Integrating Soil Erosion and Profitability in the Assessment of Silvoarable Agroforestry at the Landscape Scale

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Abstract

Silvoarable Agroforestry (SAF), the deliberate combined use of trees and crops on the same area of land, can potentially improve the environmental performance of agricultural systems in Europe. However, such changes in land use also need to be seen in terms of their economic implications. The present study makes a combined environmental and economic assessment of poplar SAF near Torrijos in Castilla la Mancha in Spain. Six different silvoarable systems were compared with existing arable agriculture. The Revised Universal Soil Loss Equation (RUSLE) was used to predict soil erosion under the different silvoarable and arable systems and an economic model was used to predict their NPV. SAF with contouring decreased predicted soil loss by 80% compared with the existing arable system. Economic analysis showed that the NPV of densely planted, but widely spaced silvoarable systems could be similar to the NPV of existing arable systems. However, current grant schemes were higher for the arable systems and made the silvoarable systems less attractive in terms of cash flow and NPV. It is concluded that where soil erosion is problematic, grant systems should not increase the attractiveness of arable systems at the expense of SAF.

Keywords: Silvoarable agroforestry, soil erosion, economic assessment, landscape modelling, scenario studies

1 Introduction

Silvoarable agroforestry (SAF) involves the deliberate combination of trees and agricultural crops on the same land management unit in some form of spatial arrangement or temporal sequence such that there are significant ecological and economic interactions between trees and agricultural components (Sinclair, 1999). Recent findings indicate that modern SAF production systems (**Figure 1**) are efficient in terms of resource use; therefore they are proposed as innovative agricultural production systems that can be both environmentally friendly and economically profitable. This would improve farming systems' sustainability and diversify farmers' income as well as provide new products to the wood industry, and create novel landscapes of high value. These possibilities are investigated in the EU-funded project "Silvoarable Agroforestry for Europe" (SAFE) (http://www.montpellier.inra.fr/safe/).

Economic and environmental assessments are usually undertaken separately (Adesina et al., 2000; Belaid and Karteris, 1995). The aim of this paper is to combine the environmental and economic assessment of SAF by modelling various scenarios and evaluating their effects on soil erosion and profitability to test three hypotheses:

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H1. SAF systems (a) reduce soil erosion and (b) increase NPV in comparison with existing arable systems;
H2. Increased tree densities in SAF systems (a) reduce soil erosion and (b) increase NPV;
H3. At equivalent tree densities, implementation design (between-row and in-row tree spacing) influences (a) soil erosion and (b) NPV.

The hypotheses are tested in a Landscape Test Site (LTS) of 16 km^2 in Spain (province of Castilla la Mancha), where the existing land use is compared with different implementation designs of SAF.

2 Material and Methods

2.1 Landscape Test Site (LTS)

Based on an Environmental Classification of Europe, which resulted from a statistical analysis of climatic and topographic data (Metzger et al., 2002), three landscape test sites of 4x4 km were selected in the three dominating environmental classes in Spain. The selection was random but was restricted to agricultural areas according to each of the PELCOM land cover classification. Aerial photographs and digital land use were made available through a collaboration with Prof. Ramon Elena Rosello (Universidad Politécnica de Madrid). During a field survey, land-use information was updated and soil maps were produced based on soil samples and topography. Digital elevation models were elaborated by digitizing the contour lines of topographic maps. Monthly averages of rainfall and temperature from the nearest weather stations were compiled. All spatial information was stored and processed in the Geographic Information System (GIS) ArcInfo 8.3. The Torrijos LTS was chosen for this pilot study. The agricultural statistics of Castilla la Mancha were used to compile the relevant agro-economic and forestry data for the Torrijos LTS.

2.2 Hypothetical SAF system

The hypothetical silvoarable systems developed for the Torrijos LTS consisted of poplar for the tree component and existing arable crops for the crop component. Three different tree densities (25, 50 and 100 trees ha-1) were selected. For each density, two different strategies in the layout of the trees in the field were considered (Table 1). The first strategy maximised the row distance and minimised the in-row tree distance (25 trees ha-1: 40 x 10 m; 50 trees ha-1: 40 x 5m; 100 trees ha-1: 20 x 5m). The second strategy minimised the row distance and maximised the in-row tree distance (25 trees ha-1: 20 x 20 m; 50 trees ha-1: 10 x 20m; 100 trees ha-1: 10 x 10m). These six different systems were compared with the current arable system in the Torrijos LTS.

