Past, Present and Future of Agroforestry Systems in Europe

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Abstract Many traditional land-use systems in Europe involved agroforestry in the pre-industrial era, but, over the years, increased mechanization led to the development of increasingly specialized crop, animal and wood production systems. As a consequence, the area under agroforestry declined in many regions of Europe, and agroforestry systems became confined to situations where understorey primary production is restricted due to cold temperatures (Boreal and Alpine areas) or drought (Mediterranean areas) and to plots that are hard to reach or too small for cultivation with modern machinery, as in Spain, Italy and the lower altitude mountain regions

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in southern and central Germany. On the whole, agroforestry continued to be practised only where it enabled farmers to obtain economic returns from lands that were otherwise relatively unproductive and mostly limited to silvopastoral practices. Since the mid-1990s, however, European policies have encouraged land management systems that combine production, environmental services (biodiversity, carbon sequestration, nutrient cycling and water quality) and social benefits, and this has created a new interest in agroforestry systems. Today, the major agroforestry practices in Europe include silvopasture and silvoarable. However, the benefits and opportunities offered by agroforestry can only be realized with substantial investments and coordinated efforts in research, education, knowledge transfer and appropriate national policies across Europe.

Keywords Environmental services • Silvoarable • Silvopasture • Policy

History of Agroforestry Systems in Europe

Land cultivation and the management of domestic animals started and rapidly spread across Europe in the Neolithic period (Pinhasi et al. 2005). During this period, the production of agricultural products in Europe was often based on forested land. This dependence was based on the use of the enhanced soil fertility immediately after forest clearing and the increased light availability for crops after tree thinning (Pinhasi et al. 2005). Further, manure from animals raised in woodlands was used to transfer nutrients to agricultural land and increase crop production (Castro 2009). In France, a recent study has concluded that using trees as fodder for ruminants was already practised in Neolithic times (Thiébault 2005); the author suggests that certain species such as ash (*Fraxinus* spp.) and deciduous oaks (*Quercus* spp.) were selected and their fodder gathered to feed animals during the seasons with lower pasture availability. Bergmeier et al. (2010) report that silvopastoral systems (the combination of trees with livestock) started 7,500 years ago in southeastern and central Europe, 6,000 years ago in Britain, north-western Germany and Denmark and 4,000 years ago in the Baltic and the Scandinavian countries. Agroforestry

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Table 1 Agroforestry practices in Europe

Agroforestry practice	Brief description
Silvoarable agroforestry	Widely spaced trees intercropped with annual or perennial crops. It comprises alley cropping, scattered trees and line belts
Forest farming	Forested areas used for production or harvest of natural standing specialty crops for medicinal, ornamental or culinary uses
Riparian buffer strips	Strips of perennial vegetation (tree/shrub/grass) natural or planted between croplands/pastures and water sources such as streams, lakes, wetlands and ponds to protect water quality
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
Multipurpose trees	Fruit and other trees randomly or systematically planted in cropland or pasture for the purpose of providing fruit, fuelwood, fodder and timber, amongst other services, on farms and rangelands
Silvopasture	Combining trees with forage and animal production. It comprises forest or woodland grazing and open forest trees

Source: Modified from AFTA, Association for Temperate Agroforestry (AFTA 1997); Alavalapati and Nair (2001); Nair (1994), Alavapati et al. (2004); Mosquera-Losada et al. (2009a, b)

systems (AFS) have been recorded from about 4,500 years ago in the south-west of the Iberian Peninsula (Stevenson and Harrison 1992). The presence of livestock in olive (*Olea europaea* L.) and orange (*Citrus sinensis* (L.) Osbeck) groves was common in Roman times, and references to intercropping crops in olive and fig (*Ficus carica* L.) groves are found in the Bible (Nair 1993).

The interaction between forestry and farming on the same plot of land was either based on the simultaneous combination of woody plants and (a) pasture or a crop (or crops) or (b) on the rotation in time of the woody and the crop components of the system. The modification in the microclimatic conditions generally produced by agroforestry (milder radiation, temperature and dryness) meant that these integrated systems were more suitable for the southern part of Europe. This may be one of the reasons why the number of extant agroforestry systems is more prominent in the Mediterranean biogeographic region of Europe than in more northerly regions (Tables 1 and 2) (Papanastasis et al. 2009; Pardini et al. 2009). The long summer drought period found in the Mediterranean area results in little tree growth and unreliable crop production, so pastoralism has always been the predominant land use. Animals managed in a traditional way on these lands graze stubble and the rough vegetation of forests and agrarian land. Stocking rates can be adjusted to match seasonal forage availability, and this is easier with smaller ruminants such as sheep or goats than with cattle due to the small size of the former (Pardini 2009). Moreover, cows eat pasture by pulling up the plant and sometimes the roots with their tong. On the contrary, goats and sheep cut the grass due to their specific mouth morphology (Mosquera-Losada et al. 1999). Therefore, goats or sheep are preferred to cows that cause bare patches on ground that are more difficult to regenerate in the Mediterranean than in more humid environments. Consequently, in Mediterranean systems, pastoralism is actually the main link between the agricultural and forestry

Table 2 Conifer tree species in stands where agroforestry practices were cited and percentage of each tree species in the European Union

Tree genera and species		European biogeographic regions							
		Med	Atl	Alp	Pan	Con	Art	Mac	Total area (%)
Abies	*A. alba* Mill.	X		X					1.6
	A. borisii-regis Mattf.	X							<0.2
	A. cephalonica Loud.	X							0.2
Cupressus	*C. sempervirens* L.	X						X	<0.2
Juniperus	*J. sabina* L.	X							<0.2
	J. communis L.	X							<0.2
	J. thurifera L.	X							<0.2
Larix	*L. decidua* Mill.			X					0.8
	L. kaempferi (Lam.) Carr.	X							<0.2
Picea	*P. abies* (L.) H. Karst.			X					21
Pinus	*P. brutia* Ten.	X						X	<0.2
	P. halepensis Mill.	X							1.2
	P. leucodermis Ant.	X							<0.2
	P. nigra J.F. Arnold	X		X	X				1.8
	P. pinaster Aiton	X							2.5
	P. pinea L.	X							0.2
	P. radiata D. Don		X						<0.2
	P. sylvestris L.	X	X	X		X	X		31
	P. uncinata Raymond ex DC. In Lam & DC.	X							0.4
Pseudotsuga	*P. menziesii* (Mirb.) Franco		X						<0.2

