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BENEFITS OF MANAGING LIVESTOCK AND TREES TOGETHER: EXPERIENCES FROM THE TEMPERATE ZONE

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Introduction

Agroforestry has been practised for thousands of years, ever since man first started to clear forests for agriculture and to manage trees, food crops and livestock on a particular area of land (Von Maydell, 1985). Most agroforestry systems involve the integration of crops and trees, there are many fewer systems world wide which have integrated livestock and trees (silvopastoral systems) consequently there has been less focus on research for livestock-based agroforestry systems than for those with crops (Sanchez, 1995). Another reason for the limited amount of research on silvopastoral systems is that, in the so-called developed countries, there has been considerable investment in research on separate agricultural and forestry systems, focusing on improvement of the efficiency of production of food and fibre. This led to the specialisation of farming and forestry (von Maydell, 1995; Sheldrick & Auclair, 2000) often based upon single-species agricultural and forestry systems. In the last 20 years or so, however, there has been a small shift in research funding which has allowed an increase in the study of these complex systems.

It was not until it became apparent that European farmers were beginning to produce more food than could be consumed within Europe that interest in more diverse forms of land use began to increase. Concern about surplus food production from highly intensive and specialized agriculture and forestry and the consequences for the environment and for animal welfare generated support for research on multiple-benefit land-use systems. The benefits which were required included, diversification of production, protection of the rural infrastructure, enhancement of the environment, protection against soil erosion and forest fires and the ability to persuade farmers to adapt their current agriculture-based systems of production. Silvopastoral agroforestry was seen to offer these benefits to grazing livestock farmers in Europe.

Those of us involved in research on grazing livestock farming looked around the world for examples of research, the results of which would allow us to evaluate the potential for such systems in Europe. However, almost all of the agroforestry research was for inter-cropping systems (Sanchez, 1995) and the main research on silvopastoral agroforestry, which had been carried out in New Zealand (see for example Maclaren, 1988), had been descriptive and the effects of interactions in these complex systems were lumped together in empirical relationships. No attempt was made to understand the relative importance of each component interaction

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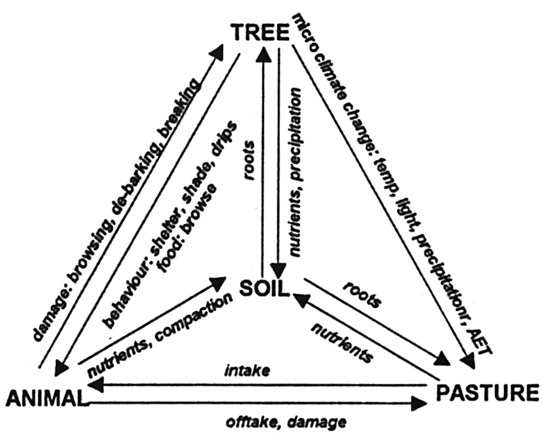
(Sinclair, 1999). These empirical relationships were also based on a single tree species (Pinus radiata) and, while they were of great use to farmers in New Zealand, they could not be interpreted in other parts of the world (Sinclair, 1999).

Silvopastoral systems are complex, see Figure 1. The research which has been carried out in Europe has been designed to provide an understanding of the processes which underlie these complex systems so that their design and management can be improved. This understanding of the underlying processes, even though it was achieved in Europe, offers an approach to the design and management of silvopastoral agroforestry systems to achieve benefits for farmers in other agro-climatic zones. Anderson and Sinclair (1993) carried out a comprehensive review of ecological interactions in agroforestry systems though much of it refers to cropping systems. This paper seeks to update information with respect to bio-physical interactions in silvopastoral systems which involve animals utilising pastures below widely-spaced trees.



Redrawn from Etienne(1996)

Tree/Pasture Interactions

Above ground

Shading is one of the main limiting factors for pasture growth in silvopastoral agroforestry, (see for example Sibbald et al. (1991) and Braziotis & Papanastasis (1995)), however there is evidence that tree canopies do not create sufficient shade to depress pasture production until the trees are well grown and that shoot pruning can dramatically reduce shading by larger trees (Sibbald et al., 1991). In the UK Silvopastoral National Network Experiment (Sibbald et al., 2001), which includes a range of upland and lowland sites planted with sycamore trees (*Acer pseudoplatanus* L.), no significant reduction in annual livestock carrying capacity of the pastures with 400 trees ha^{-1} had been recorded despite the fact that the trees were fourteen years old (Sibbald and Dalziel, 2002). There is also evidence from Mediterranean areas (Auclair, 1997) that there was no reduction in annual pasture production after 10 years of tree growth. One UK model has suggested that pasture productivity in a 200 trees ha^{-1} silvopastoral system with shoot pruning can be maintained above 80% of the starting level for up to twenty five years (Tabbush et al., 1985).

