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RESEARCH ARTICLE

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Economic profitability of agroforestry in nitrate vulnerable zones in Catalonia (NE Spain)

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Abstract

The impact of agricultural practices and the excess application of nitrogen can negatively impact the environment and cause human health problems. In Spain, the liquid manure applied in areas of intensive agriculture is creating groundwater nitrate pollution problems. The purpose of this paper is to evaluate the economic profitability of agroforestry practices in North East Spain. Therefore, it deals with an alternative land use that has attracted attention in recent years, considering its potential to reduce the negative impact of modern agriculture that combines concurrent forestry and agricultural production in the same area. Specifically, silvoarable practices, such as alley cropping (AC), edge row planting and riparian buffer (RB) strips were compared to conventional agricultural land use. Considering the current agricultural policy framework in Spain, which does not favour these practices, our results showed the economic profitability of alley-cropping practices in comparison to conventional barley production of 25 to 64 € ha^{-1} yr^{-1}. However, AC systems presented negative results compared to the traditional wheat crop (-122 to -63 € ha^{-1} yr^{-1}). The results for RB strips were strongly influenced by the high initial costs, both in irrigated and non-irrigated scenarios. Economic results were negative (between -137 and -85 € ha^{-1} yr^{-1}) compared to the conventional crops, barley and corn. These figures could be greatly increased with a policy framework that promotes these practices based on the fundamental ecosystem services they provide. Moreover, these practices allow an economic diversification that could prove to be beneficial for the majority of farmers.

Additional keywords: silvoarable practices; alley cropping; riparian buffer strips; N- leaching; economic evaluation.

Abbreviations used: AC (alley cropping); CAP (common agricultural policy); EAV (equivalent annual value); NPV (net present value); NVZ (nitrate vulnerable zones); RB (riparian buffer).

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Introduction

Modern conventional and intensive agricultural practices have an impact on the environment, causing a reduction of biodiversity, an increase in soil erosion and pollution of underground and surface waters (Palma *et al.*, 2007; FAO, 2013). Excessive application of nitrates in agriculture (inorganic N fertilisers and manures) can leach into groundwater and subsequently negatively impact the environment and pose human health problems (Leach *et al.*, 2004; Giles, 2005; Gutierrez *et al.*, 2016; Pacheco & Fernandes, 2016).

The European Commission Council Directive 91/676/EEC (Nitrates Directive), integrated in Directive 2000/60/EC of the European Parliament and of the Council (Framework for the Community action in the field of water policy), indicates the need to introduce measures to protect waters from pollution caused by nitrates deriving from agricultural sources (Cerro *et al.*, 2014; Lawniczak *et al.*, 2016) and identifies Nitrate

Vulnerable Zones (NVZs) as areas of land or water at risk of pollution (Arauzo & Valladolid, 2013), where fertiliser application procedures should be reviewed. In order to achieve the objective of these Directives, Member States are required to implement all necessary measures to prevent or limit inputs of any hazardous substances into groundwater.

In compliance with these directives, the Spanish Royal Decree 261/1996 provides a list of "Codes of Good Agricultural Practices" for farmers, to be implemented generically on a voluntary basis and "Action Programmes" to be implemented specifically within the NVZs on a compulsory basis (Velthof *et al.*, 2014). These measures limit the periods when N fertilisers can be applied, in order to prevent nutrient leaching and also limit the maximum amount of livestock manure that can be applied, corresponding to 170 kg N ha^{-1} year^{-1} (Bayo *et al.*, 2012).

Spain, Italy and the south of France are among the major pork producing countries of the EU Mediterranean area (EC, 2013), and they present similar issues with N pollution of ground water due to the lack of a correct management of manure originating from the pork industry (INE, 2009). Although the majority of the EU state members have decreased the number of reared pigs, this has not occurred in the Mediterranean countries.

Manure production in Spain, generated by stabled animals, is 76 million tonnes per year (Bigeriego, 2001). This large volume of liquid manure, especially pig manure, applied to areas of intensive agriculture is creating a significant nitrate pollution of groundwater problem (Prapaspongsa *et al.*, 2010).

The number of farms and swine bred for the Spanish pork industry has increased over the last decades according to MAPAMA (2016), reaching a total of 29M swine in 2016 and makes Spain the second largest pork producing country in the EU. In Spain, Catalonia represents the top-ranking region for swine with 7.6 million animals (26% of all Spanish stock). Catalonia produces 43% of all Spanish pork meat and represents 64% of Spanish swine exports (almost 1 million tons). The annual export revenue of pork meat in Catalonia is approx. 2 billion € (DARPA, 2017). Although the number of intensive farms has decreased by 16% over the last 10 years, it is still the most common method of pig rearing and fattening in Spain, with a total number of 68,980 intensive farms versus 14,213 extensive farms (MAPAMA, 2016). Regions such as Andalucía, Aragón, Castilla León, Extremadura and Catalonia present a similar number of intensive farms. Conversely, of these regions, Extremadura and Andalusia are the only areas where a significant number of extensive farms are also present (12,084) (MAPAMA, 2016). The pork industry in Catalonia can be defined as intensive, totalling 6,045 farms in 2016, with a high concentration of stabled animals, equal to over 460 animals per farm (Food & Water Europe, 2017).

