Silvopastoral Systems as a Strategy for Diversification and Productivity Enhancement from Livestock in the Tropics

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Summary

Silvopastoral systems present important opportunities for increasing food production from animals. This is justified by the widening gap between production and consumer requirements, and the inability of domestic supplies to meet the projected demand up to year 2020 for foods of animal origin. Increasing productivity from animals thus necessitates the development of all possible avenues of food production. In South East Asia alone, this concerns potential use for animal production of an estimated 210 million hectares of land under permanent tree crops and forests. The livestock-tree-soil interactions include animal draught power for land cultivation, effects of dung and urine on soil fertility and crop growth, conversion of crop residues and agro-industrial by-products to useful animal products, use of native vegetation and reduced cost of weed control, the beneficial effects of shade from trees on animal performance. Case studies are presented from Asia, Latin America and Africa which clearly demonstrate positive economic and ecological impacts. Areas for future research and development include characterization of livestock-based silvopastoral systems in target agro-ecological zones, compatibility and complementarity of different livestock – tree systems. Appropriate choice of livestock species, production systems and optimum age of trees for integration with livestock, effects of dung and urine on soil fertility and crop yields, efficient use of crop residues and agro-industrial by-products \textit{in situ} and assessment of the nature, extent and implications of the interactions. Attention to these areas, together with increased resource use and institutional support, can lead to improved efficiency in the management of natural resources and increased productivity from the land.

Key words: Tree crops, livestock, Southeast Asia, Africa, Americas

Introduction

Efficiency in the management and use of natural resources has become a particularly challenging task because of two main reasons. Firstly, there is the need to ensure that systems of production are compatible with sustainable agriculture. This reason is especially critical since, secondly, there is this overwhelming disparity between available supplies and projected human requirements for food of animal origin. Assessments of requirements and available supplies indicate rapid worldwide increases in consumption and production of livestock products. Projected demands of meat and milk production are expected to grow at rates of 2.8 and 3.2% annually up to year 2020 (Delgado \textit{et al}., 1999) which will put enormous pressure on natural resource management (NRM).
These projections emphasize enormous opportunities for the owners and producers of livestock. In these circumstances, it is important to pursue all avenues that can promote productivity enhancement from livestock through all available avenues of food production. The multifunctional role of livestock in farming systems is particularly for poor farmers (Devendra and Chantalakhana, 2002). These approaches must necessarily ensure, however, that increased productivity, improved livelihoods and the alleviation of poverty are consistent with the sustainable use of the natural resources and environmental protection.

This paper focuses on the relevance of silvopastoral systems as a strategy to diversify NRM, and focuses on the nature, extent and implications of livestock-tree interactions. This is further highlighted by case studies that demonstrate clear benefits in the developing tropical countries. It alludes to research and development opportunities that can provide better understanding of crop-animal-soil interactions that are associated with economic and environmental impacts and productivity enhancement.

**Silvopastoral systems as a strategy for diversification**

It is important to be clear about the definitions of silvopastoralism and agroforestry. While the two are interrelated, their scope and application is considerably different. Silvopastoralism refers to integrated systems involving agroforestry options with livestock. Agroforestry refers to the use of trees in farming systems in which these are integrated with annual crops, livestock and fish. The International Centre for Research on Agro-forestry (ICRAF) defines agroforestry as "a collective name for land use systems and technologies where woody perennials are deliberately used on the same land management unit as agricultural crops and/or animals, either in some form of spatial arrangement or temporal sequence. In agroforestry systems, there are both ecological and economic interactions between components". Agroforestry can thus be viewed more as an intervention, whereas silvopastoral systems provide the link between trees and livestock as system components.

The diversity and uses of trees reflect the many benefits that are associated with developing silvopastoral systems. These include *inter alia* forage production, improved soil fertility with legumes, fuel wood supply, and fence line and erosion control. Trees in pastures also play an important role in the conservation of biodiversity (Harvey and Haber, 1999). The use of appropriate trees in silvopastoral systems thus provides an important strategy for diversification in NRM with three principal benefits: (i) Increased total farm productivity, (ii) increased income and improved nutritional status of farm households and (iii) demonstration of sustainable agriculture.

