Ecological Interactions in Silvopastoral Systems: A Synthesis

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Abstract: With increasing interest in environmental quality and income diversification, tree-based systems such as silvopasture are receiving considerable attention as a new strategy for agroecosystem management. Properly managed silvopasture can provide many environmental benefits such as enhanced water quality and improve small-farm profitability by providing multiple income sources. However, "proper management" is an ambiguous term, since managing a silvopastoral system involves managing complex interactions involved among its tree, forage and animal components. Our knowledge about the competitive and complementary interactions that define silvopastoral system productivity and sustainability is rather limited. The objectives of this paper are to review the available literature on the complex interactions in silvopastoral systems around the world and identify research priorities. The limited literature on interactions indicates that research emphasis should be placed on this important topic so that appropriate management techniques can be developed.

Key words: Agroecosystem, silvopastoral system, farm profitability, herbivory, microclimate, forage quality.

The agroforestry system, known as silvopasture, is widely practiced, and yet only a few of its forms are documented in the literature and even fewer are known by the general public. Silvopasture is the combination of livestock-cattle, sheep, goats and other ruminants-with trees or other woody perennials and forages on the same unit of land. Silvopasture is thus a unique practice in that it aims to achieve both environmental benefits (soil enrichment, efficient nutrient cycling, carbon storage, provision of shelter, shade and food for livestock) and economic benefits (income generation, expansion and diversification, greater potential return on land investment) in an integrated fashion.

The silvopastoral systems practiced in various regions of the world offer a wealth of information on the various methods by which innovative landholders have attempted to realize these benefits. Silvopasture will thus take on many forms, depending on the objectives of the individual landholder. Unlike temperate-region practices, where silvopasture implies grazing systems, silvopastoral practices in the tropics tend to be more complex and site specific, and in fact are not easily separated from the larger agroforestry practices of which they may be a part. Thus, to describe silvopasture as an independent land-use feature separate from other agroforestry practices is a distinction that does not usually exist in reality in most tropical farm settings. Likewise, fodder systems - in which fodder (usually from fast-growing multipurpose woody perennials) is fed to nearby animals - is also a common practice in the tropics. Thus,
in a broader context, silvopasture involves both grazing systems and tree-fodder systems (Nair, 1993; Nair et al., 2005). As an association of woody and herbaceous plant communities with domesticated or semi-wild animals, silvopastoral systems are deliberately designed to optimize the use of spatial, temporal, and physical resources, by maximizing positive interactions (facilitation) and minimizing negative ones (competition) among the components (Jose et al., 2004). An understanding of the biophysical processes and mechanisms involved in the allocation of these resources is essential for the development of ecologically sound systems that are economically viable and socially acceptable (Ong et al., 1996; Rao et al., 1998). This review will focus on both the competitive and complementary interactions commonly reported in the silvopasture literature the world over.

**Competitive Interactions**

*Competition between trees and forage species*

Competition between trees and forage crops for resources such as light, water and nutrients is often reported in silvopastoral systems. An excellent review of this topic is given in Sharrow (1999). Aboveground competition for light is the most commonly studied of all the competitive vectors. Tree canopies are known to impact both the quality and quantity of light received beneath them. Since many of the warm season forage plants (C4 photosynthetic pathway) have their light saturation points at about 85% of the full sun, shading could negatively influence their yield. However, cool season forage plants (C3 photosynthetic pathway) reach light saturated photosynthesis at about 50% of the full sun. As a result, shading up to 50% may not negatively influence their growth and yield. In a comparative study of both cool season and warm season forage crops, Lin et al. (1999) examined the effects of light on forage yield. Thirty forages, including eight introduced cool-season grasses, four native warm-season grasses, one introduced warm-season grass, eight introduced cool-season legumes, five native warm-season legumes, and four introduced warm-season legumes, were grown in full sun, 50%, and 80% shade created by shade cloth over a greenhouse frame. Warm-season grasses displayed significant reductions in forage dry weight under shade regardless of growing season. All cool-season forages grown during spring-early summer showed a decrease in dry weight under shade; however, the reductions in dry weights of some of them such as Desmodium canescens and D. paniculatum were not significant under 50% shade. Cool-season grasses showed more shade tolerance when grown during the summer-fall than when grown during the spring-early summer. Seven of the selected cool-season grasses grown during the summer-fall did not display significant reductions under 50% shade as compared to full sun. Among the legumes harvested during the fall, the dry weights of both Desmodium species tested and hog peanut (Amphicarpaea bracteata L.) increased significantly under 50% and 80% shade. In addition, several other legumes such as ‘Cody’ alfalfa, white clover, slender lespedeza and ‘Kobe’ lespedeza showed no significant reductions in dry weight under 50% shade. Similar results of higher, similar
or lower yield (depending on the agroecology, species, shade tolerance and other factors) of forage species in silvopasture compared to open pasture have been reported in other studies as well (Samra et al., 1999; Guenni et al., 2005).