Pig manure used as a fertiliser is not the only cause of N contamination of ground water. Intensive agriculture, using mineral fertilisers, also produces contamination; however, a clear relationship between pork producing areas, in Spain and Catalonia, and the contamination of ground water exists. As a matter of fact, all the pork production areas in Spain (with the relevant exception of Galicia) report N contamination of groundwater and a part of their territory has been designated as nitrate vulnerable zones (Food & Water Europe, 2017).

Studies on the quality of ground and surface waters of Catalonia, indicate that 38% is contaminated by nitrates and that 34% of the surface has been designated as nitrate vulnerable zones; over the 2000-2010 period, more than 42M € was spent, in order to reduce or to prevent water pollution (CWA, 2016). The nitrate problem in Catalonia has led to the preparation of a new regional decree regarding the management of soil fertilization and manure, which is due to become effective within 2018 and various measures have also been implemented to reduce N leaching, including: catch crops, agroforestry systems, wetlands and biogas plants (Børgesen & Vinther, 2012). Currently, biogas plants are not operative due to their low feasibility and their practicality is subject to an unstable policy of support in Spain (Capodaglio *et al.*, 2016).

Furthermore, over the last fifty years, Spain has lost 60% of its buffer areas (ditches, rows of trees, hedges, wetlands), which, combined with the evolution of agricultural practices, has led to a consequent increase in erosion, runoff and drainage of nutrients (Paris *et al.*, 2002).

The objectives of N management are both agronomical and environmental and they obviously have economic consequences. Many authors (Grignani *et al.*, 2009; Oenema *et al.*, 2009; Cardenas *et al.*, 2011; Oenema, 2012; Van der Straeten *et al.*, 2012; Zavattaro *et al.*, 2012) agree that N management measures require additional activities (*i.e.* adjustment and reduction of the rate of N fertiliser applied, adjustment of stocking rate and N surplus in animal diets, reduction of the length of the grazing season, adoption of catch crops and irrigation control).

Agroforestry, which is the concurrent cultivation of trees and agricultural crops in the same area, can play a key role in reducing the environmental impact of conventional modern agriculture (Eichhorn *et al.*, 2006; Rigueiro-Rodríguez *et al.*, 2008; Dougherty *et al.*, 2009; Zamora *et al.*, 2009; Christen & Dalgaard, 2013; Smith *et al.*, 2013), however farmers' willingness to adopt these practices depends on economic and management factors (Buckley *et al.*, 2012). Recent estimates indicate that the cultivated territory, classified as agroforestry in the EU 27, is approximately 15 million hectares (den Herder *et al.*, 2017) and Spain, with 5.6 million hectares, has the largest area. Thanks to an integrated land-use system, agroforestry can provide a wide variety of ecosystem services (Torralba *et al.*, 2016) and social and economic benefits (Graves *et al.*, 2007). Regarding ecosystem services, agroforestry can contribute to climate change mitigation (Palma *et al.*, 2015), by reducing CO_2 emissions produced by agricultural activities, by improving C fixation (Paolotti *et al.*, 2016), by protecting the soil (both physically and chemically), by improving water quality and by protecting biodiversity (Liagre & Dupraz, 2008).

Agroforestry systems could provide a partial solution for N contamination (Mosquera-Losada *et al.*, 2016); Palma (2006) estimates that an agroforestry system can reduce up to 28% of N leaching. According to Briggs (2012), N leaching in silvoarable systems is reduced by 50% compared to monocultures, because the tree roots absorb the excess N not utilised by the arable crop. A more optimistic study (Dupraz *et al.*, 2005), indicates an approximate 65% reduction in leaching after 60 years and can be considered as a theoretical maximum impact of agroforestry on N leaching.

In accordance with several authors (Nair *et al.*, 2007; Palma *et al.*, 2007; Christensen *et al.*, 2013), the ability of agroforestry systems to reduce the loss of N can be conservatively estimated from 10% to 50%. Two types of agroforestry practices (Mosquera-Losada *et al.*, 2009) are particularly efficient in this regard: alley-cropping (AC) and riparian buffer (RB) strips.

