MANAGEMENT OF AGROFORESTRY SYSTEMS

Ecological, social and economic approaches

Esther Fernández-Núñez
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Title: Management of agroforestry systems: ecological, social and economic approaches

Editors: Esther Fernández-Núñez and Marina Castro

Associate editors: María Rosa Mosquera-Losada, María Lourdes López-Díaz, Pedro Álvarez-Álvarez, Giuseppe Colangelo, João Azevedo

Edition: Instituto Politécnico de Bragança 2016

Cover design: Soraia Maduro

ISBN: 978-972-745-169-2

URI: http://hdl.handle.net/10198/13444

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Chapter I

General aspects of silvopastoral systems

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Intensive program Management of agroforestry systems: ecological, social and economic approaches

ABSTRACT

The scientific history of agroforestry (AF) is brief; it wasn't until the 1990s that a collection of largely descriptive and empirical research studies was gradually transformed into a process-orientated and more robust scientific approach. AF is essentially a new term for age-old practices of integrated land-use that occurs in most parts of the world.

Silvopastoral systems (SPS) can be defined as complex management systems that integrate trees, pasture and animals in an edapho-climatic context. This introduction to SPS provides a historical perspective to highlight the sustainability of AF. It analyses the three main components of SPS, trees, pasture and animals, and their interactions as well as examines its economic and environmental benefits.

Keywords: agroforestry, benefits, components, interactions, practices.

INTRODUCTION

Agroforestry (AF) was termed in the 1970s to describe ancient and common agricultural practices used across several regions of the world, particularly tropical and Mediterranean regions. During the 1980s, AF was widely promoted as a sustainability-enhancing practice with great potential to increase crop yields, conserve soil and recycle nutrients whilst producing fuelwood, fodder, fruit and timber (Nair, 1989). In the subsequent decade, it was recognised as an applied science based on principles of natural resource management (TAC, 1999; Izac et al., 2000).

Retrospectively, first descriptions about multipurpose tree use as an AF system are found in an account of the origins of life. The ancient Indian scriptures mention the multipurpose tree species, Prosopis cineraria, as a fodder source (Flores-Delgadillo et al., 2011) and the Bible (Gen. 2:8-9) describes gardens with an assortment of trees that provide beauty and food. Home gardens were described in the Near East as early as 7000 B.C. and agricultural writers of the Roman era described a wide variety of AF systems that included livestock and the use of tree crops for food and fodder (MacDicken and Vergara, 1990).

Currently, AF is one of the most promising agricultural systems due to several reasons: i) combines productivity, sustainability and adaptability to climate change (Shibu, 2009) ii) is recognised as instrumental in assuring food security, decreasing poverty and enhancing ecosystem resilience for thousands of smallholder farmers in tropical regions (Sanchez, 1995) and iii) is an alternative approach to land use that provides ecosystem services, environmental benefits, and economic commodities as part of a multifunctional working landscape (Shibu, 2009).

AGROFORESTRY SYSTEMS AND PRACTICES

AF systems are highly diverse and complex in character and function. Hence, to understand, evaluate, and endeavour to improve them, AF systems can be classified into several categories. The most common criteria used for this classification are (Nair, 1993):

a) Structure: composition and arrangement of components (spatial, temporal).

b) Function: productive [food, fodder, fuelwood, cloth, shelter, non-timber forest products (NTFPs)] and protective [windbreaks, shelterbelts, moisture conservation, soil improvement, shade (for crop, animal and man)].

c) Socioeconomic scale: level of management (low-medium-high input) and cost/benefit associations (commercial, intermediate, subsistence).

d) Ecological areas: humid/subhumid, arid/semi-arid, highlands.