Source: Köble and Seufert (2011)

Med Mediterranean, *Atl* Atlantic, *Alp* Alpine, *Pan* Pannonian, *Con* Continental, *Art* Artic, *Mac* Macaronesian resources (Papanastasis et al. 2009). The modification of microclimatic conditions by the tree, such as the higher temperatures found under trees than in open areas in the coldest areas of Europe, may be one of the reasons why the combination of trees and pasture is currently used in alpine areas, both in mountains and in northern European countries (Rigueiro-Rodríguez et al. 2010b). It should also be noted, however, that some important AFS, such as pig farms using oak forests in Germany, originate from animal rearing based on tree resources in the medieval times (Luick 2009).

The need to use forests as a source of nutrients to maintain soil fertility on agricultural land was reduced in the 1930s with the manufacture of mineral fertilizers and their subsequent use across Europe (Isherwood 2000). This was also associated with increased mechanization on arable land, a reduced need for labour and a general increase in the quality of life for farmers (Angus et al. 2009). During the twentieth century, the increase in population and associated need for food generally led to an increase in the arable area (Angus et al. 2009). In many areas, the presence of widely spaced trees in cropland was seen as a hindrance because of the reduced crop area and increased difficulty for mechanization. The EU Common Agricultural Policy (CAP) until the early 1990s placed no emphasis on the environmental benefits of integrated tree and agricultural systems and farmers maximized their agricultural subsidies by maximizing the cropped area on their farms (Graves et al. 2009). The reduction in the practice of agroforestry was also a consequence of re-parcelling and land consolidation programmes carried out in most of the regions during the twentieth century. These measures effectively eliminated thousands of kilometres of tree and bush lines in Europe (Miguel et al. 2000). However, the reduction of forested area was less important in Mediterranean countries, where the use of fertilizers in rain-fed cropland is less profitable. An EU research project dealing with AFS concluded that loss of many traditional agroforestry systems in Europe had unfortunate consequences: loss of the knowledge base amongst farmers, simplification and standardization of landscapes, increased environmental problems such as soil erosion and water pollution, significant carbon release, reduction of biodiversity, loss of habitat for natural enemies of crop pests and the loss of a source of alternative income for farmers (Dupraz et al. 2005).

Since the 1992 reform of the CAP, the EU governments have increasingly valued the multiple services provided by forest and agricultural lands and provided incentives to increase the amount of woodland on agricultural land. Indeed, there has been a 7 % increase in the area under forest (trees) in the EU since 1990 (FAO 2011). In some instances, this has led to a reduction in agroforestry areas due to land abandonment (Garbarino et al. 2011). European policies have focused on objectives such as biodiversity conservation, improved water quality, increased carbon sequestration and soil, water and nutrient conservation, which are valued by European citizens (Eurobarometer 2008) – the very same issues that could be addressed by the promotion of AFS. Further, AFS can reduce fire risk in forest areas and promote carbon sequestration compared with exclusive arable monocultures (Nair et al. 2009, 2010; Mosquera-Losada et al. 2011b).

Current Status of Agroforestry Systems in Europe

Most of the agroforestry systems practised globally – silvoarable, forest farming, riparian buffer strips, improved fallow, multipurpose trees and silvopasture (Nair 1994; AFTA 1997; Alavalapati and Nair 2001; Alavalapati et al. 2004) – can also be found in Europe (Mosquera-Losada et al. 2009a, b) and are detailed in Table 1.

The Tree Component

Current agroforestry practices in Europe are based on a relatively narrow range of dominant tree species (Tables 2 and 3). Most of them are broad-leaved (74 %) and are found in Mediterranean environments (71 %). Indeed, oaks are the predominant tree species in current European agroforestry systems (17 species) and are particularly common in the Mediterranean. In Spain, *Quercus ilex* L. and *Q. suber* L. are the most widely found; in Greece, *Q. humilis* Mill., *Q. frainetto* Ten., *Q. coccifera* L. and *Q. trojana* Webb; and, in Italy, *Q. cerris* L., *Q. humilis* Mill. and *Q. suber* L. (Dupraz et al. 2005; Pardini 2009; Papanastasis et al. 2009). The coniferous agroforestry tree species are commonly found in the high altitudes of the Mediterranean mountains, where almost all systems are silvopastoral with coniferous species such as pines (*Pinus nigra* Arn. and *P. sylvestris* L.), junipers (*Juniperus communis* L. and *J. sabina* L.) and firs (*Abies cephalonica* Loud. and *A.* x *borisii-regis* Mattf.). Pines such as *P. halepensis* Mill. and *P. brutia* Ten. on the coast of Greece, *P. pinaster* Aiton on the coast of Italy and *P. pinea* L. and *Cupressus sempervirens* L. on the inlands of Italy are also broadly used in silvopastoral systems in the lowland Mediterranean area (Papanastasis 2004; Papanastasis et al. 2009; Pardini et al. 2009).

Agroforestry Practices in Europe

Dehesa (in Spain) or montados (as they are called in Portugal) are the most important broad-leaved agroforestry systems in Europe (Fig. 1). They occupy an estimated 3.1 million ha in the southwestern part of the Iberian Peninsula (Moreno and Pulido 2009). The most common species of oaks in this system are *Q. ilex* and *Q. suber* and to a lesser extent, deciduous oaks like *Q. faginea* Lam. and *Q. pyrenaica* Willd.; these species are appreciated because of the value of their acorns as food resource for animals grazing underneath. The structure, function, management and persistence of the dehesa system have been reviewed thoroughly by Moreno and Pulido (2009).

