacity. Due to the high C sink capacity (Delitti et al., 2003) and the vast area (approximately 200 million ha), the Brazilian savanna becomes very important in the context of climate change (Krug et al., 2006). Livestock accounts for 18% of anthropogenic GHG emissions. Most of carbon dioxide (CO_2) is derived from changes in land use, mainly deforestation (Steinfeld et al., 2006).

Climate changes lead to impacts, which are frequently related to water as the melting of glaciers, heavier floods, rising sea levels, and more intensive droughts that could result in a decline in crop yields, leading to an increase in mortality rates due to malnutrition. Mortality rates may also rise due to heat stress and the probable widespread dissemination of diseases, such as malaria and dengue (STERN..., 2006).

Photosynthesis rates increase proportionally to CO_2 levels, but as the temperature rises, respiration also does, which slows growth and harms trees. If trees die, they release CO_2. The heat reduces the amounts of water in the vegetables, favoring forest fires, a source of CO_2 emissions (Tudge, 2004). Plants and soils store nearly 25% of all global C, and the great majority of this can be found in agricultural lands. Soil degradation has become one of the major sources of C emissions (Albrecht & Kandji, 2003). The C soil influences agricultural yields, the restoration of ecosystems, and the cycle of nutrients and water. The planet's potential capability of reducing C soil through desertification control and the restoration of all deteriorated lands is, respectively, from 0.9 to 1.9 and 3.0 Pg (Pg=10^{15} g or one billion ton) annually (Lal, 2001).

2.2.3. Soil degradation

Globally, around 1.35 billion ha of the most fertile soils are already under cultivation, and ten million ha of these lands are abandoned yearly due to degradation (Wackernagel et al., 1999), resulting in the abandoning of nearly one third of all global agricultural lands over the past 40 years (Wood et al., 2006). People migrate from degraded areas in an attempt to meet the increase in food demand. However, without adequate care for soil conservation, this process will recur (Barbier, 2000). The attempt to compensate deteriorated land through the increased use of fertilizers, irrigation, and disease control brings a rise in production costs (Tilman et al., 2002).

2.2.4. Impacts on hydric resources and on biodiversity

Livestock consume around 8% of all human water use, mainly for the irrigation, compromises biodiversity as well as water quantity and quality through deforestation, soil degradation, animal waste pollution from antibiotics, hormones, pesticides, and fertilizers, resulting in eutrophication, human diseases and increased resistance to antibiotics (Steinfeld et al., 2006). It is estimated that nearly 400 million people die annually due to water related illnesses (Bennett, 2000). Water demand increases 2.5 times faster than population growth, due mainly to economic and urban expansion (Bennett, 2000). The production of one kilogram of beef pork and poultry consumes approximately 43,000, 6,000, and 3,500L, respectively (Pimentel et al., 2004).

Around 75% of available fresh water is used for irrigation. However, from 10% to 15% of global agricultural lands are degraded due to salinity and water-logging (Bennett, 2000). Furthermore, irrigated plants do not use 85% of the water that is made available through irrigation. In contrast, the population worldwide that suffers from hydric stress, a situation in which the annual fresh water supply available per person is less than 2,000m^3, tends to increase from 7% to 70% by 2050 (Sanchez, 2000).

3. FOOD PRODUCTION SYSTEMS

As anthropogenic activities, including agriculture, have resulted in deforestation, desertification, soil degradation, decrease in drinking and irrigation water supplies, the extinction of species, global warming, and the hole in the ozone layer, it therefore becomes necessary to rethink some current technical concepts (Paris & Paris, 1996).

3.1. Food production systems based on the principles of the Green Revolution

In the tropics, there is a continuous large-scale degradation of the natural resources used in agriculture, such as soil fertility. Although food production has tripled since the 1970's, the productivity of crops implemented by means of the techniques developed during the Green Revolution has begun to decline. The areas which are most favorable to agricultural production have become rarer and the marginal lands have begun to receive more attention (Sanchez, 2000).

Singh (2000) reports some consequences of the Green Revolution in India. The improved seeds are responsive to the intensive use of inputs, implying an increase in food production. However, the first evidence of environmental degradation was perceived approximately 20 years after the implementation of this technological package, consisting mainly of soil (compacting, erosion, desertification, soil salinity, and waterlogging), vegetation (deforestation), and impacts on water resources and biodiversity. Agricultural productivity has become progressively more dependent on inputs. Despite the increase in fertilizer use, amounts of soil nutrients have declined. The reduction of efficient nutrient use, chemical and physical soil degradation, and the inefficient use of water limits agricultural productivity.