Alley cropping consists in combining an arable crop with trees planted in rows (Burgess *et al.*, 2005; Cardinael *et al.*, 2015), whereas RBs consist of groups of high density trees, or shrubs, established between the arable area and a body of water (Borin & Bigon, 2002), simulating the buffer effect of riparian forests. In both cases, the tree component normally consists of a species providing an income that is either frequent (*i.e.* biomass) or significant (*i.e.* valuable timber) and can be considered as an activity able to stimulate rural development, by promoting the management of marginal areas through sustainable revenues (Rois-Díaz *et al.*, 2017).

In fact, as demonstrated by Graves *et al.* (2017a) and Rois-Diaz *et al.* (2017), the obstacles to the diffusion of agroforestry are mainly linked to the lack of profitability. In addition, farmers who choose to use their lands for agroforestry, consider profitability as the main prerequisite, followed by diversification, environmental issues and landscape benefits. An increase in productivity and economic outcomes has already been reported (Herzog, 1998; Colomb, 2009; Sereke, 2012), but the latter strictly depend on the legislative framework; for instance, in the last Common Agricultural Policy (CAP) reform, the threshold of maximum tree density to maintain the land eligible for public funding increased from 50 to 100 trees ha^{-1}. This is still a rather low value for new agroforestry systems, if age is not considered, and has yet to be adopted in many countries, including Spain (Mosquera-Losada *et al.*, 2015). Other potential lines of subsidy in the most recent CAP were those related to greening practices (Regulation 1307/2013), including, among others, crop diversification and ecological focus areas.

In the light of the above framework, the aim of this paper was to evaluate the profitability of agroforestry practices located in NVZs in a Mediterranean area, in Catalonia, NE Spain, evaluating the competitiveness of these practices in comparison to conventional crops. The economic performance was assessed by examining the various experimental plots, which differed in terms of agricultural cultivations (typical of the examined area and representative for the Spanish Mediterranean area), category of agroforestry, tree components, tree density and the presence or absence of irrigation. In addition, the potential of silvoarable systems was also evaluated in relation to the availability of subsidies for the studied area.

Methodology

Systems studied

Catalonia is located in NE Spain, characterised by a Mediterranean climate and continental influence in inland areas. The mean annual precipitation ranges from 650 mm to 800 mm (summer precipitation from 90 to 150 mm yr^{-1}), and the mean annual temperature ranges from 10 to 13°C. To all effects, Catalonia possesses many climatic and edaphic features representative of the Mediterranean area in general and of Spain in particular, in fact agroforestry practices can be adopted in entire NVZ areas of Catalonia, where the study areas are located. All these areas are dedicated to agriculture and a wide range of tree species exist, which are suited to the various site and management conditions. Moreover, most of the cereal farming areas in Catalonia mainly focus on wheat and barley production, which are often the main crops rotated on a yearly basis. The cases studied are situated in a hilly area, where the geology is characterised by a predominance of carbonate materials and the soil is primarily light clayey and light loamy (Conesa, 2007; Casals *et al.*, 2009).

Eight experimental plots, four AC cultivations and four RB cultivations, were established in March 2014 (Table 1). The AC plantation species are hybrid walnut (*Juglans × intermedia*) and ash (*Fraxinus excelsior* L.) and consider a rotation period of 50 years; the annual crop in the plots labelled AC1-AC2 was barley and in the plots labelled AC3-AC4 was wheat. The implantation specifications were not chosen with an exclusively economic objective. Rather, a high tree density was specifically chosen in order to reduce soil N content and leaching in the short and medium term in NVZs, in accordance with Andrianarisoa *et al.* (2016).

The RBs involved a double annual crop with barley and corn and different biomass crop densities harvested every 3 years, the stumps to be removed and re-planted at year 12; the plant species was *Populus* spp. In the plots labelled RB1 and RB2, there was no irrigation; in plots RB3 and RB4, both the barley and the corn were irrigated.

All scenarios refer to a square plot of 1 ha. In order to reduce nitrate leaching in the short-medium term, the experimental plots have a higher than usual density for this type of production, in order to achieve a "safe-net" zone as soon as possible. This high density implies that a higher number of thinnings must be performed.

Description of the alley cropping system

The common operations (Table 2) typical of AC systems were defined for each experimental plot. Plantation included harrowing, with a 180 HP tractor, hole preparation using a backhoe excavator, manual planting and placing plastic groundcover, sized 1 m × 1 m, for each tree. Cultivation included herbicide and insecticide treatments with a sprayer, manual pruning from year 1 to 4 and pruning with a basket lift in years 5, 7, 9 and 11 respectively.

