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Silvoarable systems in Europe – past, present and future prospects

M.P. Eichhorn[1,8,*], P. Paris[2], F. Herzog[3], L.D. Incoll[1], F. Liagre[4], K. Mantzanas[5], M. Mayus[6], G. Moreno[6], V.P. Papanastasis[5], D.J. Pilbeam[1], A. Pisanelli[2] and C. Dupraz[7]
*[1]School of Biology, University of Leeds, Leeds LS2 9JT, UK; [2]Istituto di Biologia Agroambientale e Forestale, CNR, Villa Paolina, Via G. Marconi 2, 05010 Porano (TR), Italy; [3]Eidgenössische Forschungsanstalt für Agrarökologie und Landbau (FAL), Reckenholzstr, 191CH-8046 Zürich, Switzerland; [4]Assemblée Permanente des Chambres d'Agriculture, 9 Avenue George V, 75008 Paris, France; [5]Laboratory of Rangeland Ecology, Aristotle University, 54124, Thessaloniki, Greece; [6]Centro Universitario, Forestry School, Avd. Virgen del Puerto 2, 10600 Plasencia – Cáceres, Spain; [7]INRA Montpellier, UMR Systèmes de Culture Méditerranéens et Tropicaux, 2 Place Viala, 34060 Montpellier Cédex, France; [8]Current address: Department of Animal and Plant Sciences, University of Sheffield, Western Bank, Sheffield S10 2TN, UK; *Author for correspondence (e-mail: m.eichhorn@sheffield.ac.uk; phone: +44-114-22 20112; fax: +44-114-22-20002)*

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Abstract

Mixed systems of agriculture incorporating combinations of trees and crops have formed key elements of the landscape of Europe throughout historical times, and many such systems continue to function in the present day. In many cases they represent formerly widespread traditional systems in decline and a number have already become extinct or exist only in a threatened state. The causes are both practical and economic. The agricultural subsidy regime within the European Union is presently unfavourable towards silvoarable practices, which has been a major factor in their recent decline. The silvoarable systems of Europe can be split into two classes according to location – northern Europe and the Mediterranean. The latter contains not only a greater area of silvoarable cultivation, but also a greater diversity of systems due to the broader range of commercial tree and crop species grown. In general, the systems of northern Europe are limited by light, whilst those of the Mediterranean are limited by the availability of water. Mixed systems of agriculture present an opportunity for future European rural development and have the potential to contribute towards the increased sustainability of agriculture and enhancement of biodiversity, whilst preserving landscapes that are both culturally important and aesthetically pleasing. A better understanding of the legacy of traditional silvoarable systems, combined with the formulation of a consistent definition and specific European policy towards them will be invaluable in ensuring that the benefits of mixed agriculture are fully exploited in the future.

Introduction

Silvoarable agroforestry consists of widely spaced trees inter-cropped with annual or perennial crops. Such systems have traditionally formed important elements of the European landscape, and have the potential to make a positive contribution towards sustainable agriculture in Europe in the future.

The objective of this paper is to list and quantify the existing systems of silvoarable agroforestry in Europe and to document recent changes in this land use.

Trees have traditionally served three main purposes in the agrarian economy – the production of fruits, fodder and wood for fuel, litter or timber. In addition, they have amenity value, providing shade and shelter for labourers and livestock, and combat erosion by wind and water. When grown in combination with crops, trees compete for resources, and hence the modern convention is to separate forestry and agriculture into discrete areas of land. However, to focus on the deleterious effects of trees on associated crops is overly simplistic and ignores a range of both positive and negative effects on arable productivity (Jose et al. 2004).

Trees compete with adjacent crops for water, which can inhibit arable production in areas prone to drought unless winter crops are grown. Trees also intercept rain and aid the condensation of water droplets from fog and dew (Grove and Rackham 2001). By acting as windbreaks, they slow air movement and can reduce evaporative water losses from crops (Hawke and Wedderburn 1994; Jose et al. 2004). The deeper rooting systems of trees are thought to intercept drainage water and via the process of hydraulic lift may draw water from deeper soil horizons and release it into the upper horizons where it benefits shallower-rooted plants (Dawson 1993; van Noordwijk et al. 1996; Burgess et al. 1998; Jose et al. 2004). Similarly, although the shade cast by trees may limit the growth of crops, the consequent reduction in irradiance and hence transpiration may be beneficial in arid areas, especially when growing sensitive understorey vegetable crops; in some cases, there may be a moderate beneficial effect of shading for crop yield (Lin et al. 1999). In colder climates, the tree canopy may protect against ground frosts.

Although competition for nutrients may occur, the deeper rooting systems of trees also bring up nutrients from deeper soil layers and reduce nutrient leaching from the topsoil. These nutrients are then recycled via leaf litter and turnover of roots, thereby increasing the overall resource-use efficiency of the system (van Noordwijk et al. 1996; Jose et al. 2004). Litter can itself act as a buffer against wind and water erosion, thereby increasing the sustainability of agriculture by protecting the topsoil when crops are absent. Trees may also attract sheltering livestock, increasing the deposition of manure beneath them (Grove and Rackham 2001). Scattered trees in croplands and pastures are also likely to improve soil structural characteristics beneath their canopy (Joffre and Rambal 1988; Obrador-Olán et al. 2004).

The principle advantages of silvoarable systems are in yield diversification and the production of a short-term return on land while the planted trees are still small. In order to minimise the potential for negative interactions between trees and crops, careful selection of combinations of trees and associated arable crops which have positive interactions (facilitation) is essential. The most efficient and sustainable systems are those which optimise the use of spatial, temporal and physical resources by avoiding competition between component trees and crops (Jose et al. 2004). Research has shown that mixed systems can, in some circumstances, be more productive than monocultures, especially if the trees obtain resources that would otherwise be unavailable to the crops (Cannell et al. 1996), thereby reducing the need for agrochemicals (Vandermeer 1989). By developing a better understanding of enduring traditional systems and practices, we may gain insight into the potential future applications of silvoarable techniques and their advantages.

Historical perspective

When the original forests of Europe were cleared, trees with high value were retained in the landscape. These included various fruit trees in the Rosaceae, oaks (*Quercus* spp.) and beech (*Fagus* spp.) for their production of acorns and mast as animal forage, and ash (*Fraxinus* spp.) from which lopped branches were used as fodder (Dupraz and Newman 1997). These formed elements of early agroforestry systems and were continually replaced throughout history as they did not obstruct manual cultivation techniques.

The earliest evidence for planned agroforestry in Europe dates back as far as the Copper Age (c. 2500 BC). Stevenson and Harrison (1992) identified a change in the composition of pollen cores collected from south-western Spain, with mixed oak and pine forests being replaced by scattered oaks and herbaceous vegetation. A large proportion of the identifiable pollen was from weeds of cultivation. They defined this shift as the beginnings of the *dehesas*, a land-use system characterised by partial woodland clearance followed by intermittent cultivation and grazing. Some workers have argued that the transition occurred during a period of climatic change when the region was becoming more arid (Grove and Rackham 2001). A similar and concurrent change in Italy has been identified as a possible shift towards using land for wood-pasture (Potter 1979).

The earliest stages of agriculture involved systems of shifting cultivation, with intercalated agricultural and forestry land use. As civilisation progressed towards more stable patterns of agriculture, woodland grazing and silvopastoral systems were abundant, and there was a continuous transfer of fertility from woods to cultivated land via manure (Piussi 1994). Branches of ash, elm, poplar and other trees were collected and stored to provide fodder for livestock (Meiggs 1982; Ispikoudis et al. 2004). The maintenance of soil fertility was based upon a strict connectivity between agriculture, animal husbandry and forestry. Eckert (1995) estimated that, up until 1500, 75% of the nitrogen and 90% of the phosphorus required for arable fertilisation in the Neidlingen valley (Baden-Wurttemberg, Germany) came from woodlands in the form of residues of fodder and litter (manure was often mixed with litter and spread on fields as a fertiliser) or ash from domestic fires. In classical times, charcoal was used as a source of potassium to fertilise fields (Scharrer 1958). This input was vital to maintain the sustainability of agriculture.

A further reason for the maintenance of trees in the landscape was the production of fruit for human consumption. Fruit was an essential part of the diet, being a crucial source of many vitamins (Herzog 1998a), and was culturally important for the production of alcohol. Many economically valuable tree species are dual-purpose, producing an annual fruit crop and ultimately a valuable timber end product (e.g. cherry, walnut) often in addition to litter and fuel wood.