The types of AF practices found throughout Europe are categorised as (AFTA, 1997; Alavalapati et al., 2004; Mosquera-Losada et al., 2009): *i) Silvoarable AF* (comprises widely-spaced trees intercropped with annual/perennial arable crops); *ii) Forest farming* (cultivation of high-value specialty crops under the protection of a forest canopy that has been modified to provide the correct shade level); *iii) Riparian buffer strips*: strips of perennial vegetation (tree/shrub/grass), natural or planted, between croplands/pastures, water sources (streams, lakes, wetlands) and ponds to protect water quality. European forestry management has used forested buffer strips since the 1700s (Lee et al., 2004); *iv) Improved fallow*: fast growing, preferably leguminous woody species planted during the fallow phase of shifting cultivation; the woody species improve soil fertility and may yield economic products); *v) Multipurpose trees*: fruit and other trees, randomly or systematically, planted in cropland or pasture to provide fruit, fuelwood, fodder and timber, among other services, on farms and rangelands; and *vi) Silvopasture*: combines trees with forage and/or livestock production. It comprises forest or woodland grazing and open forest trees.

SILVOPASTORAL SYSTEMS

Silvopastoralism focuses on the production of livestock and tree products in one integrated pasture system. Several types of silvopastoral systems (SPS) can be identified, according to their components and the interactions between them. Examples include:

- The Iberian *dehesa* or the Portuguese *montado*, the Nordic reindeer husbandry, and multiple sets of systems based on coniferous or hardwoods in temperate regions without specific names (e.g. Northwest Spain (Galicia), New Zealand, Northwest and Southwest USA). These types of SPS (*grazing in the forest or wood pastures*) are characterised by the deliberate integration of trees and grazing livestock operations on the same land and they are managed for both forest products and forage. The Portuguese *montado* or Spanish *dehesa* (*wood pastures*) are the same system, characterised by the presence of an open tree layer, mainly dominated by Mediterranean evergreen oaks – holm oak (*Quercus ilex* L.) or cork oak (*Quercus suber* L.) – grazed by pigs, sheep, goats, cows or bulls. In the traditional *montado*, the herbaceous layer has been maintained by cereal cultivation over long rotations. Tree cover does not follow a regular pattern, and densities vary from 20 to 80 trees per hectare (Pinto-Correia and Mascarenhas, 1999).

- In other systems, trees are planted at a very low density on pastures (*ligniculture on sward)* or they are established as linear formations (*SPS in lines*). In the first instance, the low densities allow pasture maintenance as the main process but generate further income with forest products (Rois-Díaz et al., 2006); for example, in Northeast Portugal ash is grazed by cattle. In the second instance, trees act as living fences/windbreaks to prevent erosion and offer shelter for livestock. These types of SPS are widely used in Denmark (Castro, 1998) and France (Gil-Tena et al., 2015; Zimmermann, 2006), where it is called bocage or Russian steppe.

Finally, in the Mediterranean mountain areas, the agricultural mosaic landscape has an important role in a most unusual grazing system, named by San Miguel-Ayanz (2006), a *mosaic of different land uses within one management unit*. It forms a mosaic of swards, crops and forest trees not within at the stand but at landscape level (Rois-Díaz et al., 2006).

The various patches form a discontinuity that offers greater resistance to the spread of forest fires compared to large-scale continuous forest areas (Loehle, 2004). This system has a high landscape and ecological value; hence, it is seen as strategic for biodiversity conservation (Castro and Gómez-Sal, 2016).

THE COMPONENTS OF THE SILVOPASTORAL SYSTEM

SPS are an important source of income in rural areas. They produce a wide variety of NTFPs, such as cork, honey, nuts, barks, resins, medicinal plants, mushrooms, truffles, meat, milk, or hunting and tourism. They combine long-term production (timber and fuelwood) with annual production (hay, meat, milk, eggs, etc.). The management of these systems requires a balance of resource use between trees and pasture with the added grazing animal element, to produce several products in a sustainable manner. Hence, the initial choice of SPS components, *tree-pasture-livestock*, is crucial when it is established.

Tree

In an SPS, tree functions are associated with an increase in productivity and stability of the global system compared to exclusive agronomic systems. They also have an important role in preventing or decreasing ecosystem degradation, which can be caused by some agricultural practices (Gómez-Sal, 1997). Trees can be from natural vegetation or afforestation/reforestation and are used for timber, industrial products, fodder and fruit or specifically for animal production (shadow, fodder, seeds, wood) (Rois-Díaz et al., 2006). Several types of tree species can be used in SPS, however, the choice is vital because it can have decisive impacts on pasture production and therefore livestock production and its welfare. Some morphologic characteristics, such as rooting habit, litter quality, canopy architecture, allelopathy, radiation interception, phenology, growth rate, apical dominance, good self-pruning (Rigueíro-Rodríguez et al., 2009) as well as the products they offer (leaf forage, fruits, etc.) are key determinants for the choice of tree species.