2.3 Scenarios

Scenarios are farm management options, other than field implementation design, that are used to change the existing land use to a new land use. The objective is to reflect farm management reality. For this study only one scenario was used, due to on-going improvements in the assessment process. This scenario models the complete (100%) conversion of the farm arable land area to SAF. In future, these scenarios will include decisions based on different farmer criteria (e.g. economic, biophysical and environmental criteria).

2.4 Soil Erosion

2.4.1 RUSLE for silvoarable agroforestry

The RUSLE (Revised Universal Soil Loss Equation) (Wishmeier and Smith, 1978) was used to predict soil erosion under the existing arable and the six silvoarable systems (Equation 1).

$$E = R * K * LS * C * P \qquad \text{(eq. 1)}$$

E = annual soil loss (tons ha^{-1} $year^{-1}$)
R = rainfall erositivity factor (MJ mm ha^{-1} h^{-1} $year^{-1}$)
K = soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1})
LS = slope length factor (unitless)
C = cover management factor (unitless)
P = erosion control practice factor (unitless)

The R-factor was calculated according to Renard and Freimund (1994), based on the mean annual precipitation; the K-factor was based on the soil texture components according to Römkens et al. (1986) and Renard et al. (1997), respectively. The AML (Arc Macro Language to run with ArcInfo) developed by Van Remortel et al. (2001) was used to compute the LS-factor.

Because SAF systems have an arable and a forestry component, Equation 2 was derived to calculate the C-factor for a SAF plot.

$$C = [Cov_a * C_a] + [Cov_f * C_f] \qquad \text{(eq. 2)}$$

C = C-factor of a SAF field
Cov_a = land cover fraction of the arable component (crop) (%)
C_a = C-factor for the arable component
Cov_f = land cover fraction of the forestry component (grassland strips under the trees) (%)
C_f = C-factor for the forestry component

Cov_a and Cov_f depend on the distance between the tree rows and the tree row strip width (**Figure 1**). C_f was computed according to Dissmeyer and Foster (1980), based on the trees' canopy diameter and centroid height, which are species specific.

2.4.2 Input parameter for the LTS

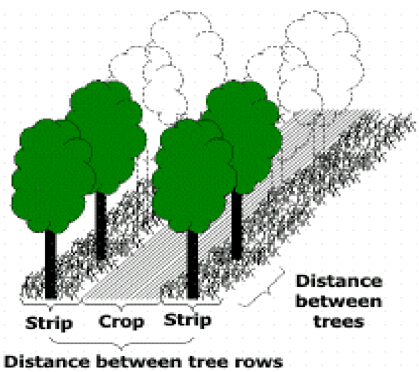


Figure 1: Conceptual design of silvoarable agroforestry (SAF)

The closest climatic station used for the study has a mean annual rainfall of 357 mm. The calculated R-factor is 621 MJ mm ha^{-1} h^{-1} $year^{-1}$. The soil map of the LTS contains seven different soil types with K-values ranging from 0.03854 to 0.04389 t ha h ha^{-1} MJ^{-1} mm^{-1}. The LS-factor values vary from 0 to 11.19 (no unit). A prototype full-grown agroforestry poplar tree of 16 m high with 8 m of canopy diameter was assumed, with the strip being invaded by natural vegetation. The C_a-factor for the study area was assumed to be 0.05, based on a crop rotation with 75% cereals and 25% grassland.

To calculate the P-factor, SAF can be considered as strip cropping. The original contouring value was reduced by 50 % according to Morgan (1995).

2.5 Economic Modelling of hypothetical farms

2.5.1 The economics of silvoarable agroforestry

A computer model (Graves et al. unpublished paper) was developed to compare the effects of silvoarable, forestry and arable enterprises on a farm business. The model assumes that the farm business comprises a series of "enterprises" which generate revenue (*R*) and costs expressed on a per unit area basis. These costs could be both variable costs (*V*), such as the costs of fertilizer, seed and sprays, and assignable fixed costs, such as labour and machinery (*A*).