The rationale for diversification of silvopastoral systems is associated with complementarities in resource use, potentially involving the management and use of the natural resources (crops, animals, land and water) in which these sub-systems and their synergistic interactions have a significant positive and greater total effect than the sum of their individual effects (Edwards *et al.*, 1988). The management and use of the natural resources in a mutually reinforcing manner enables ecological and economic sustainability. This is mediated through various crop-animal-soil interactions, the nature and extent of which differ in different agro-ecological zones. The greatest challenge for silvopastoral systems is to identify improved and integrated management of natural resources that can enhance increased productivity in whole farm systems that are driven by market-oriented access.
Types of livestock-trees interactions

The benefits of crop-animal-soil interactions are many (Devendra and Thomas, 2002). The role of livestock in silvopastoral systems provides a means to intensify resource use with various types of livestock-tree interactions. The following interactions are common:

(i) Beneficial effects of shade and available feed on livestock
(ii) Draught animal power on land preparation and crop growth
(iii) Dung and urine to increase soil fertility and crop growth
(iv) Use of crop residues and agro-industrial by-products (AIBP) from trees in situ
(v) Use of native vegetation and effects on cost of weed control, crop management and crop growth
(vi) Type of animal production system (grazing, semi-intensive and stall-feeding or zero grazing) on tree crops, increased income and environmental integrity.

The interactions can be positive or negative, depending on the type of livestock and trees, age of trees, and management systems. Among ruminants, cattle and sheep are well suited to integration with tree crops such as coconuts and oil palm. Sheep are more suited for integration with rubber where light transmission and therefore biomass production are less. Goats are more selective in their feeding habits because they are browsers (Devendra, 1996) and are therefore more suited when both browse and forages are available in agroforestry systems. In Queensland, Australia, goats caused 75% mortality in a stand of *Sesbania sesban* trees by ringbarking the stems 10-15 cm above ground level (Kochpakdee, 1991). However, sheep, cattle and buffaloes can all damage trees, especially the bark of rubber. Cattle are unsuited to rubber plantations as they can disturb the latex collecting cups. To ensure compatibility between livestock and trees, the correct choice of species, control of grazing, and also the optimum age of trees when the leaf canopy is out of reach of the animal are important considerations.

The shade within agroforestry systems reduces temperature and also provides ameliorative environments compared to open sunlight (Ovalle and Avendamo 1988), and is conducive to good animal performance. The performance becomes more significant for *Bos taurus* livestock. Daly (1984) reported a 0.9% reduced calving rate for every 0.1°C increase above 30.0°C in the rectal-temperature of cows. Calving rate depressions in British breeds and Brahman crossbreds were 10% and 10-25% respectively. Stressed cows also gave birth to lighter calves. Milk production differences are also apparent, with Davison et al. (1988) reporting increased mean yields of 2 kg/cow compared to animals without shade, concurrent with a reduced rectal temperature of 39.4°C compared with 40.0°C for animals in open sunlight. In Latin America, decreased lamb mortality and better protection of sheared sheep have been recorded as benefits of grazing under *Pinus*. In the humid tropics of Costa Rica, dairy cows that had access to shade trees had higher production (> 15%) than cows that grazed pastures without trees (Souza et al., 1999).

Of the three main tree crops in south east Asia (coconuts, oil palm and rubber), coconuts offer a particularly unique opportunity for integration with cattle, goats or sheep, with attendant economic benefits mainly because of the light transmission and long life of
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The crop of approximately 70 years. The available native vegetation together with introduced grasses can then be grazed on a semi-permanent basis. Table 1 presents a summary of the responses by cattle. The variation in animal production was directly related to type of feed biomass available, soil fertility, fertilizer strategy and light transmission.