Belowground competition is most likely to occur when two or more species have developed a specialized root system that directs them to explore the same soil strata for growth resources (van Noordwijk et al., 1996). This can be problematic even in silvopastoral systems. Researchers in the temperate zone, humid tropics, and semi-arid tropics have reported observing the greatest concentration of tree root density within the top 30 cm of soil, the region predominantly explored by crop rooting systems (e.g., Itimu, 1997; Imo and Timmer, 2000; Jose et al., 2000). Although there could potentially be niche separation between roots of forage species and trees (Fig. 1), competition has often been reported, with resultant reductions in both tree and pasture growth.

During the early establishment phase of a silvopastoral system, forage crops may exert competition on tree seedlings for water and nutrients. Herbaceous vegetation, in general, has been observed to reduce tree survival and growth in a number of trials (Carter et al., 1984; Morris et al., 1993; Bendfeldt et al., 2001; Ramsey et al., 2003). Forage yield could also be reduced once trees are established. It is more likely to happen in arid and semi-arid regions compared to humid regions. When considering silvopastoral systems in the temperate zone, it is somewhat less intuitive as to which competitive vector will limit productivity. Recent research has shown, however, that competition for water does limit system productivity in this zone. For example, Lehmkuhler et al. (2003) reported significant reduction in height growth of black walnut (Juglans nigra) trees grown...
in silvopastoral systems compared to monoculture plantations in southwestern Missouri, USA. These authors implied that tree-grass interaction for soil resources (water and nitrogen) led to the observed decrease in tree growth.

_Herbivory and physical damage to plants_

Physical damage to trees during early years of silvopasture establishment is commonly reported in the literature. Lehmkuhler (2003) examined cattle damage to tree seedlings for four species _Juglans nigra, Gleditsia triacanthos, Quercus rubra_, and _Carya illinoensis_. Cattle damage to young trees was prominent during the two years for trees without protection. _Q. rubra_ suffered the highest degree of damage from livestock. They recommended the use of an electrified fencing system to prevent cattle damage to young seedlings and saplings.

Soil physical and chemical properties

Proper stocking of a silvopastoral system will have minimal impact on soil physical properties (Goosey et al., 2005). However, soil compaction from grazing can occur in a wide range of soils and climates. It is exacerbated by low soil organic matter content and at high soil moisture content. Soil compaction increases soil strength and decreases soil fertility through decreasing storage and supply of water and nutrients, which leads to additional fertilizer requirement and increasing production cost. A detrimental sequence then occurs of reduced plant growth leading to lower inputs of fresh organic matter to the soil, reduced nutrient recycling and mineralization, and reduced activities of micro-organisms (Hamza and Anderson, 2005). In a recent study in New Zealand, Drewry and Paton (2005) showed that grazing could negatively impact soil bulk density, porosity, and hydraulic conductivity.