Whereas an economic comparison of two arable crops can often be undertaken on an annual basis, the economics of a silvoarable system are typically considered over the rotation of the tree crop which lasts many years. As most people have a preference for immediate income, there is therefore a need to 'discount' the value of revenue obtained in the future (most commonly at the opportunity cost of capital), to give the investment a "present" value, termed the "Net Present Value" (NPV) (Pearce, 1971). At a plot- scale, the NPV (€ ha^{-1}) of an arable, forestry or silvoarable enterprises can therefore be expressed as (Equation 3):

$$NPV = \sum_{t=0}^{t=T} \frac{(R_t - V_t - A_t)}{(1+i)^t} \qquad \text{(eq. 3)}$$

NPV = net present value of the arable, forestry or silvoarable enterprise within a unit (€ ha^{-1})
R_t = revenue from the enterprise (including subsidies) in year *t* (€ ha^{-1})
V_t = variable costs in year *t* (€ ha^{-1})
A_t = assignable fixed costs in year *t* (€ ha^{-1})
T = time horizon (years)
I = discount rate

2.5.2 Physical data for the LTS

The Farm Accountancy Data Network (FADN) (European Commission, 2003) for Castilla la Mancha in 2000 indicated that over 50% of the total utilised agricultural area was devoted to "specialist cereal, oilseed and protein crops" farm types. These were dominated by cereal enterprises, comprising 62% of the total utilised agricultural area (66 hectares) of the average farm. It was therefore assumed that a hypothetical arable system would comprise a four-year rotation of wheat, oats, barley and a fallow break. The wheat yield for "specialist cereal, oilseed and protein crops" farms for 2000 was 2.6 t ha^{-1}. Due to limited data, oat and barley yields were derived using the wheat yield as a relative yield indicator. Oat yields on an experimental site in Extremadura were 1.6 times that of wheat grain yields for the same site (SAFE, 2003). Barley yields in a low yielding area in northern Spain were found to be approximately 1.3 times that of wheat yields for the same site (Austin et al., 1998). These relative values for oats and barley suggested that the yields in Castilla La Mancha would be approximately 4.1 t ha^{-1} and 3.2 t ha^{-1} for oats and barley respectively.

Production data for the tree component of the silvoarable systems were derived from yield tables of pure stands of poplars (Christie, 1994). In the absence of other information, a yield class of 10 (i.e. the maximum mean annual increment of the stand is assumed to be 10 m^3 ha^{-1} a^{-1}) was taken to be representative of the growth of poplar on the site. Tree mortality of 5% was assumed. Consequently, these trees were replanted in year 2. No thinning was assumed, but pruning of the poplar was assumed to occur in years 4 and 7. Clear felling occurred in year 15, as per the usual practice with poplar in the area. Production data for the crop and tree component of the silvoarable system were developed using a shading model developed from POPMOD (Burgess et al., 2003).

2.5.3 Economic data for the LTS

Most of the economic data were derived from a variety of statistical sources (e.g. MAPYA, 2000a; 2000b; 2001) and electronic databases (European Commission, 2003) and redeveloped for use in the economic analysis.

A significant difficulty lies in assigning a correct value to harvested timber. The value of timber is often dependent on the size of each individual piece of timber. For example, one cubic meter of wood as a single piece of timber is worth more than one cubic metre of wood comprised of many small pieces of timber. The changing volume to price relationship is represented by timber price-size curves. Here, price-size curves (€ m^3) were derived for Spain from Antonanzas et al. (1992) and Molowni (1998) (**Figure 2**).

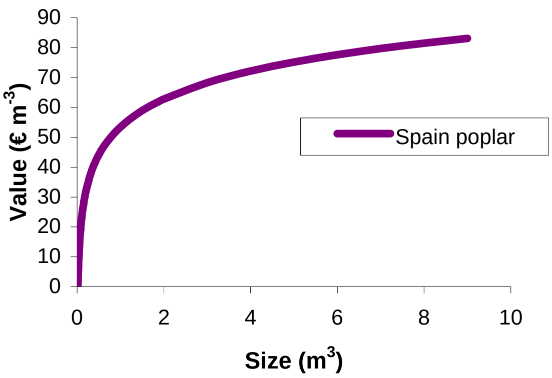


Figure 2: The value of poplar in Spain, developed from Antonanzas et al. (1992) and Molowni (1998)

A further difficulty lies in modelling the area payments available on silvoarable systems. Although there are extensive grants systems available for the establishment of forestry enterprises in Spain, these are forfeited when crops are grown under the tree canopy, as in silvoarable systems. However, the area payment is still available on crops grown in alleys, but these are reduced by twice the canopy area of the trees and may theoretically be assessed every year. In order to model the predicted grant revenue it was therefore necessary to predict the canopy development of the silvoarable systems. Here, the shading model developed from POPMOD (Burgess et al., 2003) was used to predict canopy evolution over time.

