TARGET REGIONS FOR SILVOARABLE AGROFORESTRY IN EUROPE

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Abstract
Silvoarable Agroforestry (SAF) could mitigate negative environmental impacts of agricultural land use in Europe. In a geographic information system (GIS) data on soil, climate, topography, and land cover were integrated to identify agroforestry target regions where productive growth of trees in SAF systems can be expected and where, at the same time, SAF systems could potentially reduce risk of soil erosion, contribute to groundwater protection and increase landscape diversity. The environmental benefits could justify the support of SAF by subsidies. Target regions for SAF systems were identified for Pinus pinea, Juglans ssp., Populus spp., Quercus ilex and Prunus avium. The investigation covers the entire European continent.

The analysis shows that SAF systems are possible on 56% of arable land throughout Europe (potential distribution area). On 85% of the European arable land environmental problems are high (even on soil erosion, nitrate leaching or landscape diversity). Overlaying potential distribution areas for SAF with environmental problem areas on arable land, gives the target regions in Europe. This area is about 40% of the arable land and the environmental problems could be reduced on about 9% for soil erosion, on 45% for nitrate leaching and on 79% for landscape diversity.

Keywords: Agroforestry, Geographic Information Systems (GIS), sustainable land use, environmental impact

Introduction
In Europe, agro political discussions have been conducted for many years about overproduction, subsidies, and resource protection and about the future of the farmers in general. The importance of agroforestry in this context is still marginal despite the great problem solving potential of agroforestry to help farmers in certain regions in Europe. One reason why modern agroforestry systems are hardly adopted by farmers in Europe is that it is not supported by subsidies, whereas agriculture and forestry receive government support in all countries. To promote agroforestry, policy makers and farmers have to know where silvoarable agroforestry is possible and where it make sense in terms of reducing environmental problems such as soil erosion or nitrate leaching.

Agroforestry in general is defined as a land use system with a biological interaction between at least two plant species. Silvoarable Agroforestry (SAF) comprises agricultural systems where trees and crops are cultivated on the same land-management unit in the form of spatial arrangement or temporal sequence. Successful agroforestry systems produce high-value products (e.g. good quality timber, food or
nuts), and one of the species must be perennial and have a woody consistency (Lundgren, 1982; Lundgren and Raintree, 1982; Carruthers, 1990; Nair, 1993; Sinclair, 1999).

The potential advantages of agroforestry in temperate and Mediterranean climatic zones are multifaceted. Agroforestry diversifies the arable trade and market and reduces overproduction of agricultural commodities. It could increase landscape diversity and enhance biodiversity in certain landscapes where the lack of diversity is quite evident. Other resource protection issues comprise, for example, the reduction of soil erosion and nitrate leaching in intensive managed agricultural landscapes (Anderson and Sinclair, 1993; Nair, 1993; Gordon and Newman, 1997; Herzog, 1997). Agroforestry enables farmers to cultivate poor soils as arable land and to protect large areas from afforestation. This is important to make marginal areas economically more attractive and can contribute to preserve attractive landscapes for recreation and for aesthetic values. Numerous studies support the environmental value of agroforestry within the European context (see e.g. Telleria and Santos, 1995; Burgess, 1999; Herzog, 2000; Pinto-Correia, 2000; Shakesby et al., 2002).

At the European Continent, still a lot of traditional SAF systems can be found (Byington, 1990; Dupraz and Newman, 1997). One important traditional agrosilvopastoral system in Europe is the Dehesa (in Spain), where the trees are spread over the field randomly. Other traditional systems, as for example the “Streuobst” can be found in temperate Europe (Herzog, 1998).

There are some studies about suitable areas for plants and especially for trees. Booth et al. (1989) and Booth and Jones (1998) defined climatically suitable areas for particular tree species in Africa and Latin America. They take a description of the trees requirements of climatic conditions and generate maps showing locations, which are suitable for this tree species. Booth et al. (2002) and Booth and Jovanovic (2002) describe a world-mapping program (WORLD), which indicate locations satisfying up to six climatic criteria important for tree species selection. One of the study is limited to the African Continent the other study works at a global scale where the European countries are considered very coarse. All this mentioned studies are looking only for the climatically suitable areas. The other main ecological factor, the soil characteristics, is not included.