By contrast, reindeer husbandry systems based on forest understorey resources in Finland, Norway and Sweden extend to 41.4 million ha and occupy 33 %, 34 % and 40 % of the total area of these countries, respectively (Jernsletten and Klokov 2002). Reindeer feed on the lichens growing in the understorey in northern forests,

Table 3 Broad-leaved tree species in stands where agroforestry practices were cited and percentage of each tree species in the European Union

Tree genera and species		European biogeographic regions							
		Med	Atl	Alp	Pan	Con	Art	Mac	Total area (%)
Acer	*A. campestre* L.	X							<0.2
	A. negundo L.				X				<0.2
	A. pseudoplatanus L.			X	X				<0.2
Alnus	*A. cordata* (Loisel.) Duby		X						<0.2
Betula pubescens	*B. pubescens* Ehrh.	X	X						5.0
Castanea	*C. sativa* Mill.	X	X						1.1
Celtis	*C. australis* L.	X							<0.2
	*C. occidentalis*L.				X				<0.2
Ceratonia	*C. siliqua* L.	X						X	<0.2
Corylus	*C. avellana* L.	X	X		X				<0.2
Cydonia	*C. oblonga* Mill.								<0.2
Eucalyptus	*E. globulus* Labill.		X						<0.2
	Eucalyptus spp.								0.9
Fagus	*F. sylvatica* L.	X	X	X					7.1
Ficus	*F. carica* L.	X						X	<0.2
Fraxinus	*F. excelsior* L.	X	X			X			0.6
Juglans	*J. regia* L.		X	X					<0.2
	J. nigra x J. regia		X						<0.2
Malus	*M. communis* f. mitis (Wallr.) Gams in Hegi	X							<0.2
Morus	*M. alba* L.	X							<0.2

(continued)

Table 3 (continued)

Tree genera and species		European biogeographic regions							
		Med	Atl	Alp	Pan	Con	Art	Mac	Total area (%)
Quercus	*Q. calliprinos* Webb	X							<0.2
	Q. canariensis Willd.	X							<0.2
	Q. cerris L.	X							1.0
	Q. coccifera L.	X						X	0.2
	Q. faginea Lam.	X	X						0.2
	Q. frainetto Ten.	X							0.7
	Q. humilis Mill.	X							1.8
	Q. ilex L.	X							2.2
	Q. macrolepis Kotschy	X						X	<0.2
	Q. lusitanica Lam.	X							<0.2
	Q. petraea (Matt.) Liebl	X			X	X			2.2
	Q. pyrenaica Willd.	X							0.7
	Q. robur L.		X						3.0
	Q. rotundifolia Lam.	X							0.2
	Q. suber L.	X							0.9
	Q. trojana Webb	X							<0.2
	Q. rubra L.		X						<0.2
Olea	*O. europaea* L.	X						X	<0.2
Pyrus	*P. amygdaliformis* Vill.	X							<0.2
	P. communis L.	X							<0.2
Populus	*P. alba*L.				X				<0.2
	Populus spp. (clones de chopos híbridos)	X	X						<0.2
	P. nigra L.				X				<0.2
	Populusnigra L. subsp. *thevestina* (Dode) Maire	X							<0.2

Prunus	*P. dulcis* Mill.	X						X	<0.2
	P. armeniaca L.	X							<0.2
	P. avium L.	X	X		X				<0.2
	P. domestica L.	X							<0.2
	P. persica (L.) Batsch	X							<0.2
	P. serotina Ehrh.				X				<0.2
Robinia	*R. pseudacacia* L.	X			X			X	0.5
Sorbus	*S. aria* (L.) Crantz			X	X				<0.2
	S. aucuparia L.			X	X				<0.2
	S. torminalis (L.) Crantz				X				<0.2
Tilia	*Tilia* spp.				X				0.2
Ulmus	*U. minor* Mill.	X							<0.2
	U. glabra Huds.			X					<0.2

Source: Köble and Seufert (2011)
Med Mediterranean, *Atl* Atlantic, *Alp* Alpine, *Pan* Pannonian, *Con* Continental, *Art* Artic, *Mac* Macaronesian

Fig. 1 A typical dehesa with ~80-year-old scattered holm oaks (*Quercus ilex* L.), in a stand density of ~40 trees ha^{-1}, and a native understorey of annual pasture in northern Extremadura, Spain. Pasture is permanently grazed by native breed of cows (Retinta) and bulls (Blanco cacereño) (Photo credit: Gerardo Moreno)

mainly under *Pinus sylvestris* and *Picea abie*s (L.) H. Karst. (Jernsletten and Klokov 2002). Agroforestry systems based on *Pinus sylvestris* occur in most European agroclimatic regions, mainly because of the widespread distribution of the species – 31 % of 30 European Union countries' (Finland, Sweden, Norway, Denmark, the Netherlands, Luxembourg, Belgian, Ireland, the United Kingdom, Estonia, Latvia, Lithuania, Belarus, Poland, Moldova, Romania, Bulgaria, Czech Republic, Slovakia, Hungary, Austria, Croatia, Slovenia, Germany, Italy, France, Spain, Portugal, Greece, Switzerland) forested area is under *P. sylvestris,* followed by 21 % under *Picea abies* (Köble and Seufert 2011).