Improper stocking of livestock could also have negative effects on soil chemical properties. Northup et al. (2005) examined the effects of different levels of applied grazing pressures on herbaceous vegetation and soil properties (total soil C, total N, total P, and soil-borne plant material [roots and surface litter] in the A horizon) around grass tussocks of a dry eucalypt woodland in northern Australia. Applied grazing pressures significantly affected all soil properties except total P. Concentrations of N and C were highest at locations close to plants, and levels in proximity to plants declined under sustained heavy grazing. Paddocks receiving heavier grazing pressures also produced less standing crop and tussocks were smaller and more widely dispersed. Further, areas with high amounts of soil C, N and soilborne plant materials were smaller and more widely dispersed under heavy grazing.

Complementary Interactions

Soil enrichment

A recent study in a semi-arid part of India showed that manure could play a major role in improving production of fodder species in a fodder silvopastoral system (Skekinah, 2004). Manure generated from goat and buffalo of the integrated system was composted and recycled to the cropping system. Highest maize fodder (_Zea mays_ L.) equivalent yield was obtained with the application of composted buffalo manure as a result of nutrient build up and better
release over time. Greater residual effect of organic manure application was also recorded in terms of higher yield of chickpea (*Cicer arietinum* L.) and coriander (*Coriandrum sativum* L.).

Biological nitrogen fixation can substantially improve soil fertility in silvopastoral systems with nitrogen fixing forage and/or tree species. Kumar *et al.* (2001) reported soil enrichment due to multipurpose leguminous trees in a silvopastoral system in southern India. The four tree species were *Acacia auriculiformis*, *Ailanthus triphysa*, *Casuarina equisetifolia* and *Leucaena leucocephala*. Grasses included *Pennisetum purpureum* (hybrid napier), *Brachiaria ruzizensis* (congo signal), *Panicum maximum* (guinea grass) and *Zea mexicana* (teosinte). Annual nitrogen fixation rates exceeding 350 kg N ha$^{-1}$ have been reported in temperate pastures (Sharrow, 1999). Although direct transfer of fixed nitrogen from legumes to associated tree species is possible, this can be a slow process, which requires several years for sufficient enrichment of soil nitrogen levels to benefit tree growth. For example, Waring and Snowdon (1985), reported decreased growth of *Pinus radiata* for the initial three years in a silvopasture with subclover. However, after seven years soil nitrogen was increased by 36% and tree diameters by 14% in silvopasture compared to *P. radiata* monoculture. van Sambeek *et al.* (1986) and Dupraz *et al.* (1999) have also reported similar growth increases in black walnut when interplanted with leguminous forage crops in the Midwestern USA and southern France, respectively.

**Safety net role of tree roots**

The ‘safety net’ hypothesis of nutrient capture assumes that the deep roots of trees are capable of retrieving nitrate-N and other nutrients that have leached below the rooting zone of associated agronomic crops, and of eventually recycling these nutrients as litter fall and root turnover in the cropping zone. Also, the longer temporal activity of tree roots, even at the same strata, help capture nutrients before and after a crop is planted and harvested. This would essentially increase the total resource-use efficiency of the system (van Noordwijk *et al.*, 1996). The safety net role of tree roots has been observed in alleycropping systems (Allen *et al.*, 2004a,b). Preliminary research conducted on a silvopastoral system in Florida, on flatwood soils (Spodosols) suggest that silvopastoral sites are less likely to accumulate nutrients within a soil profile compared to an adjacent fertilized pasture with cattle grazing (Nair and Graetz, 2004). This supports the hypothesis that the silvopastoral system minimizes leaching of nutrients from the soil because of enhanced uptake by deeper tree roots and shallower grass roots, compared to more localized and shallow rooting depths of the regular pasture.