Hijmans and Spooner (2001) analysed the distribution of wild potatoes using geographic information system (GIS) with a large database of locations where wild potatoes were observed. Also in the paper of Ellis et al. (2000) GIS systems were used to model agroforestry opportunities and potential tree species in Florida.

The objective of this paper is to model potential areas for silvoarable agroforestry (SAF) in European arable land, based on environmental analysis. The first question to answer is, where is it possible to plant AF-systems and with which tree species? And the second question is, where in Europe new SAF systems can be implemented to reduce the impact of land use on nature and landscape?

To identify target areas in arable land to implement new SAF systems in Europe, two issues were taken into account:
1. Analysis of suitable areas for productive tree growth on arable landscapes. The study is done with five selected tree species: Walnut (Juglans ssp.), Wild cherry (Prunus avium), Poplar (Populus ssp.), Italian stone pine (Pinus pinea) and Holm oak (Quercus ilex).

2. Analysis of regions with strong environmental problems considering soil erosion, nitrate leaching, and landscape diversity.

The potential conversion areas were executed through a GIS-analysis based on digitally available geo-information about soil properties, climate, topography, biodiversity, and land cover. A further restriction was that it should be a “coarse-grained” assessment with a resolution of 1 x 1 km. Maps were produced to identify and visualise the occurrence and potential of SAF at the European scale.

Although limited by constrained data availability, the study shows that the implementation of trees in arable landscapes in Europe would be possible throughout all climatic zones (from the south of Spain to the north of UK).

**Material and Methods**

The aim was to define regions where trees can grow in arable landscapes with an economic relevant yield. In these suitable areas for tree growing, an analysis of environmental problems defines the target regions for SAF.

**Theoretical Concept**

Target regions were defined overlaying (Fig. 1):

(i) Arable landscapes
(ii) Regions where productive tree growth in an agroforestry setting is possible. This is based on natural conditions, where the trees can grow productively:
   - Topography
   - Climate
   - Soil

(iii) Regions where environmental problems exist which agroforestry can help to solve. This is based on analysis of environmental problems:
   - High risk for soil erosion
   - High nitrate concentration in the groundwater
   - Low landscape diversity

Fig. 1: Procedure to identify target regions for silvoarable agroforestry (SAF) at the European scale.
Selected tree species

Selecting appropriate tree species is one of the most important stages in establishing agroforestry systems. Five tree species, which have been identified as having potential for use in agroforestry, were investigated.

The tree species are:
- Walnut (Juglans ssp.)
- Wild cherry (Prunus avium)
- Poplar (Populus ssp.)
- Italian stone pine (Pinus pinea)
- Holm oak (Quercus ilex)

Walnut (Juglans ssp.), Wild cherry (Prunus avium), and Poplar (Populus ssp.) grow mostly in the temperate climate. Italian stone pine (Pinus pinea) and Holm oak (Quercus ilex) are typical trees for the Mediterranean region.

Definition of environmental risk areas

Environmental risk areas are indicated as regions where a high environmental issue is present, in terms of high risk of soil erosion, nitrate vulnerable areas and low landscape diversity (uniform arable landscapes). In this area, plantation of trees on arable land can mitigate environmental risks.

Soil erosion

The assessment of soil erosion was based on indicators and values produced by the PESERA project (Gobin and Govers, 2003). Erosion indicators are calculated using a model with a physical basis, applied to regional scale.

Nitrate vulnerable zones

To define areas with high risk of nitrate leaching, “Nitrate vulnerable zones” (NVZ) from the Council Directive 91/676/EEC (European Commission, 2002) were taken. It is an environmental measure designed to reduce water pollution by nitrate from agricultural sources and to prevent such pollution occurring in the future.