There is also evidence that silvopastoral pasture productivity can be greater than that in conventional agriculture. During dry periods in temperate areas it has been shown that the combination of temperature buffering, reducing maximum temperatures, shading and reduction of wind speed resulted in greater water-use efficiency in a silvopastoral system under hybrid larch (*Larix eurolepis*). An increase of 16% in annual pasture production below the agroforestry canopy when compared with the agricultural control treatment was reported during a dry summers (Sibbald, 1999). Similar effects have been found under hybrid larch in dry summers in the south-west of the UK (Duller, 1998), despite relatively large tree canopies which reduced photosynthetically active radiation at pasture level by a maximum of 45%. In warmer climates, where soil moisture deficits are more common, such effects are probably more consistent because soil moisture conditions are globally better below trees (Etienne, 1996).

Similar increases in pasture productivity in silvopastoral systems have been reported elsewhere, for example, in Australia (Anderson and Moore, 1987) in New Zealand (Percival and Knowles, 1986) and in sub-tropical conditions (Ralph, 1990). Implications for the total productivity of silvopastoral systems (trees + pastures + animals) are therefore good and total above-ground biomass yields 30% greater than either conventional pasture or forest systems are reported in the USA four to eight years after tree planting (Sharrow, et al., 1996). These authors calculated a Land Equivalent Ratio (Mead & Willey, 1980; Dupraz & Newman, 1997) of 1.6 based on 0.96 ha of forest plus 0.64 ha of pasture which would be required to match the production of one hectare of agroforestry. Similar results, with respect to the benefits in total productivity of silvopastoral systems when compared to conventional agriculture have been reported from France (de Montard et al., 1999) and the UK (see for example, Sibbald et al., 1998a).

The effects described so far apply to annual productivity, however, the story is rather more complex since both temporal and spatial variations are involved within the growing season. In the Auvergne region of France, with a mean annual rainfall of 550 mm, ten-year-old hazel trees (*Corylus avellana*) grown for their fruits were planted in a newly-sown cocksfoot grass (*Dactylis glomerata*) pasture. In wet spring periods, cocksfoot yields were higher among the trees, than in an open control area, with no impact of tree distance. In drier periods, during late spring and summer, the farther from the trees, the higher the grass yields. Close to the trees (0.8 m), grass yields were the lowest on their south side (de Montard et al., 1999). A hypothesis to explain this phenomenon is that when there is competition for soil moisture, the area with both tree and grass roots will have greater soil moisture demands and that on the unshaded south side of the tree, higher levels of evapotranspiration will aggravate the situation. These findings contrast with findings in the UK where, in moister conditions (mean annual rainfall 1100 mm), with shading as the main constraint on pasture growth, grass yields were lowest to the north of the trees (Sibbald et al., 1991). In New Zealand, Goh, et al. (1996) found that, in spring, pastures grew better to the north of tree rows, suggesting, for a site in the southern hemisphere, that shading was a constraint.

In temperate conditions, it has been shown that the buffering effect of the trees results in warmer minimum temperatures at the extremes of the growing season (Sibbald & Griffiths, 1992). The raising of minimum temperatures at the grass meristem by one or two degrees above the critical level of 5.5°C has been shown to extend the pasture growing season with potential benefits to the grazier (Sibbald, 1992).

The UK experiment also demonstrated further spatio-temporal interactions between pastures and trees in that the lowest growth actually occurred to the north-east of the trees. While the average percentage of open growth to the north of 6m tall unpruned Sitka spruce (*Picea sitchensis* Bong, Carr) was 60%, compared to 80% to the south, the area to the north-west had 68% and that to the north-east 52%. This effect was explained by the diurnal pattern of shade and temperature in the northern hemisphere. While pasture growing to the north-west and north-east of a tree will receive the same total amount of light per day, the pasture to the north-east of a tree will be unshaded before noon when air temperatures are lower than in the afternoon when the pasture to the north-west of the tree is unshaded (Sibbald, 1996).

Some of the above-ground effects of trees, especially shading, can be managed by careful pruning of the trees to remove lower branches which may contribute only a relatively small amount to the total leaf area and therefore to the productivity of the tree. Pruning obviously allows more light to reach the species growing on the ground, however, other benefits can be achieved, for example, provision of feed for livestock, provision of fuel and fencing material and improvement of timber quality; some of these are discussed later.