**Table 1.** Cattle production from grazing experiments under coconut (Shelton, 1991; Stür *et al*., 1994).

<table>
<thead>
<tr>
<th>Country (rainfall)</th>
<th>Pasture</th>
<th>Light transmission (%)</th>
<th>Liveweight gain (kg/ha/yr)</th>
<th>Avg. daily gain (kg/ha/day)</th>
<th>Stocking rate (cattle/ha)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indonesia (1700 mm/yr)</td>
<td>Improved</td>
<td>79</td>
<td>288-505</td>
<td>0.22-0.29</td>
<td>2.7-6.3</td>
<td>Rika <em>et al.</em> 1981</td>
</tr>
<tr>
<td>Philippines (&gt;2000 mm/yr)</td>
<td>Improved</td>
<td>n.a.</td>
<td>170-315</td>
<td>0.43-0.47</td>
<td>1-2</td>
<td>Moog <em>et al.</em> 1993</td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>n.a.</td>
<td>130-158</td>
<td>0.14-0.36</td>
<td>1-3</td>
<td>Deocareza and Diesta, 1993</td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>n.a. 137-306</td>
<td>0.20-0.37</td>
<td>1-3</td>
<td>Deocareza and Diesta, 1993</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Natural</td>
<td>n.a. 51</td>
<td>0.14</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>n.a.</td>
<td>91-146</td>
<td>0.20-0.25</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>Solomon Island (2900 mm/yr)</td>
<td>Natural</td>
<td>60</td>
<td>235-345</td>
<td>0.27-0.40</td>
<td>1.5-3.5</td>
<td>Watson and Whitman 1981</td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>60</td>
<td>227-348</td>
<td>0.27-0.40</td>
<td>1.5-3.5</td>
<td>Smith and Whitman 1985</td>
</tr>
<tr>
<td></td>
<td>Natural</td>
<td>62</td>
<td>219-332</td>
<td>0.26-0.40</td>
<td>1.5-3.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>62</td>
<td>206-309</td>
<td>0.23-0.35</td>
<td>1.5-3.5</td>
<td></td>
</tr>
<tr>
<td>Thailand (1600 mm/yr)</td>
<td>Natural</td>
<td>n.a.</td>
<td>44</td>
<td>0.12</td>
<td>1.0</td>
<td>Manidool 1984</td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>n.a.</td>
<td>94-142</td>
<td>0.16-0.26</td>
<td>1.0-2.5</td>
<td></td>
</tr>
<tr>
<td>Vanuatu (&gt;1500 mm/yr)</td>
<td>Improved</td>
<td>n.a.</td>
<td>175</td>
<td>0.32</td>
<td>1.5</td>
<td>Macfarlane and Shelton 1986</td>
</tr>
<tr>
<td></td>
<td>Natural</td>
<td>n.a.</td>
<td>250-285</td>
<td>0.26</td>
<td>2.6-3.0</td>
<td>Evans <em>et al.</em> 1992</td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>n.a.</td>
<td>550</td>
<td>0.50</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Western Samoa (2900- mm/yr)</td>
<td>Natural</td>
<td>50</td>
<td>148</td>
<td>0.22</td>
<td>1.8</td>
<td>Reynolds 1981</td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>50</td>
<td>225-306</td>
<td>0.33-0.47</td>
<td>1.8-2.2</td>
<td>Robinson 1981</td>
</tr>
<tr>
<td></td>
<td>Natural</td>
<td>70-84</td>
<td>127</td>
<td>0.14</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>70-84</td>
<td>273-396</td>
<td>0.30-0.43</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Natural</td>
<td>70-84</td>
<td>401-466</td>
<td>0.27-0.32</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improved</td>
<td>70-84</td>
<td>421-744</td>
<td>0.29-0.51</td>
<td>4.0</td>
<td></td>
</tr>
</tbody>
</table>
Draught animal power is a good example of the interaction between livestock and trees. Ploughing, harrowing, cultivation and haulage are key elements and are reflected throughout Asia. In South East Asia, for example, draught animal power from buffaloes and cattle in coconut and oil palm plantations is used for various farm operations, such as tillage and haulage by small farmers who cannot afford more expensive tractor power.