Papanastasis et al. (2009) described 40 prominent silvoarable and silvopastoral systems in Greece. The most common systems include walnut (*Juglans regia* L.), almond (*Prunus dulcis* (Mill.) Webb), mulberry (*Morus alba* L.) and poplars (*Populus nigra* L. subsp. *thevestina* (Dode) Maire), olive (*Olea europaea*), carob (*Ceratonia siliqua* L.) and fig (*Ficus carica* L.) with associated crops such as maize (*Zea mays* L.) and other cereals, tobacco (*Nicotiana tabacum* L.), vines, vegetables and various forage crops (mainly lucerne (*Medicago sativa* L.)). Those systems that involve cereal crops often become agrosilvopastoral as livestock graze the stubble after grain harvest (Yiakoulaki et al. 2005; Correal et al. 2009).

In the UK, the most promising new AFS are those where trees have a particularly high value, for example, orchard intercropping systems, or the presence of trees provides animal welfare and marketing benefits, for example, "woodland eggs" from free-range hens roaming under trees.[1] Woodland grazing systems are also being encouraged within existing forests to increase understorey diversity and the regeneration of some tree species. Parkland systems, involving widely spaced broad-leaved trees in grazed pasture, are also widely valued for their landscape, biodiversity and cultural value (Isted 2006). Other systems where the trees, and crops and animals are less closely mixed include shelterbelts to provide wind protection to animals and crops, tree belts to capture ammonia from intensive pig and poultry units, and riparian planting (Hislop and Claridge 2000; McAdam 2006). The widespread traditional practice of surrounding fields with hedges including trees also results in an "agroforestry landscape." Lastly, the increased planting of perennial crops (other than just grass) in the UK (e.g. *Miscanthus*, short rotation coppice, vines and even tea) also provides farmers with more opportunities than a simple divide amongst annual arable crops, grasslands and perennial woodland systems (Lawson et al. 2011).

In Germany, the best-known extant agroforestry systems are "open orchards" (Reeg 2011). However, alley cropping agroforestry practices with fast-growing tree species such as poplar (*Populus* spp.), willow (*Salix* spp.) and black locust (*Robinia pseudoacacia* L.) treated as short rotation coppices (SRC) are currently recommended for biomass production, as they improve the use of resources and biodiversity levels compared to traditional agrarian practices (Grünewald et al. 2007; Quinkenstein et al. 2009). In recent years, many scientific as well as practical efforts have been made to promote "modern agroforestry" for its ecological benefits and to obtain higher-value wood products (e.g. veneer), especially in the southern part of Germany (Bender et al. 2009; Reeg et al. 2009). In the past, line belts were also very important in northern Europe, but since the end of the 1960s, they have been reduced by 40–80 % (Herzog 2000). Shelterbelts, windbreaks and forest belts are currently used in Hungary to protect crops and livestock from adverse factors such as strong winds (Takács and Frank 2009).

Silvopastoral practices, which include forest or woodland grazing (Fig. 2) and open forest areas, are the most important AFS in Europe; these include the before-mentioned dehesas and reindeer husbandry in coniferous forests (Mosquera-Losada et al. 2009a, b). Forest farming, which includes the production of natural or cultivated special crops for medicinal, ornamental or culinary uses, is an important type of AFS when the significant economic returns are taken into account. However, most of the harvesting practices of these non-timber products (mushrooms, medicinal plants, truffles, berries, etc.) are not controlled. European black truffle (*T. nigrum* Bull.) production systems are exclusively found in holm oak (*Quercus ilex*), downy oak (*Quercus humilis*) and hazel (*Corylus avellana* L.) forests of Spain, Greece and Italy and have been recently described by Reyna-Domenech and García-Barreda (2009). Riparian buffer strips (strips of perennial vegetation (tree/shrub/grass) between croplands/pastures and water sources to protect water quality) can be found in most of the countries of Europe, whereas improved fallow (fast-growing, preferably

Fig. 2 A silvopasture practice at Lugo, Spain. Radiate pine (*Pinus radiata*) planted in 1970 at 3.5 m×3.5 m spacing (photo 2005) at a density of 800 trees ha^{-1}. Horse authocthonous breed: Cabalo Galego de Monte. The understorey is mainly gorse (*Ulex europaeus*) (Photo credit: José Javier Santiago-Freijanes)

leguminous woody species planted during the fallow phase of shifting cultivation) is less common (Mosquera-Losada et al. 2009a, b). Multipurpose trees are nowadays mainly managed for the production of fruits such as *Quercus* spp. acorns or chestnut (*Castanea sativa* Mill.), which are of great use to feed pigs (Moreno and Pulido 2009; Mosquera-Losada et al. 2009a, b; Papanastasis et al. 2009).

Production Benefits

The principal objectives of agroforestry practices vary across Europe. In Mediterranean countries, the focus was on improving production up to the 1970s and then slowly incorporated environmental benefits (Pardini 2009; Rigueiro-Rodríguez et al. 2009). Profitability depends on the outputs that agroforestry systems provide and the value given by society to all of their products in a given period of time (Campos et al. 2010). For example, up until the 1960s, *Q. suber* (cork) dehesas were less valued than *Q. ilex* dehesas because cork was not marketed and the nutritive value of cork acorns is lower than those of *Q. ilex* (Rodríguez-Estévez et al. 2007). However, since around the 1980s, the importance of cork products has raised the economic value of *Q. suber* over *Q. ilex* dehesas. In some cases, like in silvopastoral system shaped by ash trees or other riparian trees planted in lines or scattered through, the timber harvest from the trees acts as an insurance for the owner as it can generate additional income (Castro 2009). Also, in the chestnut orchards or coppice systems, mushroom production increases the income from the system. The increased productivity associated with Mediterranean agroforestry is usually focused on the tree component providing animal feed (fruits and leaves) during drought or timber, firewood, charcoal and cork (from *Q. suber*). The marketability and profitability of some of these products is increased by using niche labelling (e.g. organic) or through associated activities such as rural tourism, especially farm tourism and on-farm game hunting (Pinto-Correia and Mascarenhas 1999; San Miguel-Ayanz 2006; Pardini 2009; Campos et al. 2010). Currently, many marginal farms survive by generating income from services related to environmental conservation which are funded and promoted by the EU and national policies (especially biodiversity conservation, soil protection via erosion control and forest fire prevention). The land-use focus has shifted to a multifunctionality of land uses. This increased focus on nature and landscape conservation also creates new opportunities for income generation from these systems (Palma et al. 2007; Castro 2009).