In 2005, the Brazilian consumption of nitrogen (N) fertilizers was of 2,201,000 tons (Agricultura..., 2005), which is still lower than that registered by China and the United States. However, the increasing use of these fertilizers in farming has been considered the key element responsible for the increasing N_2O emissions levels in Brazil, 0.25% yearly. In 1994, N_2O emissions from synthetic fertilizers were estimated at 20.76 Gg, 17% of the total agricultural soil emissions, 125.72 Gg of N_2O. The leached or drained N also participated significantly as it was responsible for 80% of indirect emissions and 22% of total emissions (Lima et al., 2006).

3.2. The search for sustainability

To reach sustainability, it is necessary to measure where we are at the moment and where we need to go. A country's carrying capacity, may in fact be greater than a peoples' demand for goods and services, depending on the total area of the country, the number of inhabitants, the level of consumption, technologies used, and productivity achieved. This occurs in the majority of industrialized nations, which in turn leads to the appropriation of other overseas areas (Wackernagel et al., 1999). For instance, the amount of grain demanded by European animal production requires an area seven times that of Western Europe, especially in developing countries (Matos, 2001).

Sustainable systems are those that optimize the use of goods and services acquired from nature without damaging the environment. Their essential principles include: integrating natural processes, such as nutrient cycling, biological N fixation, and natural enemy regeneration; minimizing the use of non-renewable inputs that damage the environment, the rural producer, and the consumer; taking advantage of the farmers' knowledge so as not to replace this human capital with high cost inputs; and exploring the work team's capacity to solve common problems. These principles aim to reconcile the production of foods and other supplies through the contribution of public goods, such as clean water, preservation of biodiversity, carbon (C) sinking, and protection against floods. Nevertheless, the financial transitions for these systems demand time and resources to develop or to adapt technologies, to surpass the effective standards, as well as to reconstruct social and natural capital (Pretty et al., 2003). This study analyzed 208 projects in 52 developing countries and concluded that increments in food production can occur through practices and technologies, such as the reduction or interruption of pesticide use as well as a more efficient use of soil and water.

The area of pastures corresponds to 26% of the Earth's surface not covered by ice. If this value is added to the crop area, considering the grain production intended for animal consumption, then 70% of arable lands worldwide are intended for livestock. Extensive grazing still occupies and deteriorates vast areas of land. However, due to the reduction in the availability of land, water, and other natural resources, a tendency toward intensification and industrialization, increasing even inputs such as residues, has become evident. Often, the small producers, due to a low availability of resources, cannot keep up with the changes and are consequently excluded (Steinfeld et al., 2006).

The production of ruminants tends to increase individual and area production. From 1970 to 1995, most of this production was carried out in 16.7% of the areas intended for pasture. Over the past three decades, the production of meat and milk from ruminants increased by nearly 40%, while areas intended for pasture increased by 4%. This occurred mainly due to a rise in production in mixed and landless systems, where an increase of nearly 80% and 94% in meat and milk, respectively, could be observed. It is estimated that by 2030, the global demand for pastures will have increased by 33%, which would be made possible through a mixture of grass and legumes, an increase in fertilizer use, and a better management of pastures (Bouwman et al., 2005).

Some researchers believe that alternatives for conservation are feasible only in lesser scale and that rural areas must become even more productive, in turn reducing the pressure on natural habitats (Nicholson et al., 2001). However, around 50% of cultivatable lands are already being used intensively. If the current agricultural techniques continue to be used to double food production, the phosphorus (P) and N residues are predicted to triple (Tilman et al., 2002). Some limitations compromise the increase in agricultural production, such as the reduction of water supply for irrigation, the decreasing efficiency and availability of fertilizers, a reduction in land availability, as well as social instability (Paris & Paris, 1996).

In the current context, mainly due to climate changes, there is a constant search for solutions to adapt to changes, such as the development of technologies to make it possible to coexist with a paucity of water, as well as alternatives for environmental mitigation, such as an increase in C stocks in agricultural systems and the improved use of N fertilizers and water (Sanchez, 2000). Thus, the focus should be in low input systems, which minimize soil and plant disturbances, emphasize perennial vegetation, and possess a greater potential to store C and N (Dixon, 1995).