The relevance and implications of livestock-tree interactions, especially the benefits, are highlighted in the results of long-term case studies. These benefits relate to improved soil fertility, increased income and development of potentially important sustainable systems. Aside from these examples, other examples of the integration of trees and especially small ruminants, with complementary advantages, include goats or sheep under cashewnut, coca, citrus, mangoes, jackfruit, kapok, tamarind and teak in many parts of South and South East Asia and Africa. In parts of sub-tropical South China and also in Vietnam, a variation to ruminant-tree crop interactions in the presence of ponds under coconuts or fruit trees which further enable the integration of fish, vegetables, pigs and ducks. This diversification and effective use of the available natural resources presents a most important means to sustain the livelihoods of small farmers, as well as maximize farm productivity.

**Advances in research on tree crops and ruminants**

- There have been significant advances in the understanding of integrated systems with ruminants and tree crops. Between annual and perennial crops, more research has been undertaken in the latter systems. Several countries in South East Asia (Devendra et al., 1996) have been active in this regard, notably Indonesia, Malaysia and the Philippines. Attention is drawn to recent publications on small ruminants in tree crops (Iniquez and Sanchez, 1991; Sivaraj et al. 1993; and Mullen and Shelton, 1995) and the reviews of research over the past 20 years on integrated tree crop systems by Chen et al. (1996) and Reynolds (1995) for cattle in coconut plantations. A critical assessment of crop-animal systems and research priorities in South-East Asia, led to the conclusion that the integration of animals with tree crops was a priority research project (Devendra et al., 1997). The main areas in which research has been undertaken include characterization of environmental conditions within plantations.
- Measurements of forage availability and quality, as well as seasonality of production.
- Assessment of the availability of crop residues and AIBP, evaluation of nutritive value and use.
- Evaluation and selection of grasses and legumes for environmental adaptation and increased herbage production.
- Measurements of animal performance under different nutritional and management regimes.
- Measurements of soil compaction and tree damage resulting from the introduction of ruminants.
- Measurements of tree crop yields in integrated systems.
- Management of animals under tree crops.
- Analyses of the economic benefits of integrated systems.
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The first four areas are the most studied and inadequate efforts have been directed at the remaining five areas. Future research and development efforts must therefore give increased emphasis to these areas. Long term animal production data for the different ruminant species are limited, as are data on the effects of grazing management, and socio-economic analyses. These analyses are essential for presenting a convincing case for the wider adoption of the systems. The overall conclusion is that much more work is required in developing methodologies for the process of integrating ruminant species with tree crops, as well as studies on the nature (positive and negative), extent and impact of crop and animal interactions on environmental indicators.

Case studies

The following case studies demonstrate good examples of the benefits and impact of livestock-tree interactions in silvopastoral systems. In all cases the benefits were associated with economic and ecological impacts.

(1) Tree crop-ruminants systems (Malaysia, Philippines and Pacific islands)

The potential for these systems is reflected in the presence of an estimated area of about 210 million hectares in South East Asia (Alexandratos, 1995) under tree crops like coconuts, oil palm and rubber that could be used also for animal production. Grazing with cattle and goats with oil palm compared to no grazing resulted in average increased yields of 3.9 MT fresh fruit bunches/ha/yr. Considering the total land area under oil palm and the sale value of fresh fruit bunches per ton, the economic advantage is substantial (Devendra, 1991).

Increased 30% yield in oil palm plantations has also been reported by Chen and Chee (1993) due to grazing. These authors also reported 20-40% reduced weeding costs for cattle under oil palm, comparable to a saving of 16-35% using grazing sheep reported by Chee and Faiz (1991). Also in Malaysia, utilizing buffaloes to transport oil palm fruit bunches from the field to collecting centres increased the farmers’ income by as much as 30% (Liang and Rahman, 1985).

In the Philippines, introduction of improved grasses or grass-legume pastures and cattle into coconut plantations resulted in total incomes ranging from US$608-809 compared to US$510 from coconuts alone (Deocareza and Diesta, 1993). By comparison, the integration of goats and sheep with coconuts over three years increased the income of farmers by between US$127-229 (PCARRD, 1994).