Canopy cover can increase pasture biomass (Souza et al., 2010) or decrease it if shading is too high (Rigueiro-Rodríguez et al., 2011). The spacing is related to the diameter of the trees and influences the rate of tree growth and forage production. Tree-to-tree and row-to-row spacings should be evaluated to optimise returns per hectare of both forage and marketable timber.

I. Coniferous species

Coniferous species, such as *Pinus* sp., *Juniperus* sp., *Larix* sp., *Pseudotsuga* sp., *Picea* sp., *Abies* sp., *Tsuga* sp. and *Taxus* sp., are commonly used in SPS. Although most of these species are not suitable as livestock feed, forest grazing can have an important role in decreasing fuelwood and fire risk (Rigueiro-Rodríguez et al., 2009; Etienne, 2002).

Tree canopy density is a crucial consideration when establishing an SPS with a coniferous species, particularly *Pinus* sp. This genus produces abundant quantities of pine needles year round, a potentially important decrease in forage production over time (Rigueiro-Rodríguez et al., 2012; Rozados-Lorenzo et al., 2007) and due to its contribution to total tree litter, potentially decreases the amount of litter used for livestock feeding. This decreases the short- and medium-term revenues that can be obtained from *Pinus* sp. compared with other species, such as broadleaves (Pasalodos-Tato et al., 2009; Fernández-Núñez et al., 2007). However, it simplifies understorey flora and, therefore, decreases species richness (Fernández-Núñez et al., 2014).

Other species, such as *Larix* sp., have a highly valuable forage production in the sub-alpine regions of Germany; also *Juniperus sp. (J. thurifera*, *J. oxycedrus*) show an acceptable browsing value in the Mediterranean climate (San Miguel-Ayanz, 2006).

II. Deciduous species

Quercus suber L. or *Quercus ilex* L. are typical in the Spanish *dehesa* and Portuguese *montado*. Oaks produce firewood, fodder and welfare for traditionally managed flocks of small ruminants (Castro, 2009). Mediterranean SPS species, such as *Castanea sativa* Mill (Martins et al., 2011) or *Fraxinus angustifolia* Vahl (Pereira et al., 2002), show higher forage production, associated with higher soil fertility, under tree crowns rather than in open areas. Conversely, it is known that oak acorns have potential nutritive values for ruminants due to their high starch and energy contents, and low levels of condensed tannins (Rodríguez-Estévez et al., 2008; Kaya and Kamalak, 2012). In *dehesas* and Mediterranean mountains, acorns are valuable resources in scarcity periods (Rodríguez-Estévez et al., 2009, 2011).

In New Zealand, *Populus* spp. and *Salix* spp. have been planted to provide green fodder during summer and autumn droughts (Hussain et al., 2009), and for soil conservation and shelterbelts or windbreaks (Wilkinson, 1999).

Pasture

The influence of the tree canopy on light penetration, water use, and temperature are key factors affecting forage production and quality, as well as the ability to support grazing animals in an SPS (Silva-Pando et al., 2002; Fernández-Núñez et al., 2014). For these reasons, it is important to understand and predict the effects of trees on understorey forage production (Percival and Knowles, 1988; Rigueiro-Rodríguez et al., 2011). Forage suitability for SPS should be assessed from the perspective of total plant and animal production, as well as species persistence, rather than shade tolerance alone. Various plant types can be used in SPS, including grasses, legumes, shrubs and forbs. The choice should be based on site adaptability, livestock needs, compatibility with overstorey tree species and landowner objectives. In Mediterranean areas, for example, pastures are usually comprised of therophytes and perennial, summer senescing herbs, which usually decrease or cease growth in winter due to the cold (Rivest et al., 2011). Legumes are the most important component of Mediterranean SPS pasture due to the low nutritional quality of senescent grass and typically low soil fertility (San Miguel-Ayanz, 2006; Porqueddu and González, 2006). Senescent legumes usually show acceptable energy and protein contents and provide protein-rich fruits and seeds in late spring and summer (Castro and Fernández-Núñez, 2014). Herbaceous, annual plants with natural reseeding, such as *Trifolium* spp. *Medicago* spp., *Ornithopus* spp., *Lupinus* spp. and *Biserrula pelecinus*, are well adapted to Mediterranean terrains (Potes and Babo, 2003).