Landscape diversity

Uniform arable landscapes were selected from PELCOM and CORINE datasets using a moving window analysis method (focal majority). PELCOM (Mücher, 2000) has a resolution of 1 x 1 km, whereas CORINE (CLC, 2000) works with a resolution of 250m.

Definition of potential distribution areas (productive tree growth on arable land)

The selection of regions where productive tree growth in an agroforestry setting is possible was based on the tree growth requirements. Both climate and soil conditions are important in determining a species’ capability to grow successfully at a specific site. Climatic factors are particularly useful in indicating broad regions where particular species are worth considering. Soil characteristics indicate more the suitability at a smaller scale.
Using the Forestry Compendium (CABI, 2003) criteria were defined to describe the optimal living condition for the five selected tree species; the information was completed by expert assessments. The climatic data were derived from Metzger et al. (2002) and Mücher et al. (2003), the soil data from the European Soil Bureau (ESB, 2002). The analysis was restricted to arable landscapes as defined in the PELCOM land cover map (Mücher, 2000). Data about topography were calculated from HYDRO1k, developed at the U.S. Geological Survey's (2003).

Productive tree growth areas are defined using the following criteria:

1) Topography:
   - Altitude range [m above sea level]

2) Climatic data:
   - Precipitation [mm/year]
   - Mean annual Temperature [°C]
   - Mean maximum Temperature of hottest month (August) [°C]
   - Mean minimum Temperature of coldest month (January) [°C]
   - Wind [m/sec]
   - Frost [days/year]

3) Soil characteristics:
   - Soil texture
   - Water regime
   - Soil type
   - Minimum depth available for root growth
   - Minimum soil water capacity (of the first meter of soil)

**European Databases and GIS tools**

Free data sources were chosen at the beginning of the study, to keep the data search phase as simple as possible and to test the availability of European environmental datasets and the quality of the final result at a continental scale.

PELCOM was one of the first datasets available for the SAFE-project. Because it has a valid spatial reference on a European scale, it was decided that the transformation of all the other datasets would have had as base the PELCOM coordinate system (Projection: Albers. Datum: WGS72). The cell size for all datasets was transferred to 1100 meters.

A European geo-database was designed when defining the main criteria that influence the potential distribution of the five selected tree species and the environmental risks.

GIS were used to standardise, integrate and query data on soil, climate, topography, and land cover. Once all the datasets converted in raster format, a simple addition between them was made and only where all the criteria were met, the area was defined as target area.

**Results**

**Analysed European countries and arable land use**

The European countries which were analysed are: Albania, Austria, Belgium-Luxembourg, Bulgaria, Czech Republic, Denmark, Finland, France, Germany,
Greece, Hungary, Irish Republic, Italy, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, and United Kingdom. They cover an area of 4.29 millions km².

All countries from the list above are overlaid with the PELCOM map (Mücher, 2000). 1.6 millions km² (= 38% of the total area) are arable land, including the PELCOM-classes:
- Rain fed arable land
- Irrigated arable land
- Permanent crops

Environmental risk areas

Soil erosion

The erosion map does not cover all selected countries listed in chapter 4.1. The following countries are excluded because of insufficient data: Albania, Finland, Norway, Sweden, and Switzerland (map 1). The analysed countries cover an area of 3.1 millions km². From this area, 5.5 % have a high or very high risk of soil erosion (> 10 t/ha/year).

Nitrate vulnerable zones

Nitrate Vulnerable Zones (NVZ) (European Commission, 2002) are defined for Austria, Belgium-Luxembourg, Denmark, Finland, France, Germany, Greece, Italy, Netherlands, Portugal, Slovenia, Spain, Sweden, and United Kingdom (map 2). The analysed countries cover an area of 3.2 millions km², from where 16% are assessed as NVZ.

Landscape diversity

All countries from the list in chapter 4.1. were included. From the 4.3 millions km², 1.16 millions km² were assessed to have a low landscape diversity. That is 27% of the whole area, and 71% of the arable land (map 3).

Potential distribution areas

The potential distribution areas mean the potential growth areas on arable land (overlaying potential tree growth areas with arable land). The criteria for defining productive tree growth are listed in Table 1. All countries from list in chapter 4.1. are investigated. For the results see also Table 2.