Coconut plantations provide and important opportunity to integrate cattle. Reynolds (1988) has calculated that beef cattle production was an important source of secondary income in Western Samoa. Based on data of liveweight gain and copra production, the contribution of beef increased gross income from 21 to 41% for a farm with cattle on natural pastures, and from 42 to 71% with cattle an improved pastures. The farms without cattle suffered a reduction in gross farm income by 70%. Stür et al. (1994) have reviewed the available information on cattle production under coconuts, citing several examples in the Pacific Islands, and concluded that the level of production in such systems with adapted forages is comparable to that obtained in open systems.

In southern India, Das (1991) has reported from an evaluation of various coconut-based farming systems, that it is more profitable to integrate a number of subsidiary crops
and animals than to grow coconuts as a monocrop. In this same zone, studies by Chinnusamy et al. (1994) between 1988-1993 on a one-hectare model farm integrating crops (grain and fodder), silvopasture (trees and grass) and goat-rearing indicated that soil physical and chemical characteristics were all improved, along with the socio-economic conditions of the farmer. In Sri Lanka, the integration under coconuts of a pasture based on *Brachiaria miliformis*, *Pueraria phaseoloides* and *Gliricidia sepium* and *Leucaena leucocephala* resulted in increases of 17% and 11%, respectively, in nut and copra yields (Liyanage de Silva et al., 1993). The nutrients returned from 73 kg of fresh manure and the application of 30 litres urine/palm/year reduced the cost of fertilizing the coconuts by 69%.

The concept of sloping agriculture land technology (SALT) has been successfully developed in the Philippines on account of the presence of about 30 million hectares of uplands, of which 80% are considered slope lands. These land areas are relatively steeper and include slopes of up to 18°. SALT is essentially a type of crop-animal system integrating the management and use of natural resources, and involving the integration of leguminous hedgerows to reduce soil erosion, improve soil fertility and nutrients for the crops (e.g. maize and black pepper) grown between the hedgerows, and provision of quality fodder for goats in a zero grazing system. Among the forages tested, *Calliandra* spp., *Leucaena diversifolia*, *Gliricidia sepium*, *Erythrina poepiggiana*, and *Flemingia macrophylla* have been particularly promising. Implicit in this system is the objective of generating regular and adequate income.

Laquihon et al. (1997) have analysed the benefits of the system from 1991-1993, and concluded that the mean annual income was US$1354 per 0.5 ha. The mean internal rate of return was 38.7%. The mean annual income was 14 times higher than the mean annual income of US$120 per 0.5 ha in the Philippines (Villar, 1998).

(2) Crop-animal systems (Sri Lanka)

In the upland areas of the mid-country in Sri Lanka, crop production involves tree crops (coconuts and fruits), root crops and herbs in stratified layers. Animals are integrated into about 20% of these farms, mainly cattle for dairying, goat and poultry production. Economic performance for the period 1985-1992 for three sizes of farmer-managed farms (0.5, 10 and 2 acres) showed that dairying contributed to most of the total gross profits of 31, 63 and 69% for the three types of farms, respectively. Among the animals, dairy cattle and goats gave the greatest income returns. Animals also significantly contributed to the improvement of soil fertility through, manure and biogas production to replace domestic fuel needs (De Jong et al., 1994).

(3) Alley farming and livestock production (Africa)

In many parts of Africa, uncertain weather conditions, especially low rainfall and other calamities impose much risk to farming systems. Strategies to overcome this risk are therefore essential, and one option that most farmers resort to is livestock keeping. Alley farming systems that use food or forage crops between hedges of multipurpose trees such as *Leucaena* and *Gliricidia* for mulch and/or forage provides an alternative, and has been successfully developed in Nigeria and is increasingly becoming important. It is a technology that improves soil fertility, improves crop yields and animal feed shortages as well as provides fuel for the household.
A recent review of the role of alley farming in African livestock production (Reynolds and Jabbar, 1994), gave the following highlights:

- Maize, the most important single food crop in Africa, gave linear response yields according to the level of *Leucaena* or *Gliricidia* applied, and up to 40% increases were recorded when all the tree prunings were returned as mulch.
- Supplementation with *Leucaena* or *Gliricidia* increased the productivity (kg weaned/dam/year) of both West African Djallonke sheep and West African Dwarf goats.
- *Leucaena* forage supplementation gave increased milk production in early lactation especially in the dry season when the basal roughage diet is of poor quality.