It is clear that there are many interactions involved above ground and that individual interaction take precedence in certain circumstances. Light (shading), temperature, shelter (wind speed) and even soil moisture have been implicated in different ways at different times and in different situations. This indicates firstly that it is not possible to entirely separate above- and below-ground interactions. It also indicates that some interactions are beneficial to the system and agroforestry systems should be designed to take advantage of them. There are, of course, knowledge gaps and priority areas involve choice of tree species and site/tree species/pasture species interactions to gain further understanding, which will help with the design of systems.

Below ground

Below-ground interactions between trees and pastures have already been implicated through impacts on soil moisture availability on pasture productivity. In the establishment phase when the trees are small, below-ground interactions are also likely to impact upon the trees. Young (1997) has recently carried out a comprehensive review of agroforestry for soil management, though much of it refers to cropping systems. Current understanding of the tree root ecology of agroforestry systems is still rather limited due in part to the heavy demands made on time and labour by root measurements compared to measurement of above-ground biomass (Schroth et al., 1996). In a review article on tree root characteristics and criteria for agroforestry, (Schroth, 1995), only two of the reviewed articles referred specifically to silvopastoral systems indicating that there is still a lack of detailed knowledge of these systems.

It has, however, been proposed by Black et al. (1996) that a rapid cycle of root production and loss may confer flexibility to the root system and thus permit avoidance of root depletion zones. Such high rates of mortality also mean that significant quantities of nutrients and carbon will be returned to the soil through root death. This suggests that tree root mortality could play an important role in driving nutrient cycling in tree-based ecosystems. The limited data available indicate that in some circumstances, the flexibility of response in the roots of grass and trees does result in them occupying different zones in the soil. In a study in France, de Montard et al. (1999) found that, during the early years of an experiment while root growth of the tree (hazel) was still slow, root growth of the grass (cocksfoot) was distributed in the profile, down to 0.9 m depth. One year later, while a similar root distribution was observed for grass without trees, the agroforestry grass limited its root growth within the 0-0.2 m upper layer of the soil profile; tree root elongation in agroforestry was similar to that of a grass-free tree, but was at an average level 0.2m lower in the soil profile. This evidence supports the hypothesis of Black et al. (1996) that flexibility of the root systems of the grass and the trees has resulted in differential utilisation of soil resources.

Trees in agroforestry systems therefore develop root systems which are different in size and in spatial distribution to conventionally grown trees. However, there is another aspect to be taken into account, in that Sinclair, (1999, citing Tomlinson (1992)) has demonstrated that roots of ash trees develop differently when grown in competition with grass or clover (*Trifolium* spp., a nitrogen-fixing legume used extensively in temperate pastures). Distribution of the roots in the vertical plane was similar but, under clover, the trees developed larger root systems measured as root length per unit volume of soil.

Earlier work on a network of sites in the UK, however, showed different responses of the same tree species, sycamore (*Acer pseudoplatanus* L.) with respect to root distribution vertically in the soil profile (Eason et al., 1994). At two sites out of three, tree roots were most abundant in the top level (0-10 cm). At the third site tree roots were most abundant in the 10-20 cm level so that root flexibility may not be consistent across species nor across sites.

Results from the UK sites which were grazed by sheep are, however, modified by a factor which was not present on the French experiment in which the grass was harvested by frequent cutting and not by grazing. The UK trees were protected from browsing by tree shelters which modified their growth form above ground (Hoppé et al., 1998) and below ground (Eason, et al., 1994). As a result of these modifications, the trees developed a root:shoot ratio which was much less than that of conventionally grown trees (Eason et al., 1994). This is a characteristic which has been recognised elsewhere (Dupraz et al., 1994) and has a direct impact on the trees' ability to compete for soil-based resources.

Schroth (1996) has provided a global view of requirements for future root research, describing a systematic method for establishing how tree root systems react to root management measures and including ranges of soil types and trees with contrasting properties. In addition to the heavy demands of below-ground research, another problem is that root work usually involves destructive sampling which may remove trees altogether or reduce their value to future research. Herbicides are often used in the early stages of tree establishment in temperate zones to reduce competition from the pasture species for water and nutrients (Sibbald & Sinclair, 1990) but their impact on tree root structure in silvopastoral systems is not fully understood. The introduction of cheap, non-destructive root sampling methods would greatly enhance the possibility of expanding research in this area.