The harvesting phase included thinning and final felling, performed by chainsaw, followed by timber delivery, by tractor and trailer, to a storage yard inside the farm. Lastly, stump destruction using a drill and field restoration to the initial conditions was considered. Timber transport from farm to sawmill was a service contract and transport distance was defined as 50 km. For operations that referred to the surface, a strip zone of 1 m width, flanking the tree rows was considered, amounting to 0.055 ha in AC1-AC2 and 0.091 ha in AC3-AC4. The four plots (Table 3) differed in the number of initial plants and type of thinning. The tree spacing plantation layout was 18 m between rows in AC1-AC2 and 11 m in AC3-AC4 and then 4 m in AC1-AC3 and 2.5 m in AC2-AC4 between rows.

The production model utilised to estimate tree volume and timber production of different qualities (veneer, sawnwood and firewood) was the one proposed by Coello *et al.* (2017) rendering a "good" quality for the site, complemented by allometric models proposed by Cambria & Pierangeli (2012).

Description of the riparian buffer crop

RB crops were planted on the side of the river, to a width of 7 m and covering a total area of 0.07 ha for each plot. Plots RB1-RB3 were planted with a low density, amounting to 10,000 plants ha^{-1} (spacing 1 m × 1 m), whereas plots RB2 and RB4 featured a high density of 20,513 plants ha^{-1} (spacing 0.65 m × 0.75 m).

Economic evaluation considered two main processes: plantation/cultivation and harvesting/chipping phases (Table 4). Plantation and cultivation included initial manual brush cutting, harrowing and ploughing, using a

Table 1. Description of scenarios analysed.

Scenario	Altitude (m a.s.l.)	Arable crop	Tree component	Initial tree density (plants ha^{-1})	Irrigation[a] (m^3 ha^{-1} year^{-1})
AC1	455	barley	walnut and ash	140	
AC2	455	barley	walnut and ash	220	
AC3	821	wheat	walnut and ash	227	
AC4	821	wheat	walnut and ash	364	
RB1	538	barley and corn	poplar	10,000	
RB2	538	barley and corn	poplar	20,513	
RB3	270	barley and corn	poplar	10,000	9,000 + 1,500
RB4	270	barley and corn	poplar	20,513	9,000 + 1,500

[a] Irrigation includes both the arable crop and the tree component.

Table 2. Summary of all the processes, number of repeats and operating rates for alley cropping (AC) scenarios.

Phases	Operation	Year	Operation	Operating rate		
				h ha^{-1} yr^{-1}	h plant^{-1} yr^{-1}	h m^{-3} yr^{-1}
Plantation	Harrowing	0		0.36		
	Preparation holes	0			0.02	
	Planting	0			0.08	
	Mulching	0			0.03	
Cultivation	Weed control	from 1 to 50		0.50		
	Protection against insects	from 1 to 50		0.50		
	Tree pruning	1, 2, 3, 4, 5, 7, 9, 11			0.08	
Harvesting	Thinning	2 times in AC1-AC2	Felling			1.00-0.67
			Forwarding	1.00-0.67		
		3 times in AC3-AC4	Felling			1.00-0.67-0.25
			Forwarding	1.00-0.67-0.33		
	Main felling	50	Felling			0.08
			Forwarding	6.00		
	Stump removal and chopping	50	Stump removal		0.03	
			Stump chopping	1.70		

Table 3. Description of harvesting activities and expected output in alley cropping (AC) scenarios.

	AC1	AC2	AC3	AC4
Initial density, plants ha^{-1}	140	220	227	364
Thinning, yr	33% trees ha^{-1}, year 12 33% trees ha^{-1}, year 20	50% trees ha^{-1}, year 8 50% trees ha^{-1}, year 17	50% trees ha^{-1}, year 12 33% trees ha^{-1}, year 20 33% trees ha^{-1}, year 30	50% trees ha^{-1}, year 8 50% trees ha^{-1}, year 17 50% trees ha^{-1}, year 30
Final density, plants ha^{-1}	62	56	51	46
Potential output, m^3 ha^{-1}	32 veneer 48 sawnwood 74 firewood	29 veneer 43 sawnwood 68 firewood	26 veneer 48 sawnwood 76 firewood	24 veneer 52 sawnwood 80 firewood

Table 4. Summary of all the processes, number of repeats and operating rates for riparian buffer (RB, h ha^{-1} yr^{-1}) scenarios.

Phases	Operation	Year	RB1-RB3	RB2-RB4
Plantation and cultivation	Brush cutting	2 times in year 0 in RB5-RB6 2 times in year 0 and 2 times in year 2 in RB7-RB8	48.00	48.00
	Field preparation	0	0.95	0.95
	Planting	0	10.98	19.39
	Weed control	1, 4, 7, 10	1.50	1.50
Harvesting and chipping	Harvesting and chipping	3, 6, 9, 12	2.07	2.70
	Stump removal	12	2.49	5.10

180 HP tractor, planting and then herbicide application (at years 1, 4, 7 and 10 respectively). Harvesting and chipping phases were expected at 3rd, 6th, 9th and 12th years. Biomass transport was considered from the field to a storage yard inside the farm, where biomass will be sold with 30% water content. At year 12, field restoration to the initial conditions with stump removal and chopping was considered.