**Microclimate**

Compared to open pastures, silvopastoral systems offer many benefits in terms of microclimate modifications. For example, in temperate regions, forage crops remain dormant during the early and late part of the growing season due to episodic radiation frost. A well-designed silvopasture can potentially extend the grazing season period on both ends of the growing season. For
example, Feldhake (2002) evaluated the effect of thermal radiation from conifer tree canopies on forage canopy temperature with variable tree density. Under 77% tree cover forage canopy temperature remained within half a degree of air temperature, however, under 7% cover, forage canopy temperature was 10.4°C below air temperature during radiation frost events.

Tree canopies can also reduce temperature during summer months so that heat stress of forage crops and/or animals can be alleviated. Heat stress has been identified as a major constraint to cattle production in the tropical and temperate regions of the world (Payne 1990; Mitloehner et al., 2001). At high temperatures, evaporative cooling is the principal mechanism for heat dissipation in cattle. It is influenced by humidity and wind speed and by physiological factors such as respiration rate and density and activity of sweat glands. The failure of homeostasis at high temperatures may lead to reduced productivity or even death (Blackshaw and Blackshaw, 1994). Providing shade, however, can reduce the energy expended for thermoregulation, which in turn can lead to higher feed conversion and weight gain. In a recent study in Texas, southern USA, Mitloehner et al. (2001) found that cattle provided with shade reached their target body weight 20 days earlier than those not afforded shade. These authors concluded that cattle without shade had a physiological (i.e., higher respiration rate) and behavioral (i.e., less active) stress response to heat that negatively affected productivity.

Forage yield and quality

Integrating trees into pasture may increase pasture production and improve nutritive value by altering both species composition and productivity. In a recent study, Buergler et al. (2005) examined forage yield and botanical composition in response to tree species, tree density, and slope position in silvopastoral system. The tree species were black walnut (Juglans nigra L.) and honey locust (Gleditsia triacanthos L.) with tall fescue (Festuca arundinacea Schreb.) as the predominant forage species. Tree species did not affect botanical composition; however, plots under honey locust trees tended to have more fescue in a dry year and more legumes and less dead herbage in a wet year. Greater percentages of warm-season grasses and fewer weeds were observed at low tree density sites during the wet year. Forage mass was greater under medium-density trees than high-density trees. Plots under black walnut yielded 13% more forage than those under honey locust. The authors concluded that appropriately spaced trees have potential to positively alter botanical composition and support greater forage production in silvopastoral systems.

Positive effects of moderate shading on crop growth have been reported in some cases. Lin et al. (1999) found that two native warm-season legumes, Desmodium canescens and D. paniculatum, exhibited shade tolerance and had significantly higher dry weight at 50% and 80% shade than in full sunlight. These authors also reported that total crude protein content of some of the forage species was greater under 50% and 80% shade than in full sun (Table 1). Burner (2003) reported that orchardgrass (Dactylis glomerata) yield across six harvests did not differ among loblolly pine (Pinus taeda) and shortleaf pine (Pinus echinata) silvopastures compared to yield
Table 1. Crude protein and total crude protein of selected grasses and legumes when grown under three levels of shade during 1994 and 1995 at New Franklin, Missouri, USA.