Organic farms, which generally focus more directly on sustainability, try to reduce environmental impacts caused by common agricultural practices. Under the conditions of hydric stress in Australia, for example, the amount of water used is six times less than that on conventional farms. On the other hand, the direct use of energy, in fuel form, is approximately 20% greater on organic farms as it demands a greater number of machines in operation since it has forbidden the use of synthetic herbicides and fertilizers. However, indirect energy expenses, such as agrochemical use, is considerably lesser on organic farms, representing only 63.8% of that spent on conventional farms. The impacts generated by each production system depend on what is produced. The impact generated by sheep farming is 20% lower on organic farms, whereas beef cattle farming caused a 15% greater impact on organic farms due to extensive grazing (Wood et al., 2006). On organic farms, there is less impact per area, for example, the emission of GHG per ha can vary from 42% to 102% when compared to conventional farms. However, if the index used considers the amount of GHG emitted per ton of pasteurized milk, the percentage in relation to the traditional properties would vary between 91% and 104% (Halberg et al., 2005).

3.3. Agroforestry systems

Agroforestry systems (AS) are land use systems and practices where wood perennials, such as trees and shrubs, are associated with agricultural crops and/or animals (Sinclair, 1999). The SPS is one of the AS type (Nair, 1985). Considering the impacts caused by the Green Revolution, the AS have been studied due to the fact that the trees pump nutrients and water from the greatest depths to the surface and facilitate the regeneration of natural resources, such as the fertility of the soil, to maintain agricultural productivity (Singh, 2000). These systems aimed at increasing crop production, conserving the soil, and becoming a source of wood, fruits, and fodder plants, have been used for at least 1,300 years (Sanchez, 1995).

3.3.1. Productive aspects of the SPS

Trees are considered competitors to pastures as they compromise forage production, which can occur depending on climate, tree species, and forage. However, these interactions can be positive, rendering the intensification of production possible.

The implementation of AS is highly recommended for deteriorated and low productive lands, in which the planting of trees could occur (Schroeder, 1994). Through polyculture systems and/or AS use, it becomes possible to reduce weeds, pests, and diseases and to optimize the use of water, light, and nutrients (Altieri, 1999). In Africa, the introduction of trees has minimized the erosion effects, which served as windbreaks, and, on a greater scale, has acted as a deterrent against desertification (Barbier, 2000).

Lands which have been cleared of trees commonly lead to a short term increase in forage production, possibly due to the higher luminosity and lesser competition for nutrients and water. Nevertheless, after some years, a reduction in productivity occurred, which may well be attributed to a higher nutrient loss and an interruption in N and P cycling and the water cycle. Thus, it was proven that the initial gains were not sustainable (Sangha et al., 2005).

If phosphorus P consumption remains at the same levels reached after World War II, it is estimated that its reserves will be depleted by 2050. Therefore, as it is a limited resource, its use must be optimized. In pH soil below 5.5, most P is linked to Iron (Fe) and Aluminum (Al) composts and is unavailable to plants (Fearnside, 2003). Cardoso et al. (2005) concluded that AS can influence the P dynamics through the conversion of inorganic P into organic P. This conversion was attributed to the organic matter added by the trees, which favor soil microorganisms. These microorganisms play an essential role in P transformation and redistribution into different organic and inorganic forms and protect the immobilized P against adsorption through the gradual release of it via microbial turnover.

In the context of climatic change, animal production is also affected by the increasing number of days in direct contact with heat stress, thus making some adaptations necessary, such as shade provided by trees (Campbell & Smith, 2000) or, in the absence of trees, by means of artificial shade. Climatic elements, such as relative humidity, wind, and temperature, can compromise animal productivity, which is more intensely affected by the higher production potential of animals (Martello et al., 2004). In Nicaragua, Betancourt et al. (2001) found that access to pastures with better tree cover reduced the heat stress of cows ($P<0.05$). The improvement of the microclimate implied an increase in grazing time ($P<0.0001$) and milk production ($P<0.05$). The highest productivity was also attributed to the intake of fruits and tree foliage.

Due to an increase in CO_2 levels, it is estimated that a reduction in precipitation and supra-optimal temperatures can compromise the development of forages, mainly of C_3. In the absence of a significant change in vegetal composition, the forage quality tends to decline in systems in which feed conversion efficiency is limited by protein, which occurs mainly in tropical areas. Supplementation practice, although costly or even impractical, can suppress the effect of forage quality reduction. However, this demand can even further marginalize some regions (Campbell & Smith, 2000).