In plots RB1 and RB2, no irrigation was foreseen, whereas in RB3 and RB4, emergency irrigation using 1,500 m^3 ha^{-1} $year^{-1}$ of water was considered.

Biomass production for RB scenarios is shown in Table 5, relating to scenarios RB1 to RB4. Experimental data regarding the yield obtained during the first two years was complemented with Sevigne *et al.* (2011) and Miguel *et al.* (2015), in order to obtain the potential yield over the four rotations.

Agricultural reference system

The cultivation method of the baseline arable system, used as a comparison, is the one typical of NE Spain, as described in Vilamanya (2014). The experimental data used in the analysis relates to the cultivation process and grain yield for barley, corn and wheat crops. It is the average data of a two-year observation period; the measured data is consistent with the average production reported in the literature for Catalonia in Vilamanya & Piqué (2015). We assume that the agronomic practices remain unaltered throughout the entire period considered. In AC1-AC2, the barley yield was 3 Mg grain ha^{-1} and 3 Mg straw ha^{-1}, whereas in AC3-AC4 the arable crop was wheat and production 4 Mg grain ha^{-1} and 4 Mg straw ha^{-1}. The portion of cropped area was calculated by subtracting the area occupied by tree rows, considering a width of 1 m for each row. The resulting area was 0.94 ha in AC1-AC2 and 0.91 ha in AC3-AC4. Furthermore, crop yields would progressively decrease due to shadowing by trees (Table 6). The agricultural yield reduction is proposed in accordance with that described in Colomb (2009), based on simulations with PlotSAFE software for a case study in Central Catalonia. The trees in the AC method have no impact on crop yields in the first 6 years and very little impact over the first 20 years (Dupraz *et al.*, 2005). Greater impact on crop yields can be assumed in the final 30 years, in relation to the density of the tree component.

On the other hand, in RB plots the cultivated area was 0.93 ha, and crop yields did not change over the whole rotation period. In RB1-RB2, the barley yield was 5 Mg grain ha^{-1} and 5 Mg straw ha^{-1} and corn fodder production was 33 Mg ha^{-1}. In RB3-RB4, the barley production was 6 Mg grain ha^{-1} and 6 Mg straw ha^{-1} and corn production was 11 Mg grain ha^{-1}.

Table 5. Description of potential output (Mg ha^{-1} yr^{-1}) in riparian buffer (RB) scenarios.

Item	Rotation	RB1	RB2	RB3	RB4
Potential output	1st (years 1, 2, 3)	5.75	6.75	8.21	9.64
	2nd (years 4, 5, 6)	6.32	7.42	9.03	10.60
	3rd (years 7, 8, 9)	6.67	7.83	9.52	11.18
	4th (years 10, 11, 12)	6.67	7.83	9.52	11.18

Table 6. Crop yield decrease assumed in alley cropping (AC) scenarios.

	Year	Scenarios		Year	Scenarios	
		AC1	AC2		AC3	AC4
Arable area, ha	1-50	0.94	0.94	1-50	0.91	0.91
Crop yield, %	1-6	100	100	1-6	100	100
	7-20	90	88	7-20	88	81
	21-36	80	83	21-30	77	72
	37-50	70	74	31-50	73	76

The sales prices utilised were the average prices in Spain in 2015, 170 € Mg^{-1} for barley grain and corn grain, 185 € Mg^{-1} for wheat grain, 27 € Mg^{-1} corn fodder (35% water content) and 60 € Mg^{-1} for straw (MAGRAMA, 2015).

Economic evaluation

The economic results were determined by comparing the direct costs and revenues of each scenario with the agricultural reference system.

In order to evaluate long-term investment, it is common to compare Net Present Value (NPV) and Equivalent Annual Value (EAV). The economic comparison of annual agricultural and multi-annual silvoarable systems that last many years was based on discounted cost benefit analysis (Dupraz *et al.*, 2005; Testa *et al.*, 2014); this method enables the comparison of revenues obtained at different intervals of time.

The NPV (in € ha^{-1}) is defined as the difference between all revenues and all costs, which are received and paid out during the complete production cycle, discounted to year zero (De Benedictis & Cosentino, 1979) according to the equation below (Blanc *et al.*, 2019):

$$NPV = \sum_{t=n}^{0} \frac{R_{t-} C_t}{(1+i)^t}$$

where Rt is the revenue from the system in year t (€ ha^{-1}), Ct are the costs in year t (€ ha^{-1}), i is the discount rate, n is the time horizon (year).