The long rotation period for trees in AFS means that estimates of the financial value of such systems must usually be based on models (Graves et al. 2005, 2011). Such models require simulation of the interactions of tree and understorey yields (van der Werf et al. 2007). In a silvopastoral system model, ash (*Fraxinus excelsior* L.) growing in lowland UK (Fig. 3) gave an increment of 15 % of the net present value when compared with treeless pastures (Sibbald 1996). The use of an AFS instead of either a conventional forestry system or a livestock grazing increased profitability around 53 % and 17 %, respectively, in a model for *Pinus radiata* D. Don stands (Fernández-Núñez et al. 2007). McAdam et al. (1999a) and Thomas and Willis (2000) found that under a range of changes in commodity prices (food and timber) and agricultural subsidy support, silvopasture (ash at 400 stems per ha) had a net benefit over agriculture (sheep grazing) ranging from 34 % (food prices constant, 1 % increase in timber price, 25 % reduction in grazing over 10 years) to 181 % (food prices down 2 %, timber prices up 2 %).

From 2001 to 2005, the Silvoarable Agroforestry for Europe (SAFE) project (Graves et al. 2007) developed a system to evaluate the biophysical and economic performance of arable, forestry and silvoarable systems in Spain, France and the Netherlands. Results showed that growing trees and crops in silvoarable systems was more productive than growing them separately (Borrell et al. 2005; Graves et al. 2007; Palma et al. 2007). Conditions that are favourable for high profitability appeared to include the use of relatively high tree densities to make full use of available resources, the use of deciduous trees and autumn-planted crops to make complementary use of light and high soil water availability to ensure that extra biomass production could be sustained. The financial predictions indicated that silvoarable systems (Fig. 4) were most attractive where both components of the system were profitable as monocultures, since an unprofitable, or relatively unprofitable component, also reduced the profitability of the mixed system.

Fig. 3 A pasture of mainly perennial ryegrass (*Lolium perenne*) under ash trees (*Fraxinus excelsior*) planted in 1989 (photo 2005) at a spacing 5 m × 5 m and stand density of 400 trees ha^{-1} in AFBI Loughgall, N. Ireland. Sheep breed: Wicklow cheviot X (Photo credit: Rodrigo Olave)

Fig. 4 A silvoarable practice at Les Eduts, France. Walnut tree (*Juglans nigra*) planted in 1978 (photo 2007) at a density of 70 trees ha^{-1} (spacing 14 m × 10 m); the arable crop is wheat (*Triticum aestivum*) (Photo credit: Fabien Liagre)

Profitability was maximized with the use of high-value trees such as walnut or short rotation trees such as poplar. It was also predicted that holm oak and stone pine (*Pinus pinea*) silvoarable systems would cause only small reductions in crop yields, relative to those in arable systems. Since these trees (oaks) are of ecological and landscape importance, for example, in areas of open woodlands (dehesas), rather than of timber production importance, additional support in the form of an agri-environment payment could be justified as for those systems with high productive trees like walnut and poplar in France. By contrast, agroforestry systems were relatively unattractive in the Netherlands, based on assumptions of a low value for timber and the particularly high returns obtained from arable land.

Environmental Benefits

Environmental benefits of AFS comprise their positive impact on biodiversity, nutrient cycling (McAdam 2000; McAdam and McEvoy 2009; Rois-Díaz et al. 2006; Moreno and Pulido 2009; Rigueiro-Rodríguez et al. 2010b; Dupraz et al. 2005), water quality and carbon sequestration (Dupraz et al. 2005; Mosquera-Losada et al. 2011b).

Biodiversity

Biodiversity is conserved and generally enhanced in AFS, compared to conventional agricultural systems (Tuupanen et al. 1997; Rigueiro-Rodríguez et al. 2010b), and in some cases, biodiversity levels are greater than in both agricultural and woodland systems (McAdam et al. 1999b). Biodiversity is modified as a result of establishing an agroforestry system, which creates an ecosystem where biodiversity depends on the initial soil conditions (Mosquera-Losada et al. 2009a, b), tree species (conifer vs. broad-leaved) and the planting density (Rigueiro-Rodríguez et al. 2010a). At a plot scale, the presence of a tree creates heterogeneity in ecological factors such as radiation, humidity and temperature, and this creates different microhabitats for plant and animal species (Rigueiro-Rodríguez et al. 2010b).

Dehesas are considered one of the most biodiverse ecosystems in Europe (Moreno and Pulido 2009), and the implementation of proper agroforestry practices could maintain this biodiversity (Díaz et al. 1997). In these systems, the rotation of arable and pasture crops under the trees promotes annual species to grow, and this helps explain this high diversity. This heterogeneity is not found in exclusive agronomic systems where uniformity is encouraged or traditional forest systems where there is a full canopy cover. The presence of different animal species in silvopastoral systems or silvoarable systems that use the stubble to feed animals causes disturbances, which usually increase biodiversity (Buttler et al. 2009).

Afforestation with fast-growing coniferous tree species instead of broad-leaves planted at a high density on former agricultural land causes a clear reduction in cover and number of pasture species. Biodiversity reduction is mainly explained by the rapid light reduction and the development of a thick layer of needles caused by the natural pruning process of the tree branches due to the lack of light (Rigueiro-Rodríguez et al. 2010a). Short rotation coppice taken as a component of an agroforestry system might increase animal diversity when compared with arable land by enhancing the structural richness, especially in cleared agricultural landscapes (Schulz et al. 2009).