In the Middle Ages, with the introduction of sustainable crop rotations, soil fertility became less dependent upon the transfer of nutrients from woods. This process was accelerated during the 19th century by the introduction of chemical fertilisers in most parts of Europe. Nowadays forestry and agriculture are discrete activities with few chemical and energetic relationships. Nevertheless, many historical agroforestry practices continue to be maintained in a traditional fashion.

At present, information regarding the status of agroforestry in general, and of silvoarable systems in particular, is quite poor in Europe due to a bias towards single crop systems in both research activities and institutional interests. Throughout the last century, there has been a marked decline in the use of silvoarable agroforestry systems across Western Europe. In many countries this decline can be attributed to the same basic causes:

- Scattered trees in arable landscapes impede mechanised agriculture and have been deliberately removed or were damaged by machinery.
- The post-war drive for increased yields led to a focus on maximising productivity through monocultural systems.
- A reduction of manpower in agriculture limited the commercial viability of labour-intensive systems, such as full stature fruit tree orchards, thus decreasing the number of systems in which arable intercropping was viable.
- Consolidation of fragmented land holdings into larger single farms and fields removed boundary trees and reduced the scope for landscape diversity.
- The subsidy regime of the Common Agricultural Policy (CAP) led indirectly to a reduction in crop associations by favouring single crop systems.
- Wooded areas were for many years ineligible for direct subsidy payments, and in many regions trees were removed to increase subsidy income.
- A stricter quality norm applied to dessert fruit (EEC regulation 1641/71) tended to standardise their production in intensively managed orchards.

Traditional silvoarable systems have gradually been abandoned in marginal agricultural areas, but on more productive soils have been replaced by crop monocultures. There is no motivation for farmers to maintain silvoarable systems which have often been perceived as an obstacle to modernisation via mechanisation.

Collection of data

This paper collates contributions from seven European countries (France, Greece, Germany, Italy, Spain, The Netherlands and the United Kingdom). These result from collection of information from bibliographical and other sources (e.g. official statistics, personal contacts and internet sites). In addition, inventories of silvoarable systems from local to national levels were compiled within the EU-funded Silvoarable Agroforestry For Europe (SAFE) project during its first year (2001–2002). In Germany, Greece and The Netherlands, these activities represented the first attempt to quantify the existing silvoarable systems in those countries. Sources of information varied between countries and the figures presented here represent the best available data.

Consistent difficulties were encountered during attempts to document the type and extent of silvoarable practices within each country. These included a lack of official statistical data resulting from a failure to distinguish between silvoarable agroforestry and conventional forestry plantations in land use surveys. The existing literature on silvoarable agroforestry was largely confined to local journals and magazines, and was inaccessible to conventional literature searches. There were also logistical difficulties in locating and contacting individual farmers to verify reports.

Systems

Silvoarable systems are considered to be those in which a long-term tree crop is combined with cultivation of a short-term (usually annual) crop on the same land. We distinguish silvoarable cultivation from silvopastoral systems in which exclusively fodder crops (legumes or grasses) are grown or which are grazed by livestock *in situ*. Some systems combine elements of silvoarable and silvopastoral cultivation; they are only included here if there is an arable component.

The combinations of trees and crops employed by European farmers are immensely varied. In this review we will concern ourselves only with those systems that are currently extensive, have been in the recent past (i.e. during the last century), or have clear potential for future commercial expansion.

The various systems are discussed in terms of their major productive trees, although the systems are often mixed in their function. Five categories are recognised: olives, fruit trees, timber trees, oaks and fodder trees. Fruit trees are considered to be those that provide a principle economic return from either fruits or nuts (e.g. almonds and walnuts) even where the trees are ultimately used for timber as the tree management practices differ markedly between fruit and timber-based systems, which require different optimal stem lengths and pruning regimes. The values presented for the extent of each system represent only those that are at least partly silvoarable, not the extent of olive groves or fruit orchards *per se*.

Other mixed forms of agriculture remain common in garden plots, and very small fields with trees on the boundaries are effectively silvoarable. These, however, are generally too small and inconsistent in their composition to be considered coherent systems in their own right. They represent the needs of individual farmers to maximise returns from a small area, and tend to be composed of fruit trees and vegetables for domestic consumption rather than for economic returns.

Regional trends

Climate imposes greater constraints on silvoarable productivity in northern Europe than in tropical or Mediterranean systems. Lower photon flux densities at higher latitudes make it increasingly difficult to support an economically viable ground crop beneath tree canopies. During the later stages of tree development, canopy closure prohibits the growth of many crops unless the tree rows are widely spaced. In linear systems, once tree height exceeds the width of the alley, the system is often no longer suitable for alley cropping.

In Mediterranean Europe, the silvoarable systems present in northern Europe are supplemented by a number of additional types. This is due to the greater diversity of economically valuable trees in the region, along with a natural tendency towards savannah-type vegetation in arid areas, since the relative size of the root system required to support the above-ground parts of the tree is greater, causing the trees to be naturally dispersed. In contrast to northern Europe, the limiting factor in most systems is water rather than light. The main additional tree species present in Mediterranean regions are olive (*Olea europaea* var. *europaea* L.), evergreen and deciduous oaks (*Quercus* spp.), carob (*Ceratonia siliqua* L.) and a greater number of Rosaceae species.

Over large parts of Mediterranean Europe, particularly the olive groves of central Italy or the *dehesas* and *montados* of southwestern Spain and Portugal, it is the trees themselves that define the landscape, and they form a consistent component within a variety of arable or pastoral land uses. They are seldom of a single dominant species, and are often spread throughout fields with no planned pattern or density. A great diversity of tree/crop associations therefore exists, and it is likely that all possible permutations occur, albeit only on a small scale, where they may be planted according to the specific needs of local farmers.

Olive tree systems

Olives form a continuous landscape element in many parts of southern Europe, with diverse crops sown between the trees (Table 1). This practice is thought to date back to pre-Roman times, when wheat was cultivated between rows of olive trees on alternate years, as this was known to increase the yield of olives in the following year. Groves were split into two sections on a rotation to increase the overall productivity (Lelle and Gold 1994). In Greece, olives cover an estimated 650,000 ha in total and are intercropped with cereals, vegetables and fodder crops (Schultz et al. 1987). Olive trees are typically planted in rows, although they may also be irregularly scattered when groves have been thinned. Oaks, carob, walnut (*Juglans regia* L.), almond (*Prunus dulcis* (Miller) D. A. Webb) and other fruit trees often form a minor mixed component.

In the central Italian regions of Umbria and Lazio, the silvoarable system formed by olive trees covers some 20,000 ha (Plate 1). As in Greece, they are commonly intercropped with cereals or fodder legumes. The olives form a consistent component of the landscape in contiguous silvo-pastoral and horticultural fields, either as scattered trees or in rows with 5–10 m between trees (a similar landscape survives in some parts of Spain, but has disappeared from France). Grape vines are sometimes grown along the tree rows as part of a formerly extensive system known as *piantata* (see below).

Fruit tree systems

Silvoarable systems based on fruit production (including nuts) covered extensive tracts in central Europe as recently as the last century, and remain widespread (Table 2). The *pré-vergers* are areas of low-density fruit tree plantations which double as grazing land; they are particularly abundant in northeast France. The fruit trees are often

Table 1. Extant silvoarable systems based around olive trees in Europe; their composition, present extent, structure and main economic products.

Component trees	Tree species	Location	Extent (ha)	Source	Stems ha-1	Layout	Firewood	Timber	Fruit	Fodder	Annual crops
1. Olive	*Olea europaea* var. *Europaea* L.	Italy	20,000	ISTAT 1990[a]	25–100	S/L	Y	Y	Y		C, V, FL, FG
2. Other fruit trees	Rosaceae	France	3000	F. Liagre[b]	25–300	S/L	Y		Y		C
		Greece	650,000	Schultz et al. (1987)	50–100	S/L	Y		Y		C, M, FL, GV, GF
		Spain	15,030	INE (2002)	50–100	L	Y		Y		C

Layout of trees is either scattered (S) or linear (L). Annual crops sown between the trees include maize (M), other cereals (C), vegetables (V), fodder legumes (FL), fodder grasses i.e. hay (FG), ground fruits such as strawberries (GF) and grape vines (GV). Fodder grasses and fodder legumes are only included if they form part of a rotation that includes arable crops. The same applies to maize where it is grown as a fodder crop.