In order to compare systems with different rotation lengths, it is useful to calculate the EAV, the infinitive net present value converted to an annual payment (€ ha^{-1} yr^{-1}).

$$EAV = NPV \frac{i\,(1+i)^n}{(1+i)^n - 1}$$

The model takes into consideration the risks or unforeseen situations that may occur during the 50 years of crop rotation. After evaluating the interest rates typically used by other authors in forestry and agriculture studies: *i.e.*, Hauk *et al.* (2014) report values between 1.5% and 6% for investments in short rotation coppice systems; Sgroi *et al.* (2015) indicate a rate of 5% for agroforestry; whereas Blanc *et al.* (2018a) propose a rate of 2.5% for investments in pluri-annual crops in rural areas; a discount rate of 3.0% was chosen. An inflation rate of 0.0 % was assumed, considering that in the reference period, the average inflation rate for Spain was 0.02% (www.inflation.eu).

Other specific risks, such as disease, drought, phytosanitary problems, windblown, etc. were not explicitly taken into account in this study. The model assumed a continuous uninterrupted cultivation of those specified crops with no modification. With regard to drought risk in plantations in the Mediterranean area, non-irrigation in agroforestry scenarios could be considered risky, even if the average annual precipitation in the study area is sufficient to ensure no water deficit. In the case of extremely dry years, the tree species would be close to their water requirement threshold, however it was not possible to take into account emergency irrigation over such a long rotation period. In addition, the instalment of permanent irrigation systems in agroforestry would require a significant economic investment.

Production costs. Production costs were calculated by taking into account service contracts, goods acquisition, labour costs, machinery costs and land remuneration. In AC scenarios, the production costs of the tree component were specifically correlated to the density of each plantation. In RB scenarios, the production costs were calculated in reference to 1 hectare and then reduced in proportion to the buffer surface of 0.07 ha.

Service contracts and goods acquisition. In AC a cost of 2.6 € per walnut plant and 1.2 € per ash plant including transport (*pers. comm*. Coello, 2016) was assumed, together with timber transport costs from farm to sawmill of 0.21 € Mg^{-1} km^{-1} (Marquez, 2014). The service contract assumed for RB *crops* was stem purchase and shipping, according to Gasol *et al.* (2010), with a cost of 0.23 € $stem^{-1}$ (*pers. comm*. BioPoplar, 2016). The irrigation cost assumed for scenarios RB3 and RB4 was 0.099 € m^{-3}, corresponding to variable water supply costs from irrigation canals in Catalonia (GOC, 2015b).

Labour costs. Labour costs, considered for operations carried out by the farmer, were established at 10 € h^{-1}, obtained from the standard costs provided by IRTA (Institute of Agrifood Research and Technology).

Machinery costs. Machinery costs were calculated using a model created by the Ministry of Agriculture, Food and Environment of Spain (MAGRAMA, 2016). The model included both fixed costs (capital recovery, interest and depreciation, taxes and insurance) and variable costs (fuel, lubricant, repair and maintenance costs) (Sierra-Pérez *et al.*, 2018). A cost of 0.6677 € L^{-1} was assumed for Spanish diesel fuel for agricultural machinery, based on the average cost in 2015 (DARP, 2015).

Land remuneration. In accordance with the Government of Catalonia (GOC, 2015a), a value of 27,000 € ha^{-1} for irrigated land and 8,000 € ha^{-1} for non-irrigated land was assumed. Adopting an interest rate of 1%, an annual land use cost of 270 € ha^{-1} yr^{-1} for irrigated land and 80 € ha^{-1} yr^{-1} for non-irrigated land was obtained.

Timber sale price. The price of timber, meeting the requirements for veneer industry (at least 3 m high, 40-45 cm diameter, straight and free of visual defects), ranges from 500 to 900 € m^{-3} (Coello *et al.*, 2009). The reference value utilised in this study was 650 € m^{-3}. Timber that does not reach veneer standards can be utilised for saw wood with prices ranging from 86 to 119 € m^{-3} for high quality timber and from 72 to 86 € m^{-3} for low quality timber; in this study a price of 86 € m^{-3} was assumed. The remaining wood would be sent to the biomass market, obtaining 32 € m^{-3} (COSE, 2015). All prices refer to timber sold to the sawmill plant.

Biomass sale price. The reference price in the Catalonia biomass market is the sale price of chipped biomass, 55 € Mg^{-1} (30% water content) sold to a storage yard, inside the farm (*pers. comm* Biopoplar, 2016).