The importance of agroforestry for biodiversity conservation is also associated with the landscapes and the practices linked to their management. For example, transhumance, the seasonal movement of animals from lowlands to highlands and vice versa, is a traditional practice in Mediterranean Europe and is very important for biodiversity (Bunce et al. 2009). It acts as an ecological connection between lowlands and highlands, but it also connects open and wooded areas placed at short distances along the corridors or paths along which animals are shepherded. In Italy, any remaining transhumance is now performed using trucks to transport the animals, and it is still in use so as to maintain the natural diversity and floristic attraction of pastures in places where tourism is important, such as in the Alps (Staglianò et al. 2000). In Greece, special silvopastoral habitats are created along these corridors characterized by pruned oak trees; the branches of these trees are used for feeding animals or building temporary huts for sheltering shepherds and their families (Ispikoudis et al. 2004; Papanastasis et al. 2009).

Nowadays, the destruction of some bird habitats due to the reduction of forests could be overcome to a certain extent if scattered trees were established between those smaller forests and planted at a minimal distance that allows those forests to be connected to one another. This is particularly important in those countries with a small forest area such as in the central Atlantic biogeographic region of Europe. In the United Kingdom, agroforestry harbours greater bird diversity than forested areas (Toal and McAdam 1995; Burgess 1999). Bergmeier et al. (2010) state that silvopastures are a "habitat of importance" for at least 37 European bird species, while for another 18 species, a high proportion of their European populations use this habitat too. A high number of the threatened and red-listed vascular plant species in central Europe are associated with silvopastoral areas (Bergmeier et al. 2010). While most of these species can be found in thermophilous woodland habitats in southern Europe, they are mainly found in silvopastoral habitats of northern Europe (Bergmeier et al. 2010). In the United Kingdom, arthropod biodiversity including beetles, spiders and snails was higher in silvopastoral and silvoarable systems than in open grassland (Peng et al. 1993; Cuthbertson and McAdam 1996; Dennis et al. 1996; McAdam et al. 1997).

Agroforestry systems are also linked to the use of marginal lands to which indigenous livestock breeds are adapted and where very productive and resource-demanding breeds are not so profitable. This is highly relevant as Europe holds around half of the world's livestock breeds, and half of them are endangered (Mosquera-Losada et al. 2005).

Nutrient Cycling and Water Quality

Temperate AFS generally result in greater nutrient cycling than pure agricultural crops because the leached nutrients from the crop rhizosphere layer can be captured by the deeper roots of trees once the crops are not able to take them up due to excess of inputs or the lack of crop growth (Lehmann 2001; Reisner et al. 2007; Bambo et al. 2009; Rigueiro-Rodríguez et al. 2009; Dupraz et al. 2005). In addition, these nutrients are made available again for crops once tree leaves fall down on the soil as leaf litter. This explains why soil fertility is higher below than at a distance from trees in agroforestry (Moreno and Pulido 2009). Moreno et al. (2007) described how nitrogen (N), phosphorus (P), cation exchange capacity and exchangeable calcium (Ca^{2+}) and potassium (K^{+}) levels were increased near the trees in a dehesa system. The importance of this better nutrient use and recycling is clear: nutrients are not lost from the system thus avoiding reduction of soil fertility and potential contamination of watercourses.

Nitrate leaching into water bodies can cause eutrophication problems in rivers and seas, and it is regulated in Europe by the Nitrates Directive (Council Directive 91/676/EEC). Computer models have suggested that agroforestry (compared to agriculture) can reduce nitrate leaching in the Atlantic region of Europe, whereas the effect in rain-fed Mediterranean areas is limited (Palma et al. 2007). Moreover, nitrate leaching was reduced in sandy soils when a mixture of sweet cherry (*Prunus avium* L.) and pasture was developed in an irrigated sandy soil in a Mediterranean environment (López-Díaz et al. 2011). Silvoarable systems in a wheat (*Triticum aestivum* L.) intercropping experiment were also found to reduce nitrate leaching in the UK (Nichols et al. 2000). In Switzerland, agroforestry experiments established on fertile arable land showed that nitrate leaching could be reduced by 46 % over that from an arable crop alone (Kaeser et al. 2011). However, no nitrate reduction was found in newly established plantations (Mosquera-Losada et al. 2010) where trees were too young and had not developed enough to explore deeper soil layers. Agroforestry has also been shown to decrease soil erosion losses and the associated loss of P (Correal et al. 2009). In soils with low P-soil retention, silvopastoral (Nair et al. 2007) and alley cropping (Allen et al. 2006) practices were found to reduce phosphorus losses in sandy soils of Florida, USA.

Carbon Sequestration

Compared to treeless systems, agroforestry is able to sequester more carbon due to the tree component which is able to store it in wood and reach deeper soil layers and higher aerial height than arable crops, as found in silvopastoral and alley cropping agroforestry practices (Howlett et al. 2011; Mosquera-Losada et al. 2011b). Cultivation of perennial woody plants to produce biomass in alley cropping contributes significantly to carbon sequestration within the soil because it supports the formation of soil humus. Moreover, the produced biomass can be used to replace fossil energy resources that further increase the utility of alley cropping in mitigating the effects of climate change (Quinkenstein et al. 2009).

The importance of AFS in the total world carbon balance system is twofold: first, the already established AFS have a large reserve of carbon that should be maintained by the preservation of these systems, and, in some dry environments (Mediterranean), shrub colonization will be promoted, fire risk will be increased and large amounts of carbon will be released to the atmosphere (Moreno and Pulido 2009); second, the establishment of AFS on cropland as a way of land-use change will increase the carbon sequestered by terrestrial ecosystems and, therefore, will help fulfil the Kyoto requirements to mitigate climate change (Nair et al. 2010). The capacity of an AFS to sequester carbon should be related to the increase of soil carbon sequestered, as this component has the largest proportion of carbon within the terrestrial systems. Carbon sequestration in agroforestry will be promoted, not only by the roots colonizing deeper soil layers but also by the litter fall and deposition of senescent materials on the soil, which will act also as a carbon resource (Fernández-Núñez et al. 2010). The dynamics of soil carbon, as affected by microenvironmental conditions created by scattered trees, which in turn depends on the light interception by each specific tree species and by the growth rate of the tree, should be further studied (Mosquera-Losada et al. 2011b). In general, silvoarable practices are able to sequester less carbon in the upper soil layers when compared with silvopastoral or alley cropping practices with perennial crops in the same edaphoclimatic conditions due to accelerated decomposition of soil organic matter following soil tillage done as a soil management practice for crop production (Nair 2012).