Tree/Animal Interactions

Trees modify the microclimate in which the pasture species grow, the same is true for the grazing animals. Patterns of sheep movements below trees have demonstrated that, in an upland site in the UK, sheep spend much more time close to trees, especially when they are resting, than would be expected if they moved at random (Sibbald et al., 1996). These trends are magnified during windy weather and at low tree densities (100 vs. 400 trees ha^{-1}) in this temperate climate. A hypothesis to explain the difference between planting densities is that there is more spatial variation in wind speed in very widely-spaced trees, while at the scale experienced by the sheep, there is a more homogenous microclimate, at higher planting densities (Green et al., 1995) making it more "worthwhile" for the sheep to move towards trees which are planted at wider spacings (Sibbald et al., 1996). Similar effects, although there are no reported measurements to date, are very likely to occur when sheep seek shade from trees in warmer climates (Young, 1997). During wet weather in the UK it was shown that the sheep tend to move away from trees. Once again, this effect was more significant at 100 than 400 trees ha^{-1}. The hypothesis is that, under the trees, large drops of water from the canopy can penetrate the fleece of the sheep, reducing its insulating properties; drops from the canopy may be unavoidable under 400 trees ha^{-1} (Sibbald et al., 1996). Because animals can choose the best micro-environment within a silvopastoral system, it is very likely that animal welfare will be improved when compared to conventional grazing systems and there is potential for animal growth rates to be better in agroforestry systems.

As mentioned earlier, trees can provide feed for livestock. It is better that access to the feed supply is controlled, for example, branches or foliage should be cut from trees rather than the animals being free to browse trees or to strip bark and break branches from them. Such damage to trees can reduce their productivity and, at worst, kill the trees. Fruits from trees are an obvious feed source and have been used traditionally in many systems, for example, in the Dehesa system in Spain where fruits (acorns) which fall from oak trees (*Quercus* spp.) provide feed at times for grazing ruminants when pasture species are not available. Another example is the provision of seed pods from the Honey Locust tree. In many parts of the world, foliage and branches are used to provide feed for livestock, though this is not a common practice in the so-called developed countries, often because of the labour costs involved.

Clearly the interactions of animals with trees is complex and will vary with site characteristics such as weather, topographical shelter, tree species, tree age and tree planting density and very likely will vary with the species and breed of the grazing animal. More research in these areas and on site/animal interactions is required.

Animal/Soil Interactions

The behaviour of animals, particularly in exposed conditions, means that the sheep spend a high proportion of their time close to trees. This has resulted in the UK in greater than average levels of soil compaction close to trees and in some cases significantly greater levels of soil compaction at lower than at higher tree planting densities (Laws et al., 1992; Wairiu et al., 1993). This latter phenomenon is partly explained by the higher animal:tree ratio at low tree planting densities and partly by the greater attraction of animals to trees at lower planting densities. There is also evidence that, in addition to spatial variation in soil physical properties around trees, development of spatial variation in chemical properties can occur. Nwaigbo et al. (1999) have demonstrated higher soil nitrogen concentrations in a zone around trees where, according to the animal behaviour data, sheep are most likely to be found grazing. In tropical areas it has been suggested (Young, 1997) that soil enrichment under tree canopies is partly due to grazing animals using the trees for shade.

Soil/Tree Interactions

The impact of soil on tree development has been covered comprehensively in other reviews, for example by Young (1997). The impacts which occur uniquely in silvopastoral systems arise through the consequences of the manner in which grazing animals use the system to their advantage. In the UK Silvopastoral Network, it has been shown (Sibbald & Agnew, 1996) that tree height extension and survival are both lower at 100 ha^{-1} than at 400 ha^{-1}. It has been argued that this is due to the greater level of soil compaction around trees at the lower planting density. Increases in soil compaction have been shown elsewhere to reduce growth of tree seedlings in a silvopastoral system (Bezkorowajnyj et al., 1993). For the same tree species, in this case sycamore, the effect is greater on an exposed, upland and relatively dry site in the north-east of the UK than in more sheltered or wetter sites in the west of the UK. The hypothesis put forward to explain this is that the sheep seek shelter more frequently on the more exposed site and avoid water dropping from the canapy less frequently because of a drier climate. It has also been demonstrated that hybrid larch (*Larix eurolepis*) is more susceptible to these effects than is sycamore (Sibbald, 1996) indicating once again species differences with respect to the processes involved in interactions.

The different responses of trees to pressure from animals suggest that more research on tree species/site interactions is needed.