[a]An estimated 20% of olive groves are intercropped (P. Paris).

[b]Estimated after consultation with National Office of Olive Tree Production and Administration (AFIDOL) and regional co-operatives.

Plate 1. Olive trees intercropped with wheat. Lazio, Italy.

Plate 2. Cherry trees intercropped with fodder beet. Saxony, Germany.

Plate 3. Walnut trees intercropped with vegetables. The trees are dual purpose, producing nuts and a timber end-product. Campania, Italy.

Plate 4. Poplar trees intercropped with wheat in an experimental plantation operated by the SAFE (Silvoarable Agroforestry For Europe) project. Vézenobres, France.

Plate 5. A *dehesa* landscape dominated by dispersed oak trees. Cáceres province, Extremadura, Spain.

Plate 6. A *dehesa* estate with scattered oak trees. The field in the foreground is pasture, while another area has been ploughed for cultivation in the autumn. Salamanca province, Castilla-León, Spain.

Plate 7. Cork oak trees intercropped with oats. Sardinia, Italy.

Plate 8. Oak trees intercropped with cereals. The distinctive branching pattern is caused by the annual shredding of leaves for fodder. Askio, Greece.

Table 2. Extant silvoarable systems based around fruit trees in Europe; their composition, present extent, structure and main economic products.

Component trees	Tree species	Location	Extent (ha)	Source	Stems ha^{-1}	Layout	Firewood	Timber	Fruit	Fodder	Annual crops
Almond	*Prunus dulcis* (Miller) D.A. Webb	Sicily	18,000	Cullotta et al. (1999)	50–100	S/L			Y		C, FL, FG
Mixed	Rosaceae	France	2000	Coulon et al. (2001)	50–300	S/L			Y		V, GV, GF
1. Peach	*Prunus persica* (L.) Batsch	France	100	Coulon et al. (2001)	200–300	L	Y		Y		GV
2. Walnut	*Juglans regia* L.										
3. Olive	*Olea europaea* var. *europaea* L.										
Mulberry	*Morus nigra* L.	N Greece	500	Schultz et al. (1987)	10–50	S/L			Y		M, FL, V
Fig	*Ficus carica* L.	Crete, Aegean Islands	10,200	Schultz et al. (1987)	10–50	S/L			Y	Y	C
Common pear	*Pyrus communis* L.	N & C Greece	7000	Schultz et al. (1987)	20–50	S/L	Y		Y		C, T, V, GV
Mixed	Rosaceae	Spain	13,484	INE (2002)	40–200	S/L			Y		C, M, V, BF

Layout of trees is either scattered (S) or linear (L). Annual crops sown between the trees include maize (M), other cereals (C), vegetables (V), tobacco (T), fodder legumes (FL), fodder grasses i.e. hay (FG), bush fruits such as *Ribes* spp. (BF), ground fruits such as strawberries (GF) and grape vines (GV). Fodder grasses and fodder legumes are only included if they form part of a rotation that includes arable crops. The same applies to maize where it is grown as a fodder crop.

dual-purpose and produce a timber end-product, especially walnut, pear (*Pyrus communis* L.) and apple (*Malus domestica* Borkh.). Some of these plantations are intercropped during the early years of tree growth, especially walnut plantations in the regions of Dauphiné and Périgord, covering 15,000 ha. Around 4,000 ha may be silvoarable at any one time (Liagre 1993). Crops are typically grown for between 5 and 15 years during an approximately 30-year cycle (Liagre 1993; Mary et al. 1998) with a variety of crops including maize and other cereals, sorghum, soybean, oil-seed rape, sunflower, tobacco, alfalfa, lavender and bush fruits (*Ribes* spp.). In Dauphiné, around 20% of walnut orchards are intercropped (80% of those below 10 years of age) (Dupraz and Newman 1997). Walnuts are found as occasional trees in fields of cereal crops throughout France, a practice dating back at least 300 years in Burgundy (Dupraz and Newman 1997).

A comparable but less regimented style of silvoarable orchard is the central European system of *Streuobst*, defined as 'tall trees of different types and varieties of fruit, belonging to different age groups, which are dispersed on croplands, meadows and pastures in a rather irregular association' (translated from Lucke et al. 1992). *Streuobst* was formerly a widespread land use system, and was typically practised in areas with highly productive arable land. The system was sub-divided into silvoarable (*Streuobstäcker*) and silvopastoral (*Streuobstwiesen*) forms. *Streuobstäcker* generally consisted of paired rows of fruit trees, intercropped close to the tree trunks, with relatively low branches to facilitate fruit harvest. The most common fruit trees were apple, pear, plum (*Prunus domestica* L.) and mazzard cherry (*P. avium* L.) planted at a density of 20–100 stems ha^{-1} (Herzog 1998b).

During the 16th and 17th centuries, German national and regional policies encouraged the planting of fruit trees and creation of *Streuobst*, which was maintained throughout the following centuries. A fruit tree survey of 1938 recorded approximately 800,000 ha of active *Streuobst* (Herzog 1998a). This area declined by 50% during the second half of the century (Rösler 1996) due to replacement by intensively managed orchards with narrow grassed alleys between rows of dwarf fruit trees (Figure 1). These permit greater mechanisation but exclude intercrops. *Streuobst* eradication

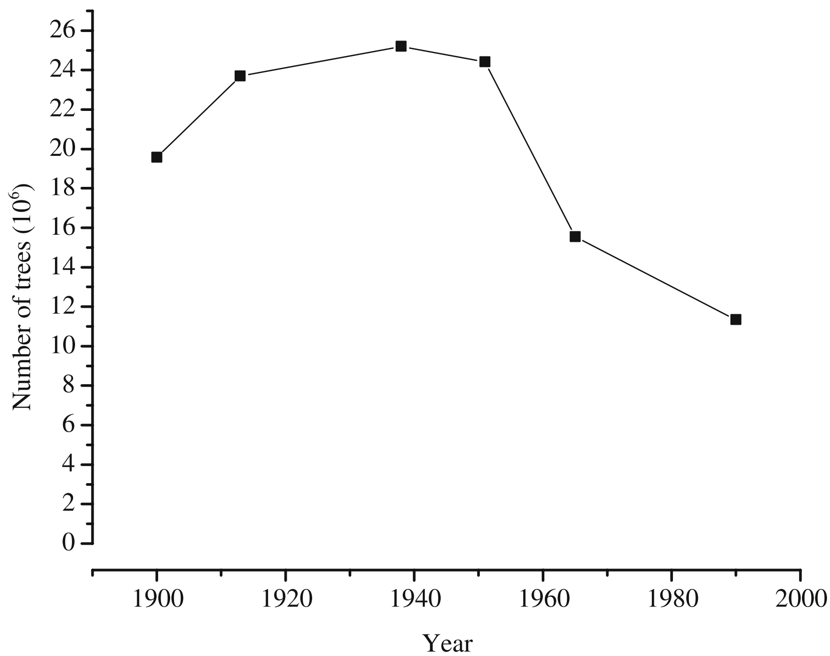

Figure 1. Number of fruit trees in *Streuobst* systems in Baden-Wurttemberg, Germany. The total land area of the region is 35,750 km^2. Trees in home gardens were included in 1900 and 1912. Redrawn from Herzog and Oetmann (2001).

programmes were originally subsidised under the CAP in favour of more standardised means of production. Those that remain operate at a loss due to the high cost of manual labour.

In more recent years, there have been subsidised schemes for protection on local to national scales. Nevertheless, the majority of sites maintain *Streuobstwiesen* rather than the arable *Streuobstäcker*, which is presently limited to a few very small fields (< 0.5 ha). *Streuobstwiesen* remains widespread in the Baden-Wurttemberg region, where fodder grasses are grown and harvested to feed sheltered livestock. Similar orchards formerly existed in the Netherlands, albeit on a smaller scale than the German *Streuobst*; the remaining fragments are maintained solely as a cultural heritage.

One of the reasons for the development of the *pré-vergers* in the 16th century and the former abundance of *Streuobst* in central Europe during the 18th century was that long-term fruit production could be combined with annual income from the arable crops in the system (Herzog and Oetmann 2001). Reasons for continued preservation may include landscape restoration, combating erosion, nature conservation or recreation, but in such cases they are not managed for economic returns. A recent fashion for hobby fruit production has led to small plots being maintained by individuals as a leisure pursuit.