<table>
<thead>
<tr>
<th>Species</th>
<th>Crude protein (%)</th>
<th></th>
<th>Total crude protein (g pot⁻¹)</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Full sun 50% shade</td>
<td>80% shade</td>
<td>Full sun 50% shade</td>
<td>80% shade</td>
</tr>
<tr>
<td>Introduced cool-season grasses</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kentucky bluegrass</td>
<td>20.3 b</td>
<td>20.7 b</td>
<td>22.7 a</td>
<td>2.45 A</td>
</tr>
<tr>
<td>Orchardgrass 'Benchmark'</td>
<td>12.6 c</td>
<td>15.7 b</td>
<td>19.6 a</td>
<td>1.80 A</td>
</tr>
<tr>
<td>Orchardgrass 'Justus'</td>
<td>19.8 a</td>
<td>16.7 a</td>
<td>18.5 a</td>
<td>1.60 A</td>
</tr>
<tr>
<td>Ryegrass 'Manhattan II'</td>
<td>15.3 b</td>
<td>16.0 b</td>
<td>18.5 a</td>
<td>1.74 A</td>
</tr>
<tr>
<td>Smooth bromegrass</td>
<td>16.7 c</td>
<td>18.1 b</td>
<td>20.2 a</td>
<td>1.64 A</td>
</tr>
<tr>
<td>Tall Fescue 'KY31'</td>
<td>14.0 b</td>
<td>15.0 b</td>
<td>18.1 a</td>
<td>1.83 B</td>
</tr>
<tr>
<td>Tall Fescue 'Martin'</td>
<td>14.3 b</td>
<td>15.5 b</td>
<td>18.5 a</td>
<td>1.75 A</td>
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<tr>
<td>Timothy</td>
<td>15.4 c</td>
<td>17.6 b</td>
<td>20.4 a</td>
<td>1.60 A</td>
</tr>
<tr>
<td>Introduced cool-season legumes</td>
<td></td>
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<tr>
<td>Alfalfa 'Cody'</td>
<td>19.4 a</td>
<td>19.9 a</td>
<td>19.4 a</td>
<td>1.49 A</td>
</tr>
<tr>
<td>White clover</td>
<td>20.1 a</td>
<td>20.6 a</td>
<td>19.9 a</td>
<td>2.49 A</td>
</tr>
<tr>
<td>Introduced warm-season legumes</td>
<td></td>
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<tr>
<td>Striate lespedeza 'Kobe'</td>
<td>13.2 a</td>
<td>13.0 a</td>
<td>12.5 a</td>
<td>3.34 A</td>
</tr>
<tr>
<td>Native warm season legumes</td>
<td></td>
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</tr>
<tr>
<td>Slender lespedeza</td>
<td>11.0 a</td>
<td>10.5 a</td>
<td>10.8 a</td>
<td>2.04 A</td>
</tr>
<tr>
<td>Desmodium paniculatum</td>
<td>11.6 b</td>
<td>11.7 b</td>
<td>12.9 a</td>
<td>2.57 B</td>
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<tr>
<td>Desmodium canescens</td>
<td>13.0 a</td>
<td>13.2 a</td>
<td>12.8 a</td>
<td>2.19 B</td>
</tr>
<tr>
<td>Hog peanut</td>
<td>9.1 ab</td>
<td>8.7 b</td>
<td>9.7 a</td>
<td>0.80 B</td>
</tr>
</tbody>
</table>

Means followed by the same letter within a row do not differ significantly from each other (Tukey's studentized range test, α = 0.05); Adapted from Lin et al. (1999).

in open pastures. In addition, orchardgrass persistence was greater in the loblolly pine system (72% stand occupancy) than the open (44% stand occupancy). In another study of a loblolly pine-mixed grass/forb silvopasture, Burner and Brauer (2003) observed a general increase in herbage quality (crude protein and digestibility) under silvopasture compared to open grown pasture.

Conclusions

Despite their complexity, silvopastoral systems are being practiced the world over. A thorough understanding of the interactions among trees, crops, and animals in these systems is necessary to determine their sustainability and profitability over the long term (Jose et al., 2004). Although considerable progress has been made in our understanding of the complex interactions in certain agroforestry practices such as alleycropping, it is limited in silvopastoral systems. This information is critical in designing sustainable silvopastoral systems and developing appropriate management protocols. Several of the research priorities identified by Jose et al. (2004) are applicable for silvopastoral systems. These include:
• Study of cultural practices that would minimize competition and maximize niche separation

• Examine ways by which animal damage to trees and soil can be minimized during early establishment phase of silvopastoral systems

• Genetic modification of components to increase productivity and reduce competition. For example, (a) genetic selection for vertical root morphology in both tree and crop components, (b) selection for greater tolerance of shade in the crop component.

• Use of modeling component interactions: modeling provides a means for integrating different positive and negative interacting vectors so that resource allocation and yield can be predicted.

References