Shades, including artificial ones, so long as they are at appropriate levels, present increased forage N levels (Ludwig et al., 2004). Generally, the tree canopy cover reduces fluctuations in light transmissions, air temperatures, and photosynthetically active radiation. Therefore, forage under the interference of trees presents lesser seasonal variation, both quantitatively and qualitatively, regarding the forage in open areas (Silva-Pando et al., 2002).

3.3.2. Environmental services of silvopastoral systems

In addition to providing products that have a high market value and interest to the agricultural producer directly, such as food and tree products (fruits, medicinal products, and wood), the AS also develop functions that, although essential, do not directly benefit the land owner as they have yet to receive a precise commercial value (Izac & Sanchez, 2001), such as environmental services including the improvement of water quality and quantity, soil conservation, C storage, and the preservation of biodiversity (Shrestha & Alavalapati, 2004). In tropical areas, it is estimated that one ha of AS can provide the amount of goods and services needed to compensate 5 to 20 ha of deforestation (Dixon, 1995). It is estimated that the global value of 17 environmental services provided by 16 biomes, as well as the worth of natural capital in these biomes, is equivalent to US$33 trillion per year. This amount is nearly double that of the world‘s GDP (US$18 trillion per year) and 250 times greater than the food production from croplands (approximately US$0.13 trillion per year) (Izac & Sanchez, 2001).

3.3.2.1. Influence on hydric resources and biodiversity

Power and potable water companies rely on continuous water flow in both quality (without contaminants and sediments) and quantity. Studies carried out on Guatemalan hydroelectric plants proved that the use of land in the surrounding regions of hydrographic basins influences this flow. In the Aguacapa Dam, around 30.000 m^3 of sediment are removed annually, rendering a maintenance cost of US$76,575.00, while in the Los Esclavos Dam the cost was of US$502,570.00. In the latter, maintenance services spend 22 days per year, at which time the generation of electricity is interrupted and revenues are lost. In the Aguacapa Dam, the AS represented the land use which generated the least amount of sediments, 11,753 tons ha^{-1}year^{-1}, whereas conventional agriculture generated the most sediment, 379,133 tons ha^{-1}year^{-1}. In the other river basin, a similar situation occurred: the AS and conventional agriculture generated 2,937 and 28,175 tons ha^{-1}year^{-1}, respectively. In addition to the erosion control, tree coverage favored water infiltration, that is, 68.92% of the water that reaches the soil occupied by forests actually infiltrates the soil. In contrast, the same values for pastures and the soil without tree covering reached only 24.75% and 6.33%, respectively (Robledo, 2003).

Cattle farms can represent a source of P loading, which causes the eutrophication of watersheds. Conversely, SPS can contribute to the improvement of water quality since grass and trees, forming 20-30 m wide riparian buffer strips, control up to 77% of P and 80% of N runoff (Shrestha & Alavalapati, 2004). Trees in pastures also serve as shelter for a great variety of bird species (Nicholson et al., 2001). Furthermore, in shaded areas, there is an increase of earthworms and arthropod populations, which favor the reduction of soil density and an increase in soil macroporosity (Rhoades, 1997).

3.3.2.2. Influence on carbon sinking

The purpose of AS is to generate sustainable food production. The C storage is a positive consequence of an increase in photosynthetic rates due to the planting of trees (Schroeder, 1994) and a lesser demand for logging previously driven by the demand for wood. The deforestation of a primary forest will emit more C than the amount stored by planted forests over a 25-year period. Thus, the preservation of these native forests must be a priority in reducing C emissions in tropical regions (Montagnini & Nair, 2004), given that low levels of stored C and low productivity can be found in deteriorated lands (Sanchez, 2000). The increase in agricultural productivity can in fact reduce GHG, which can occur by means of practices, such as direct cultivation and AS establishment, which can store more than 1.3 tons ha^{-1}year^{-1} of C (Steinfeld et al., 2006).

However, soil C storage is a finite process, and this amount could possibly be stored within the next 50 years. The AS potential in storing C is well recognized, but there are some restrictions, including future changes on climate issues, the use of land and soil, the behavior of trees in dry climates and poor soils, pests, and diseases. Moreover, to determine the net benefits of AS regarding climate change, it is necessary to improve methods for estimating C stocks and to include other gases, such as N_2O and CH_4, in the analysis (Albrecht & Kandji, 2003).

The soil microorganisms are the main CH_4 deposits. The rumen CH_4 production is inversely related to diet digestibility (Nicholson et al., 2001). Nonetheless, there is no scientific consensus in relation to the digestibility and palatability of shaded forages. Jansen et al. (1997) reported that shaded *B.brizantha* produced a greater proportion of stems and, consequently, a lower digestibility related to grass in open areas. In contrast, Carvalho et al. (2002) found a higher *in vitro* dry matter digestibility (IVDMD) in shaded forage (59.01) when compared to forage with no influence from trees (52.73).