Subsidies. Catalonia has not activated the sub-measure 8.2 of the European Regulation No 1305 (EAFRD) subsidising the introduction and maintenance of agroforestry systems. The range of subsidies for annual crops was between 120 and 150 € ha^{-1} yr^{-1} (*pers. comm*. Department of Agriculture, Livestock, Fisheries and Food, 2016), in this study an average subsidy of 135 € ha^{-1} yr^{-1} was considered. The subsidy calculated in proportion to the cultivated area was equal to 127 € ha^{-1} yr^{-1} in scenarios AC1-AC2 and 123 € ha^{-1} yr^{-1} in scenarios AC3-AC4; whereas the total RB scenario subsidy was equal to 126 € ha^{-1} yr^{-1}. The subsidies were calculated to be constant for rotations of both 12 and 50 years.

Sensitivity analysis

The sensitivity analysis enables the evaluation, within a reasonable range, of how the changes in some of the components of the model affect the comparison between scenarios (Blanc *et al.*, 2018b). Two sensitivity analyses were carried out for the AC1 and AC3 scenarios using the following variables: timber price and annual crop yield.

Given the timber price uncertainty over the next 50 years, a price range of 300 to 1,000 € m^{-3} in the sensitivity analysis was considered. The relative yield of an annual crop was calculated, in agreement with Dupraz *et al.* (2005), and Graves *et al.* (2007), for a range of productivity yields falling from 90% to 30%, over the next 50 years.

Two other sensitivity analyses were carried out for the RB1 and RB4 scenarios, producing a biomass range crop yield between 4.0 and 15.2 Mg ha^{-1} $year^{-1}$ and a biomass price range of 35 to 100 € Mg^{-1}.

Results

The economic comparison of silvoarable systems and arable scenarios refers to EAV for long-term period rotations and to profit for annual crops.

Economic results for alley cropping systems

The results obtained in the economic assessment of the tree component (Table 7), show that the increase in tree density leads to higher costs in each phase of the crop management but does not guarantee a higher income.

The total cost of the system increased when the initial density was higher. Scenario AC1 gave a total cost of 2,239 € ha^{-1}, compared with 2,790 € ha^{-1} for AC2 (25% higher), and AC3-AC4 respectively 48% and 92% higher than AC1. Plantation costs accounted for 25% in AC1 and rose to 32% in AC4. The highest costs for all scenarios were the cultivation activities, which represented on average 34% of total costs. High cultivation costs, however, can lead to high profits; in fact, appropriate and intensive pruning management has a strong impact on the timber quality. Thus, high cost scenarios do not necessarily match high revenues; in fact, low-density cultivation ensures higher quality timber.

The results of the comparison between AC systems and arable crops also indicated that the best scenario was AC1 (Table 8). In scenarios AC1 and AC2, the silvoarable system was economically viable compared to a barley crop. AC1 guaranteed an

Table 7. Economic results, NVP and EAV, of tree component in alley cropping (AC) scenarios.

	AC1		AC2		AC3		AC4	
	NPV	EAV	NPV	EAV	NPV	EAV	NPV	EAV
Plantation (1)	-568.25	-22.09	-858.00	-33.35	-892.08	-34.67	-1393.10	-54.14
Cultivation (2)	-704.62	-27.39	-957.55	-37.22	-1146.40	-44.56	-1485.42	-57.73
Harvesting (3)	-385.38	-14.98	-425.74	-16.55	-570.32	-22.17	-652.93	-25.38
Transport (4)	-466.24	-18.12	-434.77	-16.90	-521.62	-20.27	-576.05	-22.39
Land benefit (5)	-114.35	-4.44	-114.35	-4.44	-187.13	-7.27	-187.13	-7.27
Total costs (a) = 1+2+3+4+5	-2238.84	-87.01	-2790.40	-108.45	-3317.54	-128.94	-4294.63	-166.91
Incomes (b)	6371.68	247.64	5793.87	225.18	6031.80	234.43	6128.43	238.18
Benefits (c) = b-a	4132.84	**160.62**	3003.47	**116.73**	2714.26	**105.49**	1833.80	**71.27**

NPV: net present value, € ha^{-1}. EAV: equivalent annual value, € ha^{-1} yr^{-1}.

Table 8. Comparison of EAV of alley cropping (AC, € ha^{-1} yr^{-1}) scenarios and traditional crops.