Economic analysis of livestock production showed that continuous alley farming was more profitable than alley farming with fallow, or conventional no-tree farming, even when the cost of clearing trees at the end of their useful life was included (Table 2).

**Table 2.** Gross margins from three alternative farming systems in Southwest Nigeria (Naira/ha/year) over a 9-year period (Reynolds and Jabbar, 1994)

<table>
<thead>
<tr>
<th></th>
<th>Traditional farming</th>
<th>Alley farming with fallow</th>
<th>Continuous alley farming</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropping only</td>
<td>16,325</td>
<td>16,324</td>
<td>21,255</td>
</tr>
<tr>
<td>Cropping allowing for soil nutrient loss</td>
<td>16,176</td>
<td>16,204</td>
<td>21,070</td>
</tr>
<tr>
<td>Crops and livestock</td>
<td>16,176</td>
<td>18,794</td>
<td>23,749</td>
</tr>
<tr>
<td>Crops and livestock with terminal tree clearing costs</td>
<td>16,074</td>
<td>18,489</td>
<td>23,444</td>
</tr>
</tbody>
</table>

US$ = 25 Naira in 1998

Grazing cattle under coconuts and cashewnuts is common along the coastal areas of Tanzania and Kenya, as also in parts of West Africa, where there are permanent tree crops such as oil palm and rubber. In all these situations ruminants are variously grazed with a view of utilizing to advantage the available native vegetation, mainly grasses and browse plants

**Latin America**

Useful studies have been undertaken on the integration of ruminants with especially timber trees in Latin America where silvopastoral systems are becoming increasingly important. In humid Central America, there are two good examples of livestock-based agroforestry systems. In Costa Rica, Somarriba and Lega (1991) have described a system involving *Pinus caribaea* for pulp and *Panicum maximum* as the main grass. Grazing of the understorey began when the trees were 8.5 years old. The maximum stocking rate estimated for the system was 0.9 AU/ha with a liveweight gain of 450 g/hd/day. The use of livestock in the system allowed extra income to the farmer and reduced cost of weeding and risk of fire. Another example of a livestock-based agroforestry in Turrialba, Costa Rica
involves the association of *Axonopus compressus* with naturally regenerated trees of *Psidium guayaba*. The trees provide fuelwood and fruits for livestock. The livestock also helped to distribute the seed of the fruit in the pasture (Somarriba, 1985).

**Traditional silvopastoral systems in Latin America**

Most livestock farms in Central and Latin America include some silvopastoral systems that contribute partially to their economic and biotic sustainability but the densities and configuration of trees depend on cattle production systems (Beer *et al.*, 2000; Souza *et al.*, 2000), Cajas and Sinclair (2001). Valuable timber species such as *Cedrella odorata* (cedar), *Cordia alliodora* (laurel), *Pithecellobium saman* and *Albizia* spp., which are retained at low tree densities (4 to 15 adult trees/ha), are common in tropical lowland pastures (Camargo *et al.*, 2000; Souza *et al.*, 2000). In the Caribbean region of Colombia, Cajas and Sinclair (2001) found that trees were present on between 26 and 69% of pastures in each farm, at densities varying from less than 3 to more than 50 trees/ha. Trees of large stature (e.g., *Tabebuia rosea*, *Albizia caribaea* and *Sterculia apelata*) provided shade and produced timber whereas the most important fodder trees were those of medium stature (e.g., *Albizia saman*, *Guazuma ulmifolia* and *Cassia grandis*). Recent studies in the seasonally dry pacific coast of Central America showed that the tree densities in pastures on small beef farms was higher than those of medium and large beef farms, indicating that small farmers are more inclined to diversify production to reduce risk such as negative changes in prices for meat and milk (Ibrahim *et al.*, in prep). Profitability of small Costa Rican dairy farms was increased, especially when labour cost increased, by diversification with high valued timber species such as laurel (2188 vs. 1478 US$ /farm/yr for farms with and without trees, respectively) (Holmann *et al.*, 1992).