The GHG balance varies among AS modalities. Agrosilviculture systems (trees and crops and/or animals) can store C while ruminants and rice plantations are CH_4 sources. The soil under an SPS can become compact and susceptible to erosion if wrongly managed, and the systems can emit GHG into the atmosphere (Dixon, 1995).

3.3.3. Economic aspects and limitations of SPS

In Belize, SPS provided greater financial benefits than did traditional systems. The cost/benefit curve and the net present value were, respectively, 6% and 44% higher for the SPS, although the operational costs were also 43.6% greater. Other SPS benefits included wood production, biological fixation of N, C storage, increase in income, and risk of reduction due to a diversification of activities. The main constraints for the adoption for SPS were capital risk and market uncertainties (Alonzo et al., 2001).

In the SPS, the potential of cattle production outweighs unimproved pastures. Despite the AS benefits, establishment costs represent a limiting factor against its implementation (Jansen et al., 1997), which can vary from US$500 to US$3,000 ha^{-1}. This cost for non-degraded areas is less than US$1,000 ha^{-1} (Dixon, 1995), whereas the establishment cost through natural regeneration tends to be considerably lower.

In the long term, planted forests, as compared to pastures, tend to provide a better economic return.

Nevertheless, the integration of these activities, through SPS, economically optimizes this financial aspect in the short and long term (Kallenbach et al., 2006), considering that the exploration of other economic activities during a tree's growth, especially in the first years following its planting. Consequently, the C stored through AS presents an opportunity cost of 8%-16% less than that through planted forests (Shively et al., 2004). The increase of C soil through AS can vary in cost from US$1.00 to US$69.00 per ton, an average of US$13.00, which is lower than other forms of storage, such as alternative fossil fuel combustion technology (Dixon, 1995).

SPS success depends on shade tolerant forages, management practices that make the productivity and persistence under trees possible (Castro et al., 2001), technical knowledge, and the availability of manpower. Nonetheless, the SPS represent a versatile technology which is able to adapt to a variety of situations (Schroeder, 1994). Despite the expectations of AS becoming a development tool, it has received little attention and, consequently, its potential has only been superficially investigated. For this reason, it is necessary to improve this technology, especially under conditions of scarce resources and on small-scale properties (Nair, 1998).

4. PAYMENT FOR ENVIRONMENTAL SERVICES AND POLITICAL POLICIES

Environmental impacts caused by livestock often result from management errors influenced primarily by poverty, population growth, a lack of information regarding agroecosystem dynamics, urbanization, social inequality, as well as governmental and institutional weaknesses. In this manner, solutions geared only toward the direct degradation of lands by livestock are not enough to minimize the environmental impacts, rendering it necessary to implement policies that direct benefits to the low income rural population (Nicholson et al., 2001). The drafting of public policies, aimed at reducing rural poverty and soil degradation, demands a better understanding of how the current policies and public investments have been affecting soil management and landowner decision-making (Barbier, 2000). Nevertheless, due to the complexity of drafting a more appropriate and representative instrument, regulations and controls, which are often difficult to enforce, have been preferred (Paris and Paris, 1996).

Landowners commonly misunderstand that environmental policies many times result in inconveniences, such as changes in current agricultural practices, increases in production costs, and reductions in land productivity (Shrestha & Alavalapati, 2004). Therefore, to draft effective public policies, it becomes necessary to identify relevant constraints and create mechanisms that stimulate the adoption of these systems (Sanchez, 1995). Other commercial land uses which could be compatible with the SPS include sustainable forest management, the creation of hunting centers, and investment in ecotourism (Shrestha & Alavalapati, 2004).

Some measures should be taken, such as the elimination of environmentally damaging subsidies, to include environmental externalities in the prices. In addition, in some cases, direct incentives are necessary to cover payments for environmental services, such as C sinking as well as the conservation of soil, biodiversity, and water sources (Steinfeld et al., 2006). As many farming activities are vulnerable to economic crises and provide reduced profit margins, an adequate mechanism aimed at instituting payments for C storage, even if modest, would promote changes in land use (Jong et al., 2000). As the concept of C credits becomes more common, many organizations and countries will search for C sinking alternatives (Montagnini & Nair, 2004).