A comparable system, the *pomaradas*, was formerly abundant in humid parts of northern Spain, especially in the regions of Galicia, Asturias, Cantabria and Basque Country. Apple trees were planted either in lines or scattered through meadows and arable croplands containing maize or vegetables. The system is known to have existed in the region since the 13th century, although lately it has declined dramatically. The estimated number of trees in *pomaradas* fell from 3,086,000 in 1974 to 464,000 in 1997, while the abundance of pure plantations increased (Miguel et al. 2000). The same trend applies to all fruit trees in Spain.

A similar orchard system was reinvented and subsequently lost in the United Kingdom. During the early 20th century, it was common practice to grow crops early in the development of full-stature fruit trees in orchards, particularly of apple and cherry, especially in the Kent region (Hoare 1928). Soft fruits (e.g. blackcurrant, gooseberry, raspberry, strawberry) or vegetables (e.g. asparagus) were the most common intercrops (Roach 1985). Although at their peak such orchards covered c.110,000 ha in 1951–1955, rotations were lengthy (50–100 years) and the area intercropped at any one time represented only a small proportion (Roach 1985).

The *Streuobst* and *pré-verger* landscapes of northern Europe are replaced further south by systems which incorporate grape vines. These differ from the majority of silvoarable systems in that the trees are no longer the focal element and chief economic resource. Mixed vineyards have a venerable and well-documented history in the European landscape, with trees incorporated to provide living mechanical support for the grapevines and increase the economic return from the land through diversification (Meiggs 1982).

In flat fertile areas of Italy (e.g. the Po Valley), poplars (*Populus* spp.) and fruit trees (Rosaceae spp.) were used as support for the vines, organised into rows and intercropped (*piantata*), a system dating back to the Etruscan period (699–464 BC). In the most productive regions, such as Campania, the rows of vines could reach a height of 10 m. In hilly regions, the vines tended to be supported by smaller trees including ash (*Fraxinus* spp.), maple (*Acer* spp.) and mulberries (*Morus* spp.). Crops least likely to compete strongly for water during the dry season (May–October), such as wheat or fodder legumes including clovers (*Trifolium* spp.) and vetches (*Vicia* spp.), were preferred. Fragments of the system remain in many areas of peninsular Italy which are marginal for cultivation (Bertolotto et al. 1995).

In southern France, the formerly prevalent system referred to as *Joualle* was composed of rows of grapevine with peach, walnut and olive trees inserted; in some cases, the trees were used to support the vines (*hautain*). In order to maximise returns from the land, the gaps between rows would often be sown with annual crops (usually cereals). This system has greatly declined due to mechanisation, which makes the manual harvesting of such narrow crop rows uneconomical, and the French national agricultural policy of separating agriculture from forestry. A similar system continues to operate in Greece, with olive, walnut, various oak species and wild pear incorporated amongst the vines, and in Sicily intercropped vineyards still cover 153,000 ha. In Spain, specialised intensive vineyards have replaced the traditional mixed system which continues only in restricted areas. Only the combination of olives with grapevines persists to any notable extent with an estimated 48,605 ha remaining in 1999 (INE 2002).

In northern Spain intercropped small orchards (less than 0.5 ha) combining fruit trees with vegetables remain abundant, but do not cover a substantial land area, estimated at 6200 ha in total (INE 2002). Throughout the Mediterranean region, small orchards of walnut, almond, peach (*Prunus persica* (L.) Batsch), apricot (*Prunus armeniaca* L.) and olive are intercropped with vegetables and cereals.

Small-scale silvoarable plots still exist in eastern Germany (e.g. in the Magdeburger Börde), usually for household consumption rather than as commercial systems. Commonly cherry trees (*Prunus avium* L.) are undercropped with turnip, alfalfa, potatoes, oats and formerly asparagus. Such plots were established in the former DDR due to the need to maximise returns from the small amount of private land assigned to each farmer following expropriation, and to the high fertility of land in the region (Plate 2).

In the Languedoc–Roussillon province of southern France, a modern intensive agroforestry system combines peach trees with intercropped vegetables. The system is highly profitable and efficient in light use as the vegetables are able to grow through winter and spring before the trees come into leaf, although it requires irrigation.

The greatest expanse and diversity of fruit-producing silvoarable systems is found in Greece, where there is substantial regional variation in the dominant fruit tree species, although in all areas a mixture occurs. In northern and central areas pear (*Pyrus* spp.) dominates, interplanted with cereals, vegetables or tobacco. Walnut is preferred in montane areas, and is grown also for timber, while mulberry (*Morus* spp.) is favoured in Thrace. Silvoarable combinations containing figs (*Ficus* spp.), also grown for fodder, occur in Crete and the Aegean Islands (Schultz et al. 1987). Cereals (wheat and barley) are the most common intercrops in all systems.

Walnut is a major component of silvoarable systems in Italy, where it is again used as a dual-purpose fruit and timber tree in many regions. In Campania, the most important region of Italy for walnut cultivation, it is intercropped with vegeta-

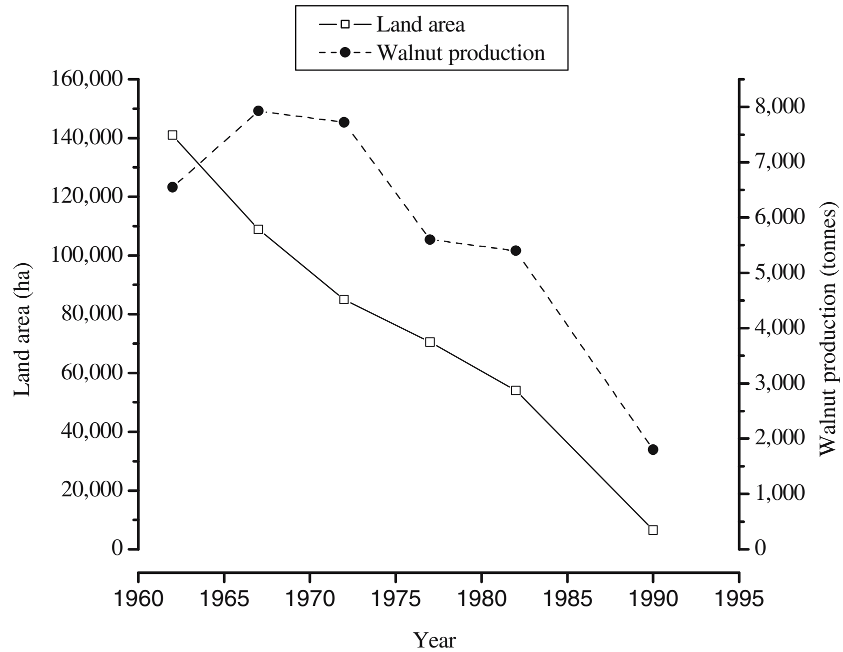

Figure 2. Area and production of walnut silvoarable systems in Italy (the 1990 area value includes pure walnut plantations). Adapted from Pisani (1980) and Statistiche Forestali (1979–1990), Instituto Nazionale di Statistica Agraria, Roma, Italy.

bles (Plate 3), and often mixed with hazel (*Corylus avellana* L.) grown for wood and nuts and as a trainer tree to improve the form of the walnut trunks. On the fertile volcanic soils of the region, tree growth is fast and a low plantation density (50 stems ha^{-1}) permits crop cultivation for a number of years. However, the system is declining rapidly (Figure 2), due to competition from foreign imports, especially from California, the greater profitability of vegetables when planted alone, and the high value of land for development in a densely populated region.

Timber tree systems

The increased demand for high-quality timber in Europe, coupled with the reduced availability of tropical hardwoods, has led to the development and expansion of a number of silvoarable systems designed specifically for the production of high-quality timber (Table 3). Several experimental systems adopted in different countries have great potential for increased application.

Silvoarable systems combining hybrid poplars grown for timber with cereal crops were pioneered in northern Italy and have since been adopted throughout northern Europe. The practice continues in the Po Valley region on flat fertile soils. Maize, soybean and cereals are grown between the tree rows during the first 2 years of a 10-year cultivation cycle, although with intensification on fertile soils the cycle may be reduced to as little as seven years. Lapietra et al. (1991) estimated that 4.1% of the area devoted to this system is intercropped at any given time. The system is presently in decline due to the European grant policy of subsidising tree planting on arable land which does not permit concurrent intercropping.