In Central America, managing live fences is also common on livestock farms. Studies in the dry and sub-humid tropics showed that more than 70% of cattle farmers have live fences with multi-purpose and to some extent timber species. Some studies showed that cost for maintenance of living fences is lower than that of “dead” fences which requires more input for their maintenance. In Nicaragua a high percentage (> 60%) of farmers and rural poor obtain firewood by pruning trees along fence lines and in pastures (Ibrahim *et al.*, in prep).

In the forest margins of eastern Brazil, silvopastoral systems have been developed involving rubber, coconut palm, pine, mangoes and Brazil nut. These systems have been used in degraded pasture areas together with inter–row cultivation of grasses for grazing. Major limitations that have been encountered are lack of persistence of the grasses due to shading, overgrazing and weed invasion (Veiga and Serraro, 1990). Cashew and other valuable timber trees have also been used in the development of silvopastoral systems (Lascano and Pezo, 1994).

**Stall-feeding systems**

Associated with the integration of ruminants and trees in agroforestry systems is the concurrent development of stall-feeding systems involving both ruminants and non-ruminants. Throughout the developing countries, extensive grazing of ruminants on roadsides and common land is the main management system. The extent of grazing varies considerably, depending on type of agro-ecological environment (irrigated or rainfed,
humid/sub-humid or arid/semi-arid), intensity of land use, available feed resources and type of farming system. In the irrigated areas of the humid zones, intensity of land use does not enable much grazing, except during the fallow periods between-rice crops. However, crop residues are generally more plentiful in this same area. In the rainfed areas, feed shortages due to dry seasons are more severe, driving the animals to search for feed in extensive grazing systems. These grazing systems often reach forest margins and tree plantations where the native vegetative under-growth provides a source of feed. Since grazing is mainly uncontrolled, significant damage to the tree crops is common, depending on the severity of grazing as well as age of the trees.

With some tree crops such as coconuts, oil palm and rubber, there are often small areas of fodder banks for use by ruminants. These areas are often set aside by the large plantations for use by the labour force who own animals to get supplementary income. Occasionally, these also involve the use of multipurpose leguminous trees to supply quality fodder for animals.

Cut-and-carry systems have evolved within agroforestry systems due to a combination of intensity of land use, number of available animals, inadequate grazing areas, available crop residues and AIBP, inadequate time to graze animals and marketing opportunities. The significance of low feed quantity and quality in coconut areas and the development of stall feeding systems are reflected in a comparison of a cut-and-carry feedlot system, a semi-feedlot system and free grazing for beef cattle in Johore, Malaysia, where coffee was grown as an intercrop under coconuts. The studies revealed higher daily liveweight gains for stall-fed animals (Sukri and Dahlan, 1986). Feed rations consisted of coffee by-products (30%), palm kernel cake (37%), urea (2%) and mineral-vitamin premix (1%) and various native forage species (Paspalum, Axonopus, Ottochloa, Ischaemum and Brachiaria) for grazing.