3 Results and discussion

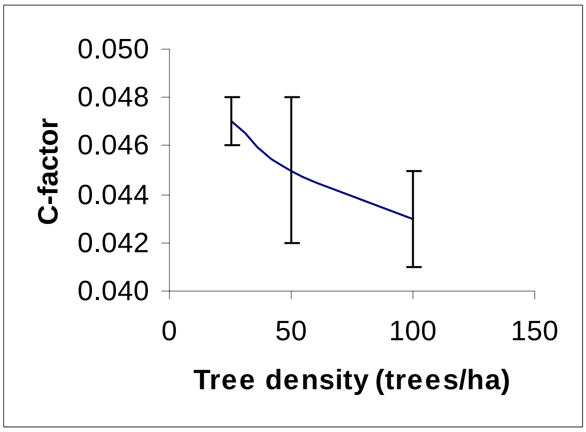
3.1 Soil erosion

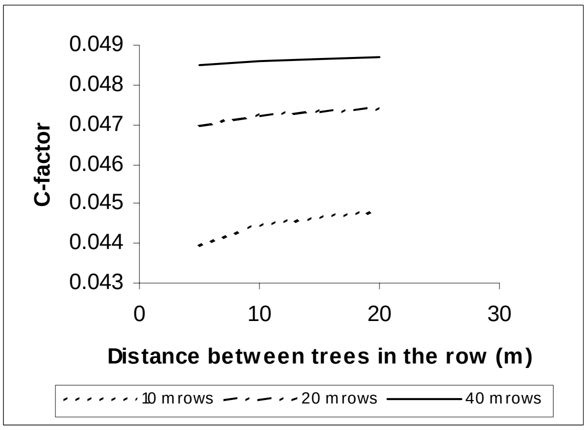
3.1.1 The C-factor as an indicator of soil erosion

Because the C-factor captures the impact of land use in the RUSLE, the effect of SAF implementation designs on soil erosion can be explored through the C-factor. The C-factors of different SAF implementation designs are shown in **Table 1**. A lower C-factor value corresponds to a lower soil loss. Increasing the tree density does not result in a linear decrease of soil erosion (**Figure 3a**). In the Torrijos LTS, SAF systems with 25 trees ha^{-1} can have almost the same erosion as 100 trees ha^{-1} system if the distance between the rows is maximised. The distance between tree rows is more important than the distance of the trees in the row (**Figure 3b**).

Table 1: C-factors for six different implementation designs of SAF.

Tree density (trees ha^{-1})	Distance between tree rows (m)	Distance between trees in the row (m)	Cov_a	Cov_f	C_a	C_f	C
0	-	-	1	0	0.05	0	0.05
25	20	20	0.90	0.10	0.05	0.008	0.046
25	40	10	0.95	0.05	0.05	0.006	0.048
50	10	20	0.80	0.20	0.05	0.008	0.042
50	40	5	0.95	0.05	0.05	0.002	0.048
100	10	10	0.80	0.20	0.05	0.006	0.041
100	20	5	0.90	0.10	0.05	0.002	0.045





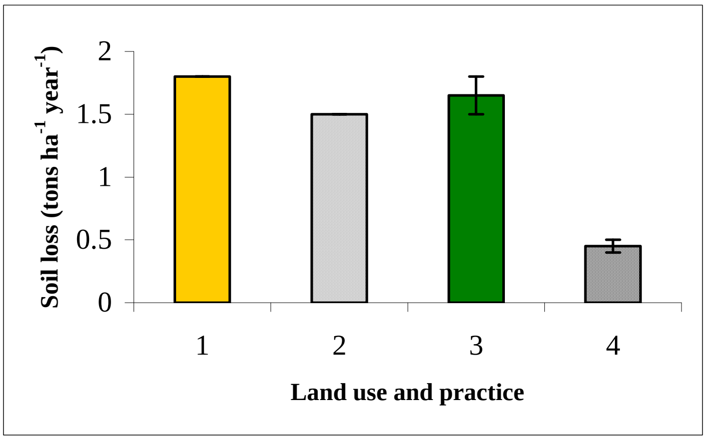
(a) **(b)**

Figure 3: The (a) relationship between tree density and the C-factor in a SAF system and (b) the influence of different between- and within-row tree spacing. Error bars (a) indicate the range of the C-factor due to different implementation designs (Table 1). The lower limit applies for minimum, the upper limit for maximum row distance