In France, intercropping of poplar became fashionable during the 18th century, and continues to be used in well-irrigated alluvial regions throughout the country, covering some c. 6000 ha (Plate 4). Typically, cereals are intercropped for the first 3 years. In northern Greece, cereals, vegetables or fodder crops may be grown among the trees. High levels of irrigation are usually required, which precludes the use of this strategy in more arid regions. Fertilisation is also necessary, along with intensive weed control and pruning of the trees. Similar systems in France are not managed with the same intensity.

Table 3. Extant silvoarable systems based around timber trees in Europe; their composition, present extent, structure and main economic products.

Component trees	Tree species	Location	Extent (ha)	Source	Stems ha^{-1}	Layout	Firewood	Timber	Fruit	Fodder	Annual crops
Poplar	*Populus* cv. (see text for details)	N Italy	12,500	Lapietra et al. (1991)	200	L		Y			C, M, S
		France	6300	Ségouin et al. (1997)	180–220	L		Y			C, M
		Greece	Unknown	Schultz et al. (1987)	10–50	L		Y			M, FL, V
1. Walnut	*Juglans regia* L.	C & S Italy	10,000	Cannata and Natale (1993)	25–100	L	Y	Y	Y	Y	C, V, FL
2. Hazel	*Corylus avellana* L.										
Walnut	*Juglans nigra* L., *J. regia*	France	15,000[a]	Mary et al. (1998)	80–120	L	Y	Y			All crops
	J. nigra, *J. regia*	Greece (montane)	7600	Schultz et al. (1987)	10–25	S	Y	Y		Y	C, T, FL, GV

Layout of trees is either scattered (S) or linear (L). Annual crops sown between the trees include maize (M), other cereals (C), vegetables (V), soya (S), tobacco (T), fodder legumes (FL) and grape vines (GV). Fodder legumes are only included if they form part of a rotation that includes arable crops. The same applies to maize where it is grown as a fodder crop.

[a]Only a proportion is intercropped in any single year.

In the United Kingdom during the 1950s, Bryant & May Forestry Ltd. established large-scale plantations of hybrid poplar in southern England for the manufacture of matches (Beaton 1987; Dupraz and Newman 1997). Alleys were cropped with cereals for 8 years, with an under-sown grass/clover mixture in the final year. The plantations were then used for grazing cattle until year 20, when canopy closure prevented the formation of pasture. The poplars were harvested at 25-years old. The availability of cheap Scandinavian lumber and the crisis in cereal prices caused these plantations to be abandoned in the 1970s. In recent years similar trial plots combining hybrid poplars with various crops have been established in the Netherlands (Edelenbosch and Dik 1995) and the United Kingdom (Beaton et al. 1999; Incoll et al. 2002).

The most common hybrid poplars used in European agroforestry plantations are *P.* x *euramericana* (Dode) Guinier (*P. nigra* L. x *trichocarpa* Torr. & Gray ex Hook.), *P.* x *interamericana* Brockh. (*P. trichocarpa* x *deltoides* Bartr. ex Marsh.) and *P.* x *canadensis* Moench (*P. deltoides* x *nigra*). New hybrids are constantly being developed to counter diseases such as poplar leaf blight (*Marssonina brunnea* (Ell. & Ev.) Magnus).

Other linear combinations of timber trees and crops exist with a limited distribution, but none have been so widely adopted. Silvoarable methods have been incorporated into systems that were formerly the preserve of pure forestry. The wider spacing between rows of trees in silvoarable systems increases rates of tree growth and can, with an appropriate pruning regime, increase the value of the timber through enhanced form and increased lumber length.

In France, a farm in Aude combines the leguminous timber tree black locust (*Robinia pseudacacia* L.) with cereals on 20 ha of land, with the aim of maintaining soil fertility while reducing the need for fertilisation. In the UK a commercial silvoarable system for the production of furniture timber includes five tree species (*Fraxinus excelsior* L., *Juglans nigra* L., *Prunus avium*, *Quercus rober* L. and *Acer pseudoplatanus* L.) with alley cropping of cereals or pulses. The tree rows contain additional specimen trees for early transplanting to urban parks, gardens and streets, negating the need for row thinning and improving the overall efficiency and profitability of the system.

In the Netherlands, innovative combinations of trees grown for high-grade timber and ground-level flower production have been attempted. The Stichting Robinia Foundation in Wageningen, an organisation promoting sustainable timber production, runs a small demonstration plot in Lelystad (0.5 ha) with several tree species (*Catalpa bignonioides* Walt., *Alnus glutinosa* (L.) Gaertner, *Prunus avium* and *Gleditsia triacanthos* L.) intercropped with hyacinth (Liliaceae) for flowers and bulbs. In Fryslân, the Boslandbouw Foundation has experimented with cedar (*Cedrus* spp.) intercropped with flowering quince (*Chaenomeles* spp.) for flower and fruit production. The potential of these systems for wider commercial application has yet to be established, although they have great aesthetic appeal.

Oak tree systems

In certain regions of Europe the landscape is defined by the presence of scattered oaks, forming contiguous arable and pastoral associations (Table 4). This is most characteristic of the *dehesas* of SW Spain and Portugal, a system of land use that may have been practised for up to 4500 years (Stevenson and Harrison 1992); see Plate 5. The *dehesa* is the dominant agroforestry system in Spain, and probably the largest such system in Europe. Estimates of present extent vary (Carruthers 1993), largely due to inconsistencies in its definition, with operational *dehesas* in the strictest sense thought to cover 2,248,000 ha in SW Spain and 869,000 ha in Portugal, where they are known as *montados* (Díaz et al. 1997); see Figure 3. Similar systems occur in northern Greece and cover much of Crete. They are also abundant in Sardinia, but have almost entirely disappeared on the Italian mainland (Grove and Rackham 2001).

Although some linear *dehesas* exist, in most cases the trees are scattered at relatively low densities (10–40 stems ha^{-1}). The shapes of the trees confirm that they have developed in an open environment, suggesting that the savannah is at least partly natural (Stevenson and Harrison 1992), although its formation may have resulted from the removal of trees from original mixed woodlands of oak and pine rather than fire followed by replanting (Plieninger et al. 2003). The constituent trees have been actively selected for

Table 4. Extant silvoarable systems based around oak trees in Europe; their composition, present extent, structure and main economic products.

Component trees	Tree species	Location	Extent (ha)	Source	Stems ha^{-1}	Layout	Firewood	Timber	Fruit	Fodder	Annual crops
1. Oak	*Quercus* spp.	C & S Italy,	180,000	ISTAT 2001[a]	10–100	S	Y			Y	C, FL
2. Pear	*Pyrus* spp.	Sardinia, Sicily									
Valonia oak	*Q*. ithaburensis subsp. macrolepis (Kotschy.) Hedge & F.Yaltirik	S & W Greece	29,600	Schultz et al. (1987)	10–50	S	Y			Y	C
1. Downy oak	*Q*. *pubescens* Willd.	N & C Greece	1,470,000[b]	Schultz et al. (1987)	10–100	S	Y			Y	C, T, Sun, FL, GV
2. Sessile oak	*Q*. *petraea* (Mattuschka) Liebl.										
3. Turkey oak	*Q*. *cerris* L.										
4. Macedonian oak	*Q*. *trojana* Webb in Loudon										
1. Evergreen oak	*Q*. *ilex* L.	W & SW Spain	2,300,000[b]	MAPA 2001	10–40	S	Y			Y	C, Sun, FL
2. Cork oak	*Q*. *suber* L.	Portugal	869,000[b]	Díaz et al. (1997)							
3. Pyrenean oak	*Q*. *pyrenaica* Willd.										

Layout of trees is either scattered (S) or linear (L). Annual crops sown between the trees include cereals other than maize (C), tobacco (T), sunflower (Sun), fodder legumes (FL) and grape vines (GV). Fodder legumes are only included if they form part of a rotation that includes arable crops.
[a]Less than 10% of arable cereal land is estimated to be *quercie camporili*, that is, containing scattered oaks (P. Paris).
[b]Only a proportion is intercropped in any single year.