The Kyoto protocol was instituted to reduce global GHG emissions to 5% or more below 1990 levels by 2012. Through the Clean Developing Mechanism (CDM), a country that exceeds its emissions quota can buy C offsets from another country that has reduced its GHG emissions. Afforestation and reforestation are accepted forms of land use recognized as a CDM, which could in turn inspire the planting of trees in developing countries (Montagnini & Nair, 2004). If the C sinking was paid off and national policies encouraged this practice, it is estimated that 10.5 million ha of AS could be implanted annually. This estimate is based on the annual figures which show that 20% of the 15 million ha are deforested annually (3 million ha) and that 3% of the 250 million degraded ha are located next to forests (7.5 million) (Sanchez, 2000).

Much of the risk related to climate changes can be reduced by implementing a strong mitigation policy. The annual costs needed to stabilize the concentration of GHG in the atmosphere at 500-550 ppm CO_2 are estimated to be approximately 1% of the annual global

GDP, while damages caused by the impacts are estimated to be 5% of the annual global GDP (STERN…, 2006).

Concerning water issues, public policies, including charging for use and accounting for externalities, are necessary to reduce pollution and waste (Steinfeld et al., 2006). Water conservation effects can be primarily seen at a local level, while issues such as the conservation of biodiversity and carbon storage can be witnessed on a global scale. Thus, there is an overall interest in the internalization of both positive and negative externalities. This would imply the need to determine a monetary value for environmental consequences of farming activities (Sanchez, 1995).

To put the ideas of natural resources preservation into practice, it is required an unification among ecologists, economists, statisticians, businessmen, landowners, and public policy-makers. This partnership could put scientific knowledge through public policy into effect. The World Agroforestry Center, based in Nairobi, Kenya, has been bringing together conservation groups, landowners, development agencies, and researchers to develop a model that rewards communities for the environmental services it provides (BRIDGING…, 2005).

The World Bank, unaware of this reality, has been financially supporting pilot projects for rural producers regarding environmental services in Costa Rica, Nicaragua, and Colombia. In this project, as a strategy to avoid perverse incentives, the existing environmental services are recognized and the landowners are financially encouraged to adopt SPS practices. All land use is indexed, and the beneficial changes in practices are rewarded. For example: the biodiversity and carbon index of one ha of improved pasture without trees are 0.1 and 0.4, respectively. The sum of these two indices is 0.5. If this pasture’s tree density was greater than 30 per ha, the index values would be, in the same order as above, 0.6, 0.7, and 1.3. The difference between the initial value (0.5) and the other land use (1.3) is 0.8. For each point, the producer receives US$75.00. Thus, in this case, the amount to be paid is US$60.00 (US$75.00 x 0.8). The average payment during the experimental period was US$112.30 per ha per year, which was enough to cover half of the investments (Gobbi and Casasola, 2001).

4.1. Environmental service indicators

Some assessment tools, aimed at quantifying the environmental impact caused by livestock, have been developed. These indicators are useful in the benchmarking process, where farmers improve their practices by learning from colleagues who use natural resources more efficiently. This includes assessed data, such as the amount of inputs and/or potential losses of, for example, nutrients, unrenewed energy sources, water, agrochemicals, and GHG. Farming management is also assessed as regards the use of direct cultivation, water quality, and the conservation of biodiversity. In the case of local or regional environmental impacts, indicators based on farming areas, such as GHG emission per ha, should be used. If dealing on a global scale, it is recommended that the environmental indicators be expressed in product units, as, for example, an excess of N and P per kilogram of meat produced (Halberg et al., 2005).

In Austria, landowners are encouraged to adopt practices such as polycultures, crop rotation, tree maintenance, and the reduced use of fertilizers and pesticides. Another tool, very popular in the United Kingdom, is the comparison between the current situation and that recommended. It could be estimated, for example, that the environmental impact was due to nitrate leaching caused by N fertilizer use. After the estimations, projections are made simulating the adoption of recommendations. In the Netherlands, agricultural producers are obliged to report their nutrient input and output. The difference between the former and the latter, called surplus, is presumed to be lost to the environment. If this surplus is above environmentally safe standards, the farmer is taxed for each kg of nutrient exceeding the limit. This last indicator is more appropriate than the previous indicators as it includes an efficient use of resources and, consequently, the environmental impacts generated (Halberg et al., 2005).

5. CONCLUSION

SPS can play a significant role in reaching economic, social, and environmental sustainability. Nevertheless, public policies that stimulate their adoption are still needed as many environmental services have yet to be valuated.

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