Future Prospects of Agroforestry Systems in Europe

Indications from Recent Research Initiatives

The potential of agroforestry systems to deliver economic, environmental and social benefits in Europe has been demonstrated by national research programmes (e.g. McAdam et al. 1999a, b; Sibbald et al. 2001; Burgess et al. 2003, 2005; Mosquera-Losada et al. 2010) and EU research projects (Dupraz et al. 2005). There are also informal networks of scientists and growers across Europe, for example, the Farm Woodland Forum in the UK[2] (http://www.agroforestry.ac.uk), and the French Agroforestry Association[3] (http://www.agroforesterie.fr/). In Spain, the Spanish Grassland Society and the Spanish Forestry Society both have agroforestry working groups. A European Agroforestry Federation based in France has recently been created to coordinate national initiatives and influence European policies. In Greece, an agroforestry network was established in 2006. In Germany, a project called "agroforestry"[4] launched in 2005 and lasting 3 years was the first recent effort at applying the concepts of agroforestry as an approach to land use as an alternative to the spatially segregated practices of forestry and agriculture (Bender et al. 2009).

As has been demonstrated, AFS are generally more productive than treeless land-use systems (Dupraz et al. 2005; Rigueiro-Rodríguez et al. 2009). However, the importance of this fact depends on edaphoclimatic conditions and the proper choice of the species and planting configuration of the tree species as well as the understorey component. Once the tree is established, aspects related to pruning and thinning should be taken into account in order to promote understorey production and concentrate growth on individual trees (instead of volume per hectare) to deliver high-quality wood. On the other hand, there is also a need to study agroforestry system implementation in dense forest stands, as this could be a way of reducing forest fire risk in southern Europe and of avoiding costly clearing operations throughout Europe and at the same time generating additional income (wool, milk, mushrooms, etc.).

All these aspects should be evaluated for different types of trees and edaphoclimatic environments for new forms of agroforestry. Research in agroforestry system establishment should also take into account the tree growth when fast- or medium-growing species are considered and the effect they have on the light reaching the understorey and its productivity. They should be modelled and should serve as a basis for different tree and understorey price scenarios, similar to the economic model based on biophysical models for silvoarable systems developed by Dupraz et al. (2005). Compatibility between the understorey and tree components should be evaluated in different environments. It has been shown that understorey legumes enhance initial tree growth, while it is reduced by the traditional sown grasses (López-Díaz et al. 2008). Also, shrubs promote initial tree growth when compared with herbaceous species, but once tree roots colonize deep soil layers, shrubs reduce tree growth when compared with herbaceous understorey development (Mosquera-Losada et al. 2011a). Nevertheless, the role of shrub understorey on silvopastoral systems varies widely amongst species, and shrubs can have contrasted effects on pasture understorey and tree overstorey productivities (Rivest et al. 2011; Rolo and Moreno 2011). Aspects related to tree regeneration and tree health seem to be of high importance in established traditional agroforestry systems such as dehesas and montados. Models to describe the impact of a range of variables on such systems should also include both environmental benefits including contamination reduction, carbon sequestration and biodiversity, and social benefits like rural tourism, landscape improvement and hunting.

Policy and Institutional Support

The research carried out during the past decades in different countries of Europe helped to include the establishment of AFS as part of direct payments in the last rural development directive (EAFRD 2005). This is a highly relevant development considering the loss in economic viability of some traditional agroforestry systems in recent decades. The degree of implementation of the Rural Development Directive (EAFRD 2005) is, however, not extensive and homogeneous throughout Europe, and at present, there is no regional or national policy to improve silvoarable systems and make them economically viable (Eichorn et al. 2006).

In most regions of Spain, there are no specific programmes to implement the EU's Agroforestry Regulation (EAFRD 2005), but funds can be accessed (e.g. in the Galicia region) for woodland grazing, harvesting the understorey under the trees to reduce fire risk and fencing. In the Andalusia region of Spain, Robles et al. (2009) developed an innovative programme to use grazing animals to maintain firebreaks and reduce the fire risk in public forests. The programme that started in 2005 with five contracts involving 1,930 grazing animals and 520 ha currently (2011) involves 59 contracts, 34,005 grazing animals and 2,200 ha (Mirazo 2011). In Spain, several regions plan to support planting of new agroforestry plots, but the success of the programme is still marginal. Planting would focus on promoting (1) silvopastoral systems in native forest and afforested lands as a strategy for reducing fire hazard (mountainous regions) and water competition (Mediterranean regions), (2) conservation and multifunctional use of traditional silvopastoral systems to preserve their high biodiversity and (3) integration of quality timber trees with crops and pastures in intensively managed fields (Atlantic region and irrigated lands in Mediterranean regions) to reduce pollution caused by agrochemicals and enhance C sequestration on farmlands. Forest and firebreak grazing has also been used in France as a tool to reduce forest fire risk (Rubino 1996).

In Germany, there is currently no specific support for agroforestry, and many German farmers have no knowledge or experience of such integrated land-use systems. Furthermore, there is a lack of institutions to inform and advise farmers in this regard (Reeg 2011). However, the need to increase renewable energy production (particularly in the light of recent decisions against nuclear power) means that new ways must be sought to increase land productivity, such as short rotation coppice in combination with grassland or other crops. Such systems can result in ecological benefits (Dimitrou et al. 2009) or negative environmental externalities, especially with respect to water issues (Raftoyannis et al. 2011).