Conversely, species such as *Dactylis glomerata* L., is well known for its shade tolerance and has been successfully used in SPS in north-western Spain (Mosquera-Losada et al., 2006) and New Zealand (Peri et al., 2007). Furthermore, it has high productivity and nutritional quality (Mosquera-Losada et al., 2006). However, species with only a slight shade tolerance, such as *Lolium perenne* L., are recommended during tree establishment in low-density tree plantations, or to accompany tree species with open canopy structures (Lin et al., 1999; Fernández-Núñez et al., 2014).

Livestock

The selection of animals for a particular SPS will depend on landowner objectives and markets, as well as the established tree and forage species. Many landowners prefer beef cattle and sheep, although other livestock possibilities include goats, horses, pigs, and chickens, for example.

Tree/animal interactions influence many SPS processes. For example, in *dehesa* systems, animal activity accelerates the turnover of organic carbon in the soil (Simón et al., 2013) and promotes more productive grass communities (San Miguel, 2001). Also, most of the nutrients ingested by grazing animals are eventually returned to the soil as faeces and urine (Barrow, 1987; Vendramini et al., 2007), which are important sources of nitrogen, phosphorous, potassium, sulphur, magnesium and calcium (Oyanarte et al., 1997). The distribution pattern of these nutrients may be influenced by the presence of trees because animals are attracted to trees for shelter (Sibbald et al., 1995) from heat, cold and inclement weather. It is known that heat stress and cold affect livestock performance, decreasing average daily weight gain (Fraser, 2004). In an SPS, tree shade is distributed throughout the pasture and greatly decreases high-temperature stress, improving animal welfare and increasing grazing time (Garrett et al., 2004; Panadero, 2010; Betteridge et al., 2012). Conversely, in a pine SPS, Mancilla-Leytón et al. (2013) reported that trampling and fertilisation during goat grazing accelerated litter decomposition, promoted nitrogen incorporation and decreased pine needle accumulation on the soil surface, consequently decreasing fire risk.

However, thorough management is required to ensure the livestock do not damage young trees, particularly trees introduced to established pastures (Lehmkuhler et al., 2003; Rigueiro-Rodríguez et al., 2009). It is important that the tree develops rapidly because, in the early phase of the SPS system, one of the most limiting factors to the animal introduction is the low height and diameter of trees, which may confer less resistance to damage caused by animals. Individual tree protectors may be necessary to protect trees, increasing the initial cost to the farmer (Eason et al., 1996).

INTERACTIONS BETWEEN SILVOPASTORAL SYSTEM COMPONENTS

The interaction of components can be defined as the influence of one component within the system on the performance of both the other components and the whole system (Atangana et al., 2014). In SPS, complex interactions occur among trees, pasture and animals. These interactions can be positive or negative (Smith, 2010); and occur among the various components in terms of space occupation (both vertical and horizontal stratification); above- and below-ground (Anderson and Sinclair, 1993). Describing the interactions between SPS components over time is crucial to understand the evolutionary production of the system (Bergez et al., 1999). Trees and pasture compete for water, nutrients and light resources; young tree roots share approximately the same soil volume as the pasture but the intense competitiveness of pasture provides it with an advantage (Mauer and Palátová, 2003). As the tree grows, roots deep in the soil can absorb water in particular layers inaccessible to the pasture, which shelters it from competition. Conversely, the tree crown limits the radiations available for pasture, particularly at the adult stage, sometimes leading to the death or a rarefaction of the pasture under the tree. Alternatively, it can protect the pasture from radiation and wind, consequently, pasture transpiration decreases and its growth improves when drought appears. The animal can modify tree growth by branch browsing and soil compaction at the young tree stage. It also modifies the distribution of mineral nutrients by faeces and urine; these mineral nutrients can be absorbed by pasture roots in the soil surface and by tree roots deep in the soil. Trees create shelter and forage for animals; and animals may modify tree growth by browsing, rubbing, and soil compaction or by dung and urine (Bergez et al., 1999).