European walnut (Juglans regia)

The definition of the potential distribution area of Walnut trees (Juglans hybrids) is based on the requirements of Juglans regia, which is found today in most of Europe except for northern and northeastern regions (Norway, Finland, Poland). It grows well on fertile, deep, and well-drained soils (CABI, 2003). Walnut trees are economically important, because of their fruits and the decorative, valuable timber (Becquey, 1997).

Map 4 shows the potential distribution area of Walnut trees. The potential distribution for Juglans hybrids covers an area of 242’961 km². This is 14.9 % of the European arable land. The main distribution is in flat regions in Germany, France, Italy, and the eastern part of Austria.

Wild cherry (Prunus avium)
Prunus avium is found on lowland plains, and also on slopes and hills over most of Europe. It may be found scattered along moist river valleys, or in the edges of woods and in hedgerows (Ducci et al., 1988). In general it needs a deep moist soil for good growth (Teissier, 1980; Savill, 1991). Current interest in wild cherry wood production in natural forests and in plantations in Europe is high, as it produces an attractive patterned wood (Zimmermann, 1988; Schalk, 1990).

Map 5 shows the potential distribution area of Prunus avium, which covers an area of 296'335 km² (=18.2 % of the European arable land). In some part it has the same distribution as Juglans regia, but it ranges to colder and more continental climate.

Black Poplar (Populus deltoides)

The definition of target areas was based on the tree requirements of Populus deltoides, because it has been extensively used in poplar hybridization programs throughout the world, producing fast-growing clones.

Populus deltoides primarily grows on the moist alluvial soils along streams, and on sandy soils or well-drained soils with a high water table to supply year-round moisture (Albertson and Weaver, 1945; Dickmann and Stuart, 1983; Hupp, 1992; Kaul, 1995). The wood of poplar is commonly used for the manufacture of a number of products, as for example pallets, furniture, matches, and packing cases.

Map 6 shows the potential distribution area of Populus deltoides. It covers an area of 547'054 km² (=33.6 % of the European arable land). The potential distribution area is very large and in reality it will be even larger mainly in the Mediterranean region, because of the resolution of the maps (1100 meter x 1100 meter). Smaller areas, e.g. along rivers and streams can not be displayed.

Italian stone pine (Pinus pinea)

Pinus pinea has a distribution limited to the Mediterranean basin (Richardson and Rundel, 1998). It can grow almost on all soil types, including very poor soils, but it grows best on sandstone and sandy substrates (Barbéro et al., 1998). Pinus pinea is cultivated for different purposes such as fruits (seeds), solid wood, wood-fibre and environmental protection (e.g. erosion control, drift sand control) (Maitre, 1998).

Map 7 shows the potential distribution area of Pinus pinea, which covers an area of 65'405 km². This is 4.0 % of the European arable land.

Holm oak (Quercus ilex)

Quercus ilex is a typical Mediterranean tree. It is more important in the western part of the Mediterranean Basin than in the eastern part (Barbéro et al., 1992). Quercus ilex can grow on a great range of soil types, from littoral sandy soils to granite soils, but it does not tolerate waterlogged soils (CABI, 2003). The wood is used for firewood and to produce good quality charcoal. The acorns of subsp. rotundifolia are also collected and fed to animals (CABI, 2003).

Map 8 shows the potential distribution areas of Quercus ilex. It covers an area of 155'957 km² (=9.6 % of the European arable land).
Target regions for SAF (with Juglans, Prunus, Poplar, Quercus or Pinus)

Target regions are resulting from overlaying the environmental problems-areas with the potential distribution areas (see Fig. 1). These target regions cover an area of 652'351 km² (Table 2). This means that around 40 % of the arable land in Europe was defined as target regions for at least one of the five tree species under investigation. Of this area, 9 % were classified as being in danger of erosion with an erosion rate of more than 10 tonnes of soil per hectare per year. 45 % of the arable land were categorised as a nitrate vulnerable zone, 79 % have a uniform arable landscape.