In Italy, the regional plans for implementation of the rural development regulation (1257/1999) have led to some interest in agroforestry systems. For example, in the Tuscany Region, the 2000–2006 rural development plan supported the conversion of cropped fields with over 30 % slope to pasture, planting of timber trees and energy biomass plantations on formerly cropped fields and establishment of windbreaks and hedges around fields. The new plan for 2007–2013 for Tuscany increased the level of support which now includes conversion of cropped fields with slopes more than 20 % to pasture, the establishment of timber trees in pasture or cropped fields and establishment of riparian buffers and truffle forests. These regional examples are in line with the rest of the country and demonstrate increased interest in environmental themes and the presence of legislative support to tree reintroduction in pastures and cropped fields, especially in steep areas.

In the UK, in the 2007–2013 rural development plans, the four regional governments (England, Scotland, Wales and Northern Ireland) did not provide specific support for the establishment of agroforestry systems, although there is support for forestry systems with widely spaced trees and for parkland systems. The new UK government elected in 2010 has recently set targets for increased tree planting, uptake of stewardship schemes, and expansion of linear features (DEFRA 2011), which should provide opportunities for agroforestry. In Northern Ireland, with certain stipulations, silvopasture establishment is fully eligible as an agricultural subsidy for paying farmers by the EU called Single Farm Payment.

There is still a consistent separation of forestry and agriculture (including intensive animal rearing) in most European countries. Although silvopastoral and silvoarable systems were experimentally established in several European countries in order to demonstrate their technical and economic feasibility to farmers, institutional and policy support for agroforestry is weak or non-existent in most countries. For example, in Italy, there are no national research programmes on the topics of agroforestry or agro-silvopastoral systems. In Germany, as there is currently a strong focus on enhancing woody biomass production, the future development of agroforestry will strongly be linked to the application of high productive short rotation forestry in alley cropping systems. In Greece, several efforts have been made in the last few years to attract the interest of land management authorities and farmers in the ecological and economic importance of the traditional agroforestry systems and stress the need for their conservation. These included seminars to foresters and agronomists, research projects to collect scientific information, inventories and dissemination networks. In 2006, the Greek Agroforestry Network was established to coordinate these activities. Nevertheless, Greece has not yet implemented article 44 of the EU regulation 1698/2005 about the financial support for agroforestry practices in Europe. In the UK, the Farm Woodland Forum continues to represent the interests of scientists and practitioners involved in agroforestry development. On the island of Ireland, where there are separate national controlling state bodies for agriculture and forestry, a Cross Border Agroforestry Development Group has been formed to establish demonstration sites on both sides of the border.

The most important European project dealing with agroforestry (SAFE project) concluded that at a European scale, 90 million ha are potentially suitable for silvoarable agroforestry and 65 million ha would benefit from silvoarable plantations to contribute to mitigation of some key environmental problems such as soil erosion or nitrate leaching. Even if 20 % of the farmers in these areas adopt agroforestry on 20 % of their farm, it would result in 2.6 million ha of silvoarable agroforestry in Europe (Reisner et al. 2007). The quality timber that would be available from this activity would help reduce the need of imported high-quality tropical timber as well as tropical deforestation, which is another important goal of the Kyoto protocol. However, within the latest European Rural Development document (EU 2009), it is expected that the established measures of AFS will only cover 60,000 ha of agricultural lands owned by 3,000 farmers. One of the main results of the SAFE programme was to underline the great interest of European farmers in silvoarable systems. A survey to evaluate the possibility of adoption of agroforestry practices by the farmers in individual country participants concluded that tree planting was no longer considered as an obstacle and almost 50 % of farmers were ready to set up a silvoarable plot on their own farm (Liagre et al. 2005). The evidence from this project has resulted in a new research and development programme being set up to promote agroforestry projects. The French National Association was created in 2007 and France counts now almost 4,000 ha of modern agroforestry (Liagre 2009).

In terms of tourism and other services offered by farms, a new kind of agro-silvo-pastoral system that integrates conventional agriculture and delivers a wider range of valuable services can considerably enhance tourism. These new integrated systems would benefit from the complexity based on their diversity of resources, which include agriculture, forestry and livestock rearing on pastures (Pardini et al. 2008a, b).

Development of policies to promote these systems as well as their implementation in the different regions of Europe should also be considered. Trends in modern social needs have increased people's awareness of environmental values. The Millennium Ecosystem Assessment[5] pointed out the consequences of ecosystem change for human well-being and proposes a value for each service/ecosystem. Hence, some of these systems could incorporate agroforestry practices as providers of services for human welfare, as proposed in the Millennium Ecosystem Assessment. These agroforestry practices are already being implemented in Portugal and are currently under development in other countries. A demonstration of (1) environmental benefits of agroforestry, (2) the types of agroforestry systems and practices that maximize benefits and (3) edaphoclimatic and socioeconomic conditions under which the goals are achievable is needed to assure the long-term support of European Common Agrarian Policy (CAP) funds to agroforestry implementation in Europe.

Education at different levels, to farmers, technicians, policymakers and university students, should also be established. Over the last few years, there have been various training courses in the different countries, including international courses (ERASMUS Program (EuRopean Community Action Scheme for the Mobility of University Students),[6] but, more efforts should be made to overcome the traditional separation between forestry, agricultural sciences and land management.

Even though European policies have encouraged land management systems that combine production, environmental services (biodiversity, carbon sequestration, nutrient cycling and water quality) and social benefits, and this has created a new interest in agroforestry systems, a strong effort should be made to increase the presence of agroforestry practices in the European continent. The benefits and opportunities offered by agroforestry can only be realized with substantial investments and coordinated efforts in research, education, knowledge transfer and appropriate national policies across Europe.

End Notes

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