3.1.2 Soil loss in the LTS

Sixty-nine percent of the LTS is arable land from which the average potential soil erosion is 37 tons ha^{-1} $year^{-1}$. The actual soil erosion based on the C- and P-factors is on average 1.8 tons ha^{-1} $year^{-1}$ for non contouring practices and 1.5 tons ha^{-1} $year^{-1}$ if contouring practices are applied. By implementing SAF, the same area can have soil erosion rates varying from 0.4 to 1.8 tons ha^{-1} $year^{-1}$ depending on the design (**Table 1**) and on the contouring practices (**Figure 4**).

Changing the arable system to SAF without contouring or introducing contouring practices without SAF lead only to minimum reduction of soil erosion. But when SAF is combined with contouring practices, erosion is reduced by approximately 80%.



1 Traditional arable cropping, no contouring
2 Traditional arable cropping, contouring
3 SAF, no contouring
4 SAF, contouring

Figure 4: The average soil loss from arable land on the Torrijos LTS, as affected by land use (C-factor) and practice (P-factor). Error bars indicate the range of soil erosion due to different implementation designs (Table 1). The lower limit applies to minimum row distance, the upper limit to maximum row distance

3.2 Economic results

The NPV of the arable system was higher than for the silvoarable systems at all discount rates, except at 0% where the 20 m x 5 m system (€3675 ha^{-1}) gave a higher value than the arable system (€3535 ha^{-1}) (**Table 2**). However, in Europe, discount rates of between 2.5% and 5% are commonly used and the existing arable system was more profitable than all the silvoarable systems at these discount rates.

Table 2: The predicted revenue, grants and costs associated with the arable and silvoarable systems and the net present value at each of five discount rates

Tree spacing	Arable system	Silvoarable 25 trees ha^{-1} (20 x 20 m)	25 trees ha^{-1} (40 x 10 m)	50 trees ha^{-1} (10 x 20 m)	50 trees ha^{-1} (40 x 5 m)	100 trees ha^{-1} (10 x 10 m)	100 trees ha^{-1} (20 x 5 m)
Crop income (€ ha^{-1})	4622	3961	4181	3344	4048	2991	3510
Crop grants (€ ha^{-1})	1222	1088	1088	953	1002	710	781
Crop costs (€ ha^{-1})	5602	1687	1780	1499	1780	1499	1687
Tree income (€ ha^{-1})		571	571	1142	1142	2284	2284
Tree grants (€ ha^{-1})		0	0	0	0	0	0
Tree costs (€ ha^{-1})		418	418	552	552	822	822
Net present value, including grants at discount rate of:							
0.0%	3535	3124	3229	3040	3446	3317	3675
2.5%	2994	2591	2680	2469	2804	2602	2888
5.0%	2576	2188	2266	2046	2327	2087	2319
7.5%	2250	1879	1948	1728	1968	1710	1902
10.0%	1992	1640	1701	1486	1694	1430	1592
Net present value, excluding grants, at discount rate of:							
0.0%	2313	2140	2140	2087	2444	2607	2894
2.5%	1959	1658	1748	1640	1939	1960	2194
5.0%	1686	1454	1454	1315	1570	1502	1696
7.5%	1473	1232	1232	1076	1296	1172	1336
10.0%	1304	1062	1062	897	1091	932	1073

The relatively high NPV of the arable system in comparison with the silvoarable systems was largely due to the higher availability of grants. The tree component of the silvoarable system received no grant revenue at all. The predicted area payments made on the silvoarable systems decreased over time and the area payments in the most densely planted systems were the most heavily reduced. At densities of 50 and 100 trees ha^{-1}, the predicted area payments were lower where the trees were planted less densely along the rows (and therefore in more rows per hectare), due to greater predicted canopy coverage of the alley crops by the tree component. Thus, under the current grant system, a farmer might consider it worthwhile planting fewer rows with more trees in them to maximize the payments made on the alley crop.