**Beneficial impacts**

Table 3 presents a summary of beneficial impacts resulting from the application of the available technologies. There are both socio-economic and environmental benefits, but more importantly, these together contribute to the development of sustainable agriculture. Silvopastoral systems are unique in a sense that they contribute to increased farm productivity and at the same time to the conservation of natural resources. In Latin America presently, silvopastoral systems are being promoted to enhance livestock farms to generate environmental services such as carbon sequestration and conservation of biodiversity. CATIE is managing a silvopastoral project that involves payment for environmental services to livestock farmers in Colombia, Nicaragua and Costa Rica. These payments are based on land use changes. Higher payments are made for systems that contribute to higher increases in biodiversity and carbon sequestration compared to degraded pastures. An economic analysis conducted on livestock farms in the three countries showed that income generated from payment of environmental services varied between 10 to 15% of net farm income.
Table 3. Benefits of some technological options in crop-animal systems for demonstrable sustainable agriculture in Asia (Devendra, 1996)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Soil Conservation</th>
<th>Soil fertility</th>
<th>Increased animal performance</th>
<th>Increased crop yields</th>
<th>Increased food security</th>
<th>Increased income/stable households</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Supplementation</td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>2. Draught animal power</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>3. Legumes (feed, green manure, hedges and in rice bunds)</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td>+</td>
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<tr>
<td>4. Food-feed systems</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>5. Three strata forage system</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>6. Alley cropping</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>7. Sloping agriculture land technology (SALT)</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>8. Manure availability</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>9. Rice-fish integration</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>10. Ruminants-tree crop integration</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

The use of more intensive silvopastoral systems involving combinations of trees with improved pastures, together with the conversion of natural pastures to secondary forest resulted in highest income/ha compared to other land use systems (Table 4). Intensive silvopastoral systems are also associated with increased animal productivity that permits the liberation of fragile lands for reforestation programs. However, there is need to strike a balance between the area of farm under pastures and forest to optimize farm income. The management of intensive silvopastoral systems has a higher demand for labour than that of grass monoculture systems and the expansion of the area under silvopastoral systems offers a source of employment for rural poor which should enhance their livelihoods. Ruiz (2002) found that the number of labourers contracted on farms with intensive silvopastoral systems was higher than those with only forest systems (2500 vs 625).
Silvopastoral Systems as a Strategy for Diversification and Productivity Enhancement from Livestock in the Tropics

Table 4. The effect of different combinations of land use systems on farm income/ha in Nicaragua (farm size 123 ha)

<table>
<thead>
<tr>
<th>Land use option</th>
<th>Natural pastures+trees, %</th>
<th>Improved pastures-trees, %</th>
<th>Improved pastures+trees, %</th>
<th>Secondary forest, %</th>
<th>Income/ha, US</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>70</td>
<td>1060</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>50</td>
<td>1850</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>50</td>
<td>40</td>
<td>1500</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>10</td>
<td>50</td>
<td>30</td>
<td>1593</td>
</tr>
</tbody>
</table>

Areas for future research

The foregoing review and discussion of livestock-based agroforestry systems in general, and livestock-tree interactions in particular clearly suggest that research on holistic systems is generally weak. Associated with this is sparse information on livestock-tree interactions. The opportunities for research to redress this situation offer exciting possibilities for integrated natural resource management. The following research areas inter alia merit attention:

- Detailed characterization and systems analysis of individual environments that favour livestock-based agroforestry systems.
- Assessment of the nature and extent of livestock-tree-soil interactions both negative and positive, effects of integrating animals on trees and of trees on animal performance, as well as economic and environmental impacts.
- The effects of dung and urine on soil fertility, savings in the use of inorganic fertilizers and effects on crop yields, as well as nutrient recycling.
- The efficient use of available feed resources (grasses, crop residues and AIBP) in the development of more controlled and zero grazing systems.
- Development of sustainable livestock-based silvopastoral systems.

Conclusions

Silvopastoral systems are potentially very important, but have been inadequately developed. These systems present major opportunities for productivity enhancement, especially from livestock. The nature of livestock trees interactions are variable and the benefits of the more positive effects are inadequately understood. These areas justify more research and development emphasis in the future. Most of the research has been undertaken in South East Asia and Latin America with demonstration of successful benefits; however, much more information is necessary about the economic and environmental impacts of the interactions. Limited case studies indicate that with increased resource use and more focused research, silvopastoral systems provide an important opportunity to demonstrate efficiency in NRM and sustainable agriculture.
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Silvopastoral Systems as a Strategy for Diversification and Productivity Enhancement from Livestock in the Tropics


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