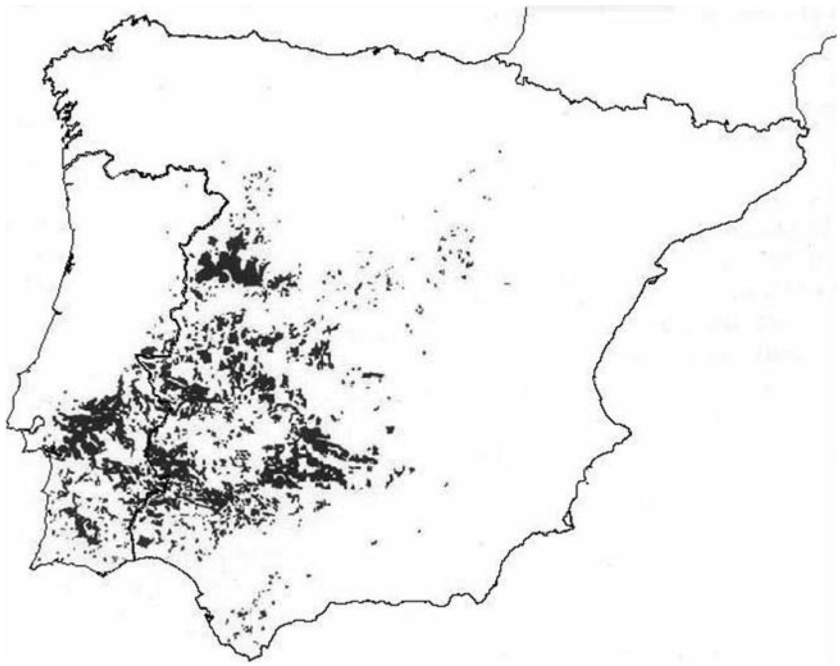

Figure 3. Distribution of *dehesas* in Spain and Portugal. Reproduced from Blanco et al. (1997, p. 510).

sweet acorn production, and consist mostly of evergreen oak (*Quercus ilex* L.), but also contain cork oak (*Q. suber* L.) and Pyrenean oak (*Q. pyrenaica* Willd.).

The ground beneath the trees is periodically sown with cereals, fodder crops or sunflower, or is used as wood-pasture. The lengths of the rotations vary from 2 to 12 years depending on soil conditions and the local structure of the *dehesas*. The system is therefore sometimes referred to as being agro-silvo-pastoral, since it combines a range of different practices, with arable cultivation shifting somewhat irregularly over successive years. Pigs, sheep, cattle, cereals, acorns and fuel wood are the main products (Grove and Rackham 2001), although cork can be a valuable commodity.

Within the *dehesas*, only a small proportion is cropped in any given year, with estimates ranging between 10.3% (MAPA 1985; Campos et al. 2003) and 16% (Escribano and Pulido 1998); see Plate 6. Moreover, crops are only harvested from 30% of the cultivated land, with the remainder being grazed directly by cattle or used as fodder, supplemented by acorns from the trees (Escribano and Pulido 1998).

The *dehesas* system was developed primarily for the production of the fine hams that are a speciality of the region, since pigs are known to fatten better in savannah than woodland. This is because savannah oaks produce substantially more acorns than woodland trees (Díaz et al. 1997), combined with the availability of understorey grasses and herbs for grazing, which are beneficial for their protein content. Cattle, sheep and goats are also raised in *dehesas* and benefit from foraging on acorns. The economic importance of acorns in *dehesas* is far greater than the relative value of pannage in northern European woodlands, and in 1957 it was estimated that acorns comprised one sixth of the value of all forest products in Spain (Parsons 1962; Balabanian 1984). Acorns were formerly a common human food (*belotas*), not only in times of famine, although acorn-bread is now seldom baked (Grove and Rackham 2001).

The minimum size of an operational *dehesas* estate is thought to be around 400 ha (Grove and Rackham 2001). Management is labour-intensive and increased labour costs in Europe threaten this way of life. Cork cutting is lucrative but offers only seasonal employment with no specific subsidy payments available. The development of metal screw caps for wine bottles may well threaten the cork industry in the future (Jefford 2003).

Lopped branches from the trees are used for firewood or charcoal production and as fodder in winter. The trees tend to be lopped in a distinctive pattern, particular to different regions, which determines their crown shape. Branch pruning is typically performed during the year before arable cultivation to increase light availability for the crops. Although valuable trees in many other ways, savannah oaks tend to produce low quality timber.

A subtle change in *dehesas* management practices has occurred over the last 30 years (Romero Candau 1981). The traditional rotation involved crop cultivation approximately every 4 years (although this could vary from 2 to 12 years), with grazing during the intervening period. Ploughing prevented the invasion of inedible shrubs (such as *Cistus* spp., *Erica* spp., *Arbutus unendo* L.) and maintained high quality pasture in succeeding years. The crisis in cereal production in the 1970s led to this practice being abandoned for some 20 years, following which severe bush encroachment has reduced the value of the pasture (Dupraz and Newman 1997) and created a substantial uncontrolled fire hazard. However, it has been argued that there may be an advantage to encroachment as this allows natural regeneration of oaks which would otherwise not occur in managed *dehesas* (Pulido and Díaz 2005).

Dehesas are in a less threatened state than many traditional land use systems, due in part to protective legislation. Approximately one million hectares were lost between 1950 and 1980 when cereal cropping was more profitable. Only water shortages restricted the ability of irrigation schemes to convert more *dehesas* into purely arable cropland. Since 1984, regional law has forbidden substitution of oak woodland in Extremadura. Nevertheless, there is some evidence of a more recent decline from 2.3 to 1.7 m ha between 1985 and 1998 (Miguel et al. 2000), although the reliability of these data is compromised by the lack of a firm definition of *dehesas* and an absence of systematically collected information. A more subtle change in structure may be occurring through alterations in tree density as a decline of 23% between 1951 and 1981 has been documented (Miguel et al. 2000). Almost no oaks have been planted for the last century, which has led to concerns over the long-term regeneration of the system (Grove and Rackham 2001).

Figure 4 illustrates the decline of intercropped open woodland in Spain, which refers to tradi-

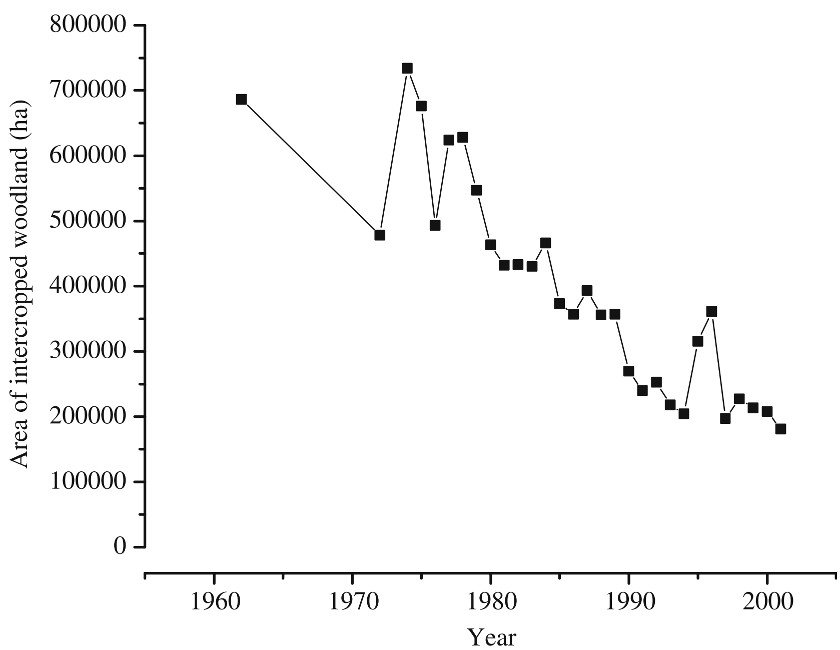

Figure 4. Area of intercropped woodlands (equivalent to planted *dehesas*) between 1962 and 2001 in Spain. Data from Anuario de Estadística Agraria (Annual of Agricultural Statistics) 1962–2001.

tional *dehesa* systems in approximately 90% of cases. It must be noted that open woodland itself is not in decline in Spain, with new woods developing on abandoned agricultural land in marginal areas. Instead it is the actual practice of mixed arable cultivation that has been greatly reduced.