The interactions depend on the animal and tree types, the age of the trees and management systems. Among ruminants, cattle and sheep are well suited to integration with trees. Goats are more selective in their feeding habits because they are browsers and, therefore, more suited to SPS when both browse and forages are available (Castro and Fernández-Núñez, 2016). To ensure compatibility between livestock and trees, the correct choice of species, grazing control, and the optimum tree age when the leaf canopy is out of reach of the animal, are important considerations.

BENEFITS OF SILVOPASTORAL SYSTEMS

SPS can provide many social, economic and environmental benefits. In SPS, the production of trees, forage and livestock inhabit the same area and often at the same time, which could be the most efficient use of the resources. Such a system also decreases economic risk because it produces multiple products, most of which have an established market (Devendra and Ibrahim, 2004). SPS can produce wood, forage, meat, milk and fruit, for example. This increases the economic benefits of landowners over time because trees provide long-term returns, while forage and livestock generate an annual income (Fernández-Núñez et al., 2009; Pasalodos-Tato et al., 2009).

In an SPS, tree canopy decreases the effects of meteorological factors (wind, intense rain, temperature changes) and provides livestock and wildlife (birds, mammals, invertebrates) with shade and shelter (Bergez et al., 1997; Souza et al., 2010). Tree canopy provides protection from summer heat and winter cold, and can also contribute to the feeding (leaves, fruits) of livestock during shortage periods (Sotomayor et al., 2016).

SPS favour biodiversity by creating complex habitats that support diverse plants and animals (McDermott et al., 2015), possess a rich soil biota and increase connectivity between forest fragments.

Compared with agricultural areas, SPS can contribute to a decreased risk of soil erosion because tree roots can enhance water infiltration and improve water storage by increasing the number of soil pores. Tree roots and trunks also act as physical barriers to decrease the surface flow of water and sediment. Depending on the tree species and the climate characteristics, tree roots explore deep soil horizons and extract nutrients from soil inaccessible to grasses (Moreno and Pulido, 2009). Therefore, SPS tend to increase nutrient recycling. Trees also deposit the nutrients on the ground with the natural fall of foliage, twigs, and fruits.

In an SPS, livestock grazing can be used as a tool to lower fire risk by decreasing the amount, height and distribution of fuel (Mancilla-Leytón et al., 2013; Castro and Fernández-Núñez, 2014). Alternatively, decreasing the stand density to promote forage production (Casals et al., 2009) will lessen the likelihood of wildfire and can result in a high-value of timber (Montagnini et al., 2003).

SPS can be used to recycle urban and agricultural organic waste with the added benefit of increased forage production from the additional nutrients (López-Díaz et al., 2007; Ferreiro-Domínguez et al., 2016). Other demonstrated environmental benefits of SPS include the improvement of water infiltration, soil retention, soil productivity, land rehabilitation (Martínez et al., 2014) and the decreased need for external inputs, such as fertilisers, because manure from the pasture livestock contributes to nutrient recycling in the system (Vendramini et al., 2007).

Climate benefits of SPS are substantial due to the increased carbon content stored in the soil and vegetation and avoidance of deforestation (Ibrahim et al., 2010). SPS also decrease emissions associated with manufacturing and fertilisers use. Fertilisers are energy-intensive to produce, and once applied to the land they emit nitrous oxide, a greenhouse gas with a warming effect more than 300 times that of carbon dioxide (Cambria and Pierangeli, 2012; Somarriba et al., 2013).

Finally, from an aesthetic and recreational perspective, SPS are more attractive compared with forest plantations or open pastures. They can increase wildlife diversity and, therefore, increase opportunities for hunting and wildlife watching, for example (Bugalho et al., 2011).

However, not all benefits will be possible in every SPS, depending on the SPS design, level of management, external circumstances, and management objectives.

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