Without grants, some of the more densely planted silvoarable systems have higher NPV than the arable system at a 2.5% discount rate (10 m x 10 m and 20 m x 5 m systems) and a 5% discount rate (20 m x 5 m system). In silvoarable systems planted at the same density, it is those systems with fewer tree rows (and more trees on each row) that have higher NPVs, largely because the alley crop area is increased and shading of the crop reduced, so that income from the crop component is increased.

It is worth noting at this point that farmers may not choose to view the NPV of competing enterprises as the sole criterion of choice. The short term cash-flow of an enterprise is especially important if farmers require immediate returns to survive. The cumulative cash flows of the arable and silvoarable enterprises (0% discount rate) show that for most of the rotation the arable enterprise provides higher cash flows than the silvoarable enterprise (**Figure 5**).

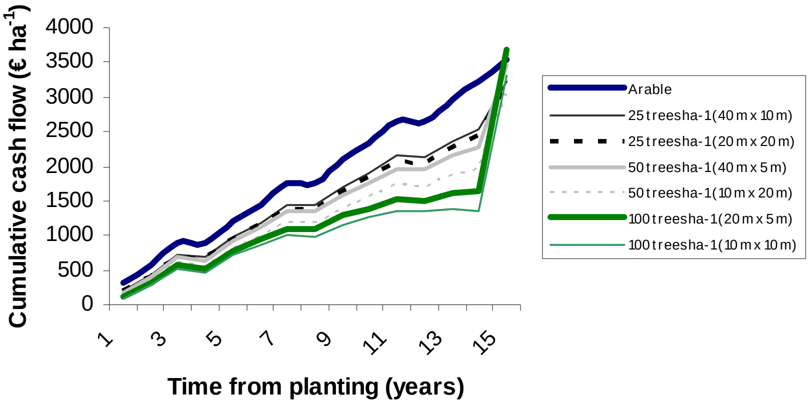


Figure 5: The predicted cumulative cash flow (€ ha^{-1}) for an arable system and each of six silvoarable systems (discount rate = 0%)

Given the current grant scenario and commonly used discount rates, the 40 m x 5 m system and the 40 m x 10 m system are the main alternatives to the arable system, but would not be selected on the basis of NPV alone. However, if competing with the same grant payments as the arable system, silvoarable systems with wide alleys and closely planted tree rows could provide a viable alternative to arable systems at the discount rates commonly used in Europe, provided that farmers are willing to view the investment over a time horizon of 15 years.

3.3 Integrated assessment

Silvoarable systems can reduce soil erosion compared with the existing arable systems, especially, if combined with contouring practices or, in the case of no contouring and in systems of equal density, when between-row distance is minimized. However, silvoarable systems are less profitable than the existing arable system (assumed discount rate 5%), and at equivalent densities, minimizing between-row tree distance also reduces profitability. This 'conflict of interests' between environmental and economic goals is illustrated in **Figure 6**. **H1** as a combined hypothesis must therefore be rejected, because although soil erosion is reduced under silvoarable systems (**H1$_a$** is confirmed), profitability is also reduced at the assumed discount rate of 5% (**H1$_b$** is thus rejected).

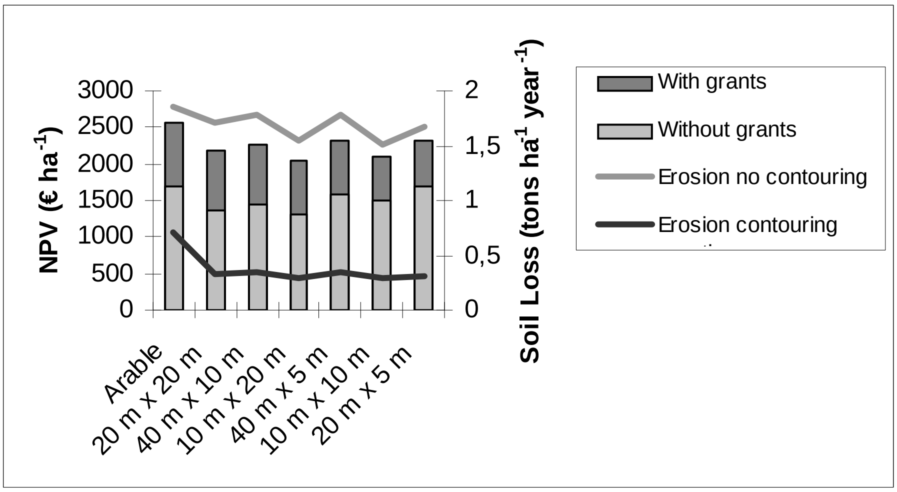


Figure 6: Common assessment of NPV (at 5% discount rate) and soil erosion in the Torrijos LTS