Silvoarable oak systems are widespread in Greece, with cereals grown commercially between scattered trees at densities ranging from 10 to 100 stems ha^{-1}. A variety of oak species (*Quercus pubescens* Willd., *Q. petraea* (Mattuschka) Liebl., *Q. cerris* L. and *Q. trojana* Webb in Loudon) are found in northern and central areas, associated with cereals, tobacco, sunflower and fodder crops. In southern and western areas, Valonia oak (*Q. ithaburensis* subsp. *macrolepis* (Kotschy.) Hedge & F. Yaltirik) is most abundant, usually with intercropped cereals.

Similar systems persist in marginal areas of central and southern Italy and Sardinia, with scattered oaks present at densities ranging between 7 and 250 stems ha^{-1}. The system is referred to as *seminativo/pascolo arborato*. Various oak species are involved, most commonly *Q. pubescens* and *Q. cerris*, although cork oak occurs in Sardinia, where the system is similar to *dehesas*; see Plate 7. Wild pear sometimes forms a minor element. The trees were formerly used for fuel wood production, but increasingly they are not managed and are retained purely as landscape elements, or to reduce erosion. A rotation of wheat and clover is grown beneath the trees, with oats being a less common intercrop.

In northern Europe, the *Siegerländer Hauberg* of Nordrhein-Westfalen, Germany, was an ancient agroforestry system, practised for approximately 2500 years. The system combined the growth of trees for fuel wood with crop production and grazing on a long rotation. The dominant tree species were oak and birch (*Betula* spp.). According to historical records, trees in the *Hauberg* system were cut for firewood and charcoal at 16–20 year intervals with the stumps being left in the ground to allow re-growth. After tree felling, any remaining ground vegetation was removed or burnt, and for the following one or two years crops were grown between the stumps. The system was then left fallow for a further 5–7 years. Once the trees were of a size at which they could tolerate the presence of livestock (6–7 m height; A. Becker, pers. comm. 2005), the area was grazed with sheep and cattle. This silvopastoral land use continued until the next felling.

The *Hauberg* was a collective system of land management, farmed by the entire village community. At the end of the 19th century the *Hauberg* cooperatives began to allow the trees to develop to full stature as timber became more valuable than firewood. This transformation occurred at a slower rate than may have been expected, and in 2000 between 6000 and 7000 ha of traditionally managed forest still survived. The reasons for its maintenance included the need for protection against erosion and control of drainage, preservation of biodiversity, and the maintenance of a landscape recognised as being historically important and culturally unique. It is, however, no longer commercially viable as there is a limited market for the wood products and intercropping is excessively labour-intensive and has been abandoned.

Fodder tree systems

In several of the examples given above, most notably the *dehesa* system, the trees provide an important source of fodder. There are also many cases, both historical and contemporary, of trees being managed exclusively for their leaves as a valuable food source for livestock during seasons when ground vegetation for grazing is sparse (Lachaux et al. 1988; Dupraz and Newman, 1997). This applies especially to the more arid areas of the Mediterranean. In Greece, where the growing season for grasses is short, the leaves of deciduous oaks are shredded and dried to feed sheep throughout the rest of the year (Ispikoudis et al. 2004); see Plate 8. In the central mountains of Spain, humid *dehesas* on north-facing slopes combine deciduous oak and ash, with the latter being used as a fodder tree. The extent to which these systems contain an arable component is unknown.

Crete and the Aegean Islands contain silvoarable combinations with figs; carob is also favoured in Crete (Schultz et al. 1987), where the pods provide an important source of stored fodder (Table 5). In Sicily, carob is grown over some 20,000 ha and is intercropped with cereals and fodder legumes. The pods are also utilised as a raw material in the food processing industry. A similar system exists in the Balearic Islands of Spain.

Table 5. Extant silvoarable systems based around fodder trees in Europe; their composition, present extent, structure and main economic products.

Component trees	Tree species	Location	Extent (ha)	Source	Stems ha^{-1}	Layout	Firewood	Timber	Fruit	Fodder	Annual crops
Carob	*Ceratonia siliqua* L.	Sicily	20,000	Cullotta et al. (1999)	100–125	S/L	Y		Y	Y	C, FL
		Crete	7900	Schultz et al. (1987)	25–100	S/L				Y	V, GF

Layout of trees is either scattered (S) or linear (L). Annual crops sown between the trees include cereals other than maize (C), vegetables (V), fodder legumes (FL), and ground fruits such as strawberries (GF). Fodder legumes are only included if they form part of a rotation that includes arable crops.

Non-native trees have more recently been considered as fodder sources in the Mediterranean. The use of honey locust (*Gleditsia triacanthos*), a leguminous tree native to America, has been promoted for many years (Wilson 1993). Other species considered include *Amorpha fruticosa* L., *Robinia pseudacacia*, *Colutea arborescens* L., *Corinilla emerus* L., *Medicago arborea* L. and *Morus latifolia* Poir. (Dupraz and Newman 1997) and species characteristic of dry regions, such as *Acacia* spp. and *Atriplex* spp. (Correal 1987; Dupraz and Newman 1997).

Present status of agroforestry in Europe

In three of the northern European countries included in this review (Germany, The Netherlands, and United Kingdom), silvoarable agroforestry no longer has a significant role in the agrarian economy, and multifunctional land use generally persists only on a small scale. The *Hauberg* system, formerly practiced extensively in west-central Germany, has almost completely vanished. The intercropped fruit orchards of central Europe, *Streuobst* and *pré-vergers*, are much diminished in extent and now largely silvopastoral. Other ancient types of silvoarable agroforestry are often very poorly documented and little is known about their former content or extent.

Current silvoarable practices in France are relatively well documented and there are movements to preserve existing practices and encourage novel approaches. As an example of a system operated as a going concern, Claude Jollet (Charentes Maritimes) maintains 56 ha of walnut and wild cherry trees (c. 25 years old), intercropped with barley and sunflower. It is estimated that by 2005 there will be more than 80 similar silvoarable projects in France.

Silvoarable agroforestry remains of great importance in many regions of the Mediterranean. The systems are usually relicts of formerly extensive agricultural practices now restricted to more marginal areas, especially olive grove intercropping and *dehesas*. Despite their historical importance, and the threats posed by the expansion of modern intensive agriculture, they have been relatively poorly studied in terms of their economic importance and role in preserving local and regional biodiversity.

The greatest diversity of silvoarable systems is found in Greece, where a large variety of combinations of trees and crops exists. These are generally characterised by small plot areas, with a number of different tree species present, often dispersed throughout the field and at the margins, but without a fixed pattern or spacing. A range of understorey crops with different management are often planted side by side. This poses an obstacle to the strict categorisation of systems. At present in Greece there is no regional or national policy to improve silvoarable systems and make them economically viable. A particular problem nationally is that the typically short length of land tenancies does not encourage farmers to initiate novel long-term management practices such as agroforestry. The trees belong to the landowner rather than the tenant, which is a considerable disincentive.

Silvoarable agroforestry remains widespread in Italy, although it has declined during the latter part of the last century. In many cases, silvoarable systems survive in regions where the terrain and climate have impeded intensification (e.g. in Umbria, a relatively dry, hilly region; Bertolotto et al. 1995). Recent interest in silvoarable techniques has been stimulated by the demand for high-quality local timber for domestic furniture manufacture. Many of the systems described

Table 6. Recent trends in the extent of silvoarable systems (ha) in Spain.

System	1962	1972	1982	1989	1999
Fruit + annual crop[a]	402,005	[d]	78,999	27,562	13,484
Vineyard + annual crop[a]	[d]	[d]	21,677	8175	8359
Olive + annual crop[a]	242,628	[d]	39,092	20,219	15,030
Woodland trees + annual crop[b]	685,893	478,375	433,000	357,000	213,100[c]

[a]Data derived from National Agriculture Census (INE, 1963, 1975, 1985, 1991 and 2002).
[b]Data derived from Annual Report of Agricultural Statistics (MAPA, 1985 and 2001). Refers to annual crops grown under mature woodland trees covering between 5–20 % of the surface (open woodland). This type of intercropped system refers to *dehesas* in more than 90% of cases.
[c]MAPA (2001) also gives a value of 600,000 ha for 1999. The discrepancy reflects the difference between the area cropped on a rotation and that which was cropped in that particular year.
[d] Data not recorded.

above have been in existence for centuries in Italian agriculture but have substantially declined.