Conclusions

The environmental impact in arable landscapes in Europe is considerable. 5.5 % of the arable land has a high risk for soil erosion, 16 % are classified as Nitrate Vulnerable Zones, and 71 % were assessed to have low landscape diversity. On 1.39 millions km2 (85 % of European arable land) at least one environmental problem exists.

The potential distribution area of the five selected tree species (Juglans ssp, Prunus avium, Populus ssp., Pinus pinea, and Quercus ilex) covers an area of 906’887 km² (= 21.2 % of the European countries area). Therefore, the area where trees can grow on arable land in an agroforestry setting is very high with a proportion of 55.8 %.

Target regions are intended to be areas where species are worth considering for planting trees for agroforestry systems on farms. Tree species may survive in different environments but may not be suitable for commercial production.

The target regions cover an area of more than 650’000 km2 that is ca. 40 % of the arable land in Europe. The study shows that productive growth of the investigated tree species can be expected throughout all climatic zones from north to south and from west to east. The development and introduction of new agroforestry techniques could contribute to reduce environmental risks on a considerable share of the European arable area.

Some limitations of the study have to be keep in mind:
- The first limitation is based on the resolution. Data were analysed with a resolution of 1 x 1 km. That means, that going into a site, the specific edaphic or microclimate condition can be different. A tree species suited to an area may not be profitable due to other factors, such as insects, diseases, weeds, limited availability of a suitable variety, and market access.
- The second issue is the data availability. The description of environmental requirements used here is based on ranges of factors. The factors used have been widely applied around the world to assist species selection (see CABI, 2003). They have the advantage that the climatic requirements are based on simple monthly mean temperature and rainfall data, which are available for whole Europe. But, this long-term average data used do not reflect year-to-year variations, so problems may be experienced if trees are established for example in low rainfall areas during a drought period.
- The third issue is the limitation of our assessment model. The model relies on a relatively few climate and soil requirements to create target regions maps. Requirements were selected because of their importance and availability.
Additional requirements likely would strengthen the target regions maps but the necessary data are not available. A strength effort to produce first the database and the geo-information would be necessary.

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References


Map 1: High soil erosion (>10 t/ha/year).

Map 2: Nitrate Vulnerable Zones.

Map 3: Low landscape diversity.
Map 4: Potential distribution area of *Juglans* ssp.

Map 5: Potential distribution area of *Prunus avium*.

Map 6: Potential distribution area of *Populus* ssp.
Map 7: Potential distribution area of *Pinus pinea*.

Map 8: Potential distribution area of *Quercus ilex*.
Map 9: Target regions for silvoarable agroforestry in Europe.
Table 1: Minimum requirements for productive tree growth.