Under different tree densities, soil erosion under silvoarable systems when contouring is used, are similar; without contouring, however, a slight decrease in soil erosion with increased tree density can be observed, especially in closely spaced tree-row systems. No generalisation can be made concerning the relationship between tree density and NPV (assumed discount rate 5%). As a combined statement, **H2** can therefore be rejected, because NPV does not increase with tree density (**$H2_b$** is rejected). Also, soil erosion in the contoured system shows negligible reduction with increased tree density (**$H2_a$** is rejected), although soil erosion is decreased slightly with increasing tree density in non-contoured systems and **$H2_a$** can therefore be confirmed for this specific situation.

At equal tree densities, soil erosion is influenced by implementation design in non-contoured systems - widely spaced tree-row systems result in greater soil erosion than closely spaced tree row systems. In contoured systems, implementation design has little effect on soil erosion. Profitability is also influenced by implementation design, and widely spaced tree row systems give higher NPVs than closely spaced tree row systems. This is because wider rows allow more land to be put under the alley crop and tree shading is also reduced. Additionally as grants payable on silvoarable systems are inversely related to tree canopy area, wider row spacing increases area payments made on the alley crop. This potentially reduces the effectiveness of silvoarable systems for erosion control, as farmers may be tempted to establish silvoarable systems with wider row spacing to maximise revenue. As a combined statement, **H3** can be confirmed in the case of non-contoured systems, because at equal tree densities, wide tree rows are observed to increase predicted soil erosion (**$H3_a$** is confirmed) and NPV also increases in wide tree row systems (**$H3_b$** is confirmed). However, in contoured systems, different implementation designs have negligible effect on soil erosion (**$H3_a$** is rejected) and **H3** would therefore have to be rejected as a combined statement.

In summary, erosion is always better controlled under SAF, compared with existing arable agriculture, especially when contouring is used. In SAF, increased tree density has minimal effect on soil erosion in contoured systems, but more effect in non-contoured systems. Under current grant schemes, profitability is reduced in silvoarable systems, compared with the existing silvoarable system. Increasing tree density does not increase NPV, but at equal densities, widely spaced tree rows give greater NPVs than closely spaced tree-rows.

4 Conclusions and outlook

The results of this study have shown that **H1$_a$** can be confirmed if SAF is implemented with contours in the Torrijos LTS (**Figure 4**). **H1$_a$** is also confirmed under non-contouring, when tree row distance is minimized in SAF systems. **H1$_a$** must be rejected when the current arable system takes contouring practices into account and the SAF system is implemented without contouring (**Figure 4**). Under current circumstances farmers are unlikely to adopt silvoarable systems due to lower cash flows and NPVs than when compared with existing arable systems. Thus, the hypothesis **H1$_b$** of this paper is not confirmed.

However, in the absence of grant payments, widely spaced and densely planted silvoarable systems have similar NPVs to the arable systems at discount rates of between 2.5% and 5%. The present grant system, however, distorts this balance in favour of arable crops. To date, no special grants for SAF exist and this may be a major reason for the low uptake of silvoarable systems. The results suggest that minor modifications of the grant system would make SAF a viable alternative for farmers, leading to reduced soil erosion and increased profitability, in comparison with existing arable systems (i.e. a possible positive interpretation for **H1**). The modifications to the grant schemes could be justified by improved soil erosion control and other environmental benefits accruing as a result, under silvoarable systems, as demonstrated in this case study. In the Torrijos LTS, assuming equivalent grant payments for arable and silvoarable systems, the most suitable alternative of the modelled SAF systems, given the combined objectives of reduced soil reduction and maximized NPV, would be those that: (1) include contouring; (2) have relatively high planting densities, and; (3) have relatively wide between-row spacing.

The results presented here are a pilot study for an integrated assessment which will be extended to other test regions in Spain, France and The Netherlands and in which other tree species will be taken into account. Furthermore, the environmental assessment will be extended to water recharge, nutrient leaching, landscape and biodiversity issues. In the economic assessment, the main criteria will be cash flow and the NPV. The integrated environmental and economic assessment will then be conducted using multicriteria analysis.

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