Animal/Tree interactions

It is well known that grazing animals will browse and rub on trees and shrubs potentially causing considerable damage (Mitchell & Kirby, 1990). In silvopastoral systems in the so-called developed countries where labour costs are very high, the need to protect the trees from the animals has always been recognised because livestock can be left unattended for periods of time. In silvopastoral systems in countries where labour costs are much lower, regular herding of livestock may significantly reduce the potential for livestock damage to trees. In conventional forestry in the so-called developed countries, protection is achieved by fencing animals out of planted areas. In silvopastoral systems it is possible to keep animals out of the planted area until the trees have achieved a stage of development when browsing and bark stripping are no longer a problem. This is the case in New Zealand with fast-growing radiata pine (*Pinus radiata*) when grazing by sheep can be re-introduced five years after planting without causing significant damage (Knowles, 1991). Radiata pine produces a protective sheet of resin over debarking injuries minimising their impact on timber quality (Knowles, 1991). In areas with lower potential rates of tree growth or when slow-growing hard wood trees are used, the exclusion of grazing animals for lengthy periods, of five to 20 years, will result in an unacceptable deterioration of pasture quality (Dupraz & Newman, 1997). Under these circumstances, it is inevitable that relatively expensive methods of tree protection will be used to allow continuous grazing. However, it has been shown that extruded-polythene tree shelters (Potter, 1991) can produce low root:shoot ratios (Eason et al., 1994; Dupraz et al., 1994) and, as a consequence, modifications to these shelters have been proposed for Mediterranean areas (Dupraz et al., 1997). In the UK, the extruded-polythene tree shelters have been removed after tree emergence being replaced by wider net guards which create more favourable conditions for balanced tree growth (Sibbald & Agnew, 1996). More natural methods of protection for valuable trees may be considered in other countries, for example the use of thorny branches from other, less-valuable trees or shrubs could be placed around trees or unpalatable grasses with spiky leaves could be used.

Interactions at other scales

Increased interest in agroforestry systems in the UK and Europe has resulted partly from its potential to provide environmental benefits over conventional agriculture. Hoppé et al. (1997), McAdam et al. (1997) and Burgess (1999), have described the potential benefits in terms of increased floral and faunal diversity in the UK. However, when agroforestry replaces conventional agricultural or forestry systems there will also be an impact at the landscape scale. Agroforestry land cover will provide new vistas for local people and for tourists and this must not be forgotten when we consider design and management strategies. This may be particularly relevant in Europe, where, with reform of the Common Agricultural Policy, for example, greater subsidies would be paid for environmental benefits than for production. More information on the environmental and landscape impacts of silvopastoral systems is needed.

Conclusions

It is clear that interactions in silvopastoral systems are very complex. We have made some progress in understanding them at the process level, a level of understanding which is essential if we are to devise design and management protocols which will maximise outcomes over the range of multiple benefits which are now expected of land-use systems in various parts of the world. We can, in a general way, recommend appropriate tree planting densities, methods of tree protection against animals and methods of reducing competition between trees and grass, especially during the very early tree establishment period. We can predict the likely consequences of particular tree planting patterns with respect to patterns of pasture production in time and space. However, there are many areas in which we lack sufficient knowledge to provide specific recommendations at the individual site level and these give pointers to areas in which future research should be focused. These include:

- Choice of tree species and site/tree species/pasture species interactions to gain further understanding which will help with the design of systems, for example in the layout of tree rows or pruning regimes to control pasture production through manipulation of micro-climate.
- Schroth (1996) has provided a global view of requirements for root research in agroforestry.
- The introduction of cheap, non-destructive root sampling methods would greatly enhance the possibility of expanding research on roots.
- More research on site/animal interactions is required; for example, do animals use trees differently in different climates?

- Design of tree protection. We need new designs which will, cost effectively, protect trees and encourage good growth form. Is protection required for the lifetime of the tree? Are there locally available natural sources of tree protection material (thorny shrubs, pasture species with spiky leaves)
- Are we using the best tree species and within species, are we using the best provenances or clones with structures above and, especially, below ground, to respond well to silvopastoral methods?
- Pastures species/varieties. Are we using the best pasture species to respond well to silvopastoral methods and to be complementary with the tree component while providing appropriate energy and nutrition to the grazing animals? See for example Koukoura & Papanastasis (1996).
- Animal welfare. Are there real animal welfare benefits in silvopastoral systems?
- Timber quality. How do silvicultural practices in silvopastoral systems impact on timber quality? See for example Janin et al. (1997).
- How do we scale-up any of this information from experiments to practical systems in a complex area like agroforestry (van Noordwijk & Ong, 1996)

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