<table>
<thead>
<tr>
<th>Criteria</th>
<th><em>Juglans ssp.</em></th>
<th><em>Prunus avium</em></th>
<th><em>Populus ssp.</em></th>
<th><em>Pinus pinea</em></th>
<th><em>Quercus ilex</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude range</td>
<td>0 - 900 m</td>
<td>0 - 1700 m</td>
<td>0 - 1000 m</td>
<td>0 - 950 m</td>
<td>200 - 1200 m</td>
</tr>
<tr>
<td>Precipitation / year</td>
<td>450 - 1500 mm</td>
<td>580 - 1800 mm</td>
<td>500 - 3000 mm</td>
<td>300 - 800 mm</td>
<td>300 - 1200 mm</td>
</tr>
<tr>
<td>Mean annual temperature</td>
<td>8 - 19°C</td>
<td>6 - 14°C</td>
<td>6 - 20°C</td>
<td>10 - 18°C</td>
<td>12 - 21°C</td>
</tr>
<tr>
<td>Mean maximum temperature of August</td>
<td>20 - 30°C</td>
<td>&lt;18 - 30°C</td>
<td>22 - 30°C</td>
<td>27 - 35°C</td>
<td>25 - 37°C</td>
</tr>
<tr>
<td>Mean minimum temperature of January</td>
<td>&gt; -4 - 4 °C</td>
<td>&gt; -8 - 4°C</td>
<td>&gt; -10 - 11°C</td>
<td>&gt; -4 - 10°C</td>
<td>&gt; -3 - 10°C</td>
</tr>
<tr>
<td>Soil texture 1)</td>
<td>medium, medium fine, fine</td>
<td>medium, medium fine, fine</td>
<td>coarse, medium, medium fine</td>
<td>coarse, medium</td>
<td>coarse, medium, medium fine, fine</td>
</tr>
<tr>
<td>Water regime 2)</td>
<td>dry, semi-wet</td>
<td>dry, semi-wet</td>
<td>semi-wet, wet</td>
<td>dry, semi-wet, wet</td>
<td>dry, semi-wet</td>
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<td>Soil type</td>
<td>Arenosol, Cambisol, Chernozem, Fluvisol, Greyzem, Luvisol</td>
<td>Arenosol, Cambisol, Chernozem, Fluvisol, Lithosol, Luvisol, Rendzina, Vertisol</td>
<td>All soil types</td>
<td>Arenosol, Cambisol, Lithosol, Rendzina, Regosol</td>
<td>Acrisol, Arenosol, Calcisol, Cambisol, Fluvisol, Leptosol, Luvisol, Regosol, Rendzina, Vertisol</td>
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<tr>
<td>Minimum soil depth available for root growth</td>
<td>&gt;1m</td>
<td>&gt; 1 m</td>
<td>&gt;1.5m</td>
<td>&gt; 1 m</td>
<td>Not relevant</td>
</tr>
<tr>
<td>Minimum soil water capacity of the 1 m of soil</td>
<td>150 mm</td>
<td>100 mm</td>
<td>300 mm</td>
<td>100 mm</td>
<td>50 mm</td>
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<tr>
<td>Wind (max. average wind speed)</td>
<td>&lt; 7 m/s</td>
<td>No information</td>
<td>&lt; 7 m/s</td>
<td>&lt; 9 m/s</td>
<td>&lt; 9 m/s</td>
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<tr>
<td>Frost</td>
<td>&lt;100 days/year</td>
<td>tolerant</td>
<td>&lt;180 days/year</td>
<td>&lt;80 days/year</td>
<td>&lt;100 days/year</td>
</tr>
</tbody>
</table>

1) Definition of the soil texture classes:
- coarse = clay <18% and sand >65%
- fine = 35% < clay <60%
- medium = 18% < clay <35% and sand >15%, or clay <18% and 15% < sand <65%
- medium fine = clay <35% and sand <15%

2) Definition of water regime (dominant annual average soil water regime class of the soil profile):
- dry = not wet within 80cm for over 3 months, nor wet within 40cm for over 1 month
- semi-wet = wet within 80cm for 3 to 6 months, but not wet within 40cm for over 1 month
- very wet = wet within 40cm depth for over 11 month
- wet = wet within 80cm for over 6 months, but not wet within 40cm for over 11 months
Table 2: Target regions for SAF in Europe.

<table>
<thead>
<tr>
<th>Species</th>
<th>Potential distribution area ha</th>
<th>% of arable land</th>
<th>Target regions ha</th>
<th>% of arable land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juglans ssp.</td>
<td>24296074</td>
<td>14.9</td>
<td>19740303</td>
<td>12.1</td>
</tr>
<tr>
<td>Prunus avium</td>
<td>29633505</td>
<td>18.2</td>
<td>22264121</td>
<td>13.7</td>
</tr>
<tr>
<td>Populus ssp.</td>
<td>54705431</td>
<td>33.6</td>
<td>42249328</td>
<td>26.0</td>
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<td>Pinus pinea</td>
<td>6540534</td>
<td>4.0</td>
<td>3766972</td>
<td>2.3</td>
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<td>Quercus ilex</td>
<td>15595690</td>
<td>9.6</td>
<td>8810373</td>
<td>5.4</td>
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<td>Total area</td>
<td>130771234</td>
<td>80.4</td>
<td>65235093</td>
<td>40.1</td>
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