In Spain, regular national agricultural census data throughout the last 50 years provide a clear picture of extant silvoarable systems and allow trends in their distribution to be identified, although the census categories are often broad and do not specify tree or crop species within systems. For example, irregularly structured *dehesas* are recorded in the same category as linear poplar/maize silvoarable systems. Despite the continued survival of the *dehesas*, silvoarable systems are a minority land use relative to conventional arable cropland, and are mostly found on more marginal arable soils. During the latter half of the 20th century, the most pronounced trend was a reduction in the intercropping of fruit trees, which declined by 97% between 1962 and 1999. During the same period, intercropped olive systems decreased by 94%. This trend has continued (Table 6). Despite some inconsistencies in classifications between years, the general pattern of severe decline is evident. Contributory factors specific to Spain include the migration of people from marginal agricultural land, causing silvoarable fields to revert to woodland, the consolidation of fragmented land holdings into larger single farms and irrigation projects which reduce the need for shade trees among crops.

Future prospects for silvoarable agriculture

The modern focus on sustainable agriculture and conservation of nature and landscapes in Europe has increased the interest in silvoarable systems and encouraged the establishment of research projects. Multifunctional land use has been identified as a potential means of increasing the biological species richness of farmland through increased habitat diversity as well as protecting against erosion and reducing the need for agrochemical input (Vandermeer 1989; Jose et al. 2004). Reisner et al. (2005) identified target regions within 32 European countries for silvoarable agroforestry involving five commercial tree species (*Prunus avium*, *Juglans* sp., *Populus* sp., *Pinus pinea* and *Quercus ilex*). They concluded that at least one of these species could grow productively in an agroforestry context on 56% of the utilised arable land while simultaneously contributing to protection of soil from erosion on 6 m ha, combat nitrogen leaching on 30 m ha and increase landscape diversity, and hence potentially biodiversity, on 42 m ha. The use of tree species such as conifers in northern Europe may expand the potential applications of agroforestry.

It is necessary to be cautious in claiming environmental benefits for silvoarable systems in general, especially in the context of the increased sustainability of agriculture. Considerable experience accumulated in the tropics has shown that management of intercropped systems is often intensive. The high cost of manual labour in Europe is likely to lead to a greater reliance on agrochemical input, especially when unfavourable combinations of trees and crops are employed. The combined peach and vegetable systems of southern France, which require intensive fertilisation and irrigation, provide an appropriate example.

In their review of agroforestry practices in temperate regions around the globe, Newman and Gordon (1997) conclude that the most successfully optimised systems are those for which there is a clearly defined market for a tree product. In assessing the prospects for the preservation of traditional silvoarable systems, and the scope for novel and innovative approaches to combinations of trees and crops, we should therefore focus upon the economic value of the trees.

There is a pressing need in Europe for a local source of high quality hardwoods to replace tropical sources (Smith 1990). Europe is now almost self-sufficient in other timber and wood-based products, largely derived from sustainable forests in Scandinavia, but high-grade timber retains a high market value. Deciduous broad-leaved species are preferred to conifers, principally to satisfy market needs, but also for environmental, cultural and aesthetic reasons (Dupraz and Newman 1997). The economic potential for timber silvoarable systems is difficult to assess due to a lack of research and great variability in the local incentives provided to farmers for tree planting.

Timber trees are thought to have greater potential than fruit trees in silvoarable systems, as they avoid the constraints posed by fruit harvesting that might limit the choice of intercrops. In addition, fruit trees are sensitive to competition from other crops at critical stages in the growing season (e.g. flowering, fruit setting), whereas timber trees are more resilient and there is no critical period for determining diameter growth rates (Dupraz 1994; Dupraz and Newman 1997). Market demands for standardised fruit also favour their production in intensively managed orchards.

There has been an increase in recent years in the use of trees purely for fodder production. This has been investigated in the Rougier des Camarès area in southern France as a means of combating erosion in fields previously sown purely with annual fodder crops (Dupraz and Newman 1997). Trees may have a valuable role in maintaining the integrity of soils and combating erosion in other areas of Europe. They might also be used to limit the leaching of mineral nutrients from cropland (Nair and Graetz, 2004), which may be a particular problem for irrigated soils in Mediterranean countries.

There may be environmental benefits to silvoarable systems at a regional scale. Increased tree planting could absorb greater amounts of carbon and therefore mitigate future increases in atmospheric CO_2 (Herzog 1994). The search for alternative energy sources has led to silvoarable systems being considered as a source of bio-fuels (Herzog 1994; Hall 1997). Short rotation coppice (SRC) of willows (*Salix* spp.) operates on a commercial basis in Sweden over some 15–17,000 ha for biomass energy production, but remains experimental elsewhere in Europe. Such 'carbon-neutral' fuel sources have been highlighted as potential alternatives to fossil fuels for energy production at local levels (Newman et al. 1991). An experimental wheat intercropping was attempted at Long Ashton Research Station, Bristol, UK. This found that the reduced arable yield made the system economically unfeasible under current commodity prices and subsidy regimes, but demonstrated reduced nitrogen leaching as compared to pure arable cultivation during the later stages of the cycle (Nichols et al. 2000). Other species have been investigated as potential candidates for SRC within Europe, including hybrid poplars (Mitchell et al. 1999), black locust (Paris et al. 2002) and *Eucalyptus* spp. There is no historical precedent for combined coppice and arable production.

There are several obstacles to be faced by farmers and institutions who are current or potential practitioners of silvoarable agroforestry and who may benefit from increased knowledge and awareness of its potential applications. Firstly, there is a lack of received knowledge on former agroforestry systems that have now largely disappeared. Secondly, the current focus on single crop systems within agricultural research institutions and universities reduces the advice and training available to farmers wishing to manage trees in an agricultural environment. Although there has been a recent surge in research interest in silvoarable agroforestry, all experimental findings on novel systems are necessarily preliminary as modern scientific research has yet to cover the lifespan of a cohort of trees in a plot.

In modern Europe, both agriculture and forestry only exist in their present forms because they are to some extent maintained by subsidies. This has led to the formulation of regulations that separate agricultural and forestry land use into distinct categories. Agroforestry systems, as they fall between the two types of land use, often qualify for neither set of subsidy payments, with the result that their uptake and maintenance is passively discouraged. For example, EEC Regulation 1257/1999 provides grant funding for tree planting on arable land, but does not permit intercropping. The current political climate is therefore generally unfavourable and mixed agriculture requires more powerful promotion at the regional level.

In this context, a recently approved European Council Regulation on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) states that "Agriforestry systems have a high ecological and social value by combining extensive agriculture and forestry systems, aimed at the production of high-quality timber and other forest products. Their establishment should be supported" (EAFRD 2004). Article 41 of the document proposes to support the creation of agroforestry systems on agricultural land. The prospects for the adoption of silvoarable methods within Europe have therefore improved greatly.

Attitudes towards mixed agriculture amongst national governmental bodies have altered in recent years. In France, a census of silvoarable practices commissioned by the Environment Ministry was conducted in 2000 by the SOLAGRO Association and INRA, Montpellier (Coulon et al. 2001). An informal network of interested parties was formed to lobby for the reform of agricultural and forestry laws to support agroforestry systems and has succeeded in changing the application of subsidies. Since 2001, intercrops are eligible for CAP subsidies (DPEI/SPM/C2001-4008, 8th March 2001), agroforestry plantations receive forestry subsidies (DPEI/SDF/C2001-3010, 7th May 2001) and the area planted with trees is eligible for the European PCPR subsidy for lost arable income (DERF/SDF/C2001-3020, 8th August 2001). Agroforestry is therefore currently strongly supported by the regulations within France.

Conclusions

There are two distinct geographical and climatic zones with respect to European silvoarable agroforestry – northern Europe and the Mediterranean. The latter contains a broader range of systems, reflecting the higher diversity of commercial crops and plant resources. In general the form and structure of systems are determined by light limitation in northern Europe and by water limitation in the Mediterranean.

Although extant silvoarable practices in Europe are mostly residual elements of formerly widespread systems, there is still a considerable diversity. The precise quantification of silvoarable systems in Europe is difficult due to lack of documentation. The application of a consistent definition of silvoarable agroforestry in land use surveys and recognition of their unique characteristics would go some way towards an accurate appraisal of their present extent and importance in the landscape of Europe. Their productive role in the European countries studied here is not yet fully understood and deserves more attention, especially in the context of the diversification of farm income and development of sustainable farming systems, two issues of immense strategic importance to the future of European agriculture. There are economic, environmental and aesthetic reasons to encourage their adoption in all regions of the European Union.

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