		AC1	AC2		AC3	AC4
Alley cropping	Forestry (1)	160.62	116.73	Forestry (1)	105.49	71.27
	Barley (2)	-115.03	-110.51	Wheat (2)	35.47	9.92
	Subsidies (3)	127.00	127.00	Subsidies (3)	123.00	123.00
	Total (a) = 1+2+3	172.60	133.22	Total (a) = 1+2+3	263.96	204.19
Arable	Barley (4)	-26.13	-26.13	Wheat (4)	191.48	191.48
	Subsidies (5)	135.00	135.00	Subsidies (5)	135.00	135.00
	Total (b) = 4+5	108.87	108.87	Total (b) = 4+5	326.48	326.48
Difference	(c) = a-b	**63.73**	**24.35**	(c) = a-b	**-62.52**	**-122.29**

EAV 59% higher than the annual profit of only arable crops, in AC2 this gap reduced to 22%. The AC3 and AC4 scenarios both returned negative economic results in comparison to an agricultural crop, and the profit was respectively 19% and 37% less than a wheat crop. The low profit margin of crop production in the final years of rotation caused the decrease in revenues. In scenarios AC1 and AC2, the barley crop profits became negative after the 20th year, while in AC3 and AC4, profit from the wheat crop was reduced to 11 € ha^{-1} and 17 € ha^{-1} respectively at year 50. The production costs of annual crops were 728 € ha^{-1} for barley (242 € Mg^{-1}) and 821 € ha^{-1} for wheat (205 € Mg^{-1}). These values were consistent with the production costs recorded for traditional crops in Spain.

Economic results for riparian buffer crops

The results for RB crops were strongly influenced by the high initial costs (Table 9). In fact, the plantation and cultivation phases represented 77% of costs, in scenario RB1, and 83% in scenario RB2. These values decreased to 54 and 63% in irrigated scenarios, RB3-RB4, where irrigation costs represented between 12 and 15%, respectively. Furthermore, the low production of biomass, also observed in scenarios with irrigation, determined reduced revenues. An additional factor that determined high production costs was the land benefit, which accounted for 10-15% in the scenarios without irrigation, but increased up to 27% of costs in the scenarios with irrigation.

However, the limited cultivated area, 0.07 hectares, guaranteed the economic viability of this crop in RB scenarios, because the negative economic results did not significantly affect the total profit. Results for RBs (Table 10), indicated a reduction in profits of 8-10%/ha in the scenarios without irrigation and 31-34% in the scenarios with irrigation.

The production costs of barley and corn were respectively 666 € ha^{-1} and 524 € ha^{-1} in non-irrigated scenarios and 1285 € ha^{-1} and 1716 € ha^{-1} in irrigated scenarios.

Sensitivity analysis results

The results of sensitivity analysis conducted for scenarios AC1 and AC3 are provided in Figs. 1a and 1b. Figure 1a illustrates that at the point with

Table 9. Economic results, NPV (net present value, € ha^{-1}) and EAV (equivalent annual value, € ha^{-1} yr^{-1}) of the biomass component in riparian buffer scenarios.

	RB1		RB2		RB3		RB4	
	NPV	EAV	NPV	EAV	NPV	EAV	NPV	EAV
Plantation and cultivation (1)	-4226.61	-424.61	-6931.31	-696.33	-5460.17	-548.54	-8164.87	-820.26
Harvesting and chipping (2)	-435.74	-43.78	-629.42	-63.23	-435.74	-43.78	-629.42	-63.23
Irrigation (3)	0.00	0.00	0.00	0.00	-1493.10	-150.00	-1493.10	-150.00
Land benefit (4)	-796.32	-80.00	-796.32	-80.00	-2687.58	-270.00	-2687.58	-270.00
Total costs (a) = 1+2+3+4	-5458.67	-548.39	-8357.06	-839.57	-10076.59	-1012.32	-12974.98	-1303.49
Incomes (b)	3355.93	337.14	3940.41	395.86	4362.60	438.28	5629.16	565.52
Benefits (c) = b-a	-2102.74	-211.25	-4416.64	-443.70	-5713.99	-574.04	-7345.82	-737.98
Benefits × 0.07 ha [(d) = 0.07 × c]	-147.19	**-14.79**	-309.16	**-31.06**	-399.98	**-40.18**	-514.21	**-51.66**

Table 10. Comparison of equivalent annual value (EAV, € ha^{-1} yr^{-1}) in buffer scenarios and traditional crops.

		RB1	RB2	RB3	RB4
Riparian buffer	Biomass (1)	-14.79	-31.06	-40.18	-51.66
	Barley (2)	468.49	468.49	52.92	52.92
	Corn (3)	341.74	341.74	143.03	143.03
	Subsidies (4)	126.00	126.00	126.00	126.00
	Total (a) = 1+2+3+4	921.44	905.16	281.77	270.29
Arable	Barley (5)	503.75	503.75	118.97	118.97
	Corn (6)	367.46	367.46	153.79	153.79
	Subsidies (7)	135.00	135.00	135.00	135.00
	Total (b) = 5+6+7	1006.21	1006.21	407.76	407.76
Difference	(c) = a- b	**-84.77**	**-101.04**	**-125.99**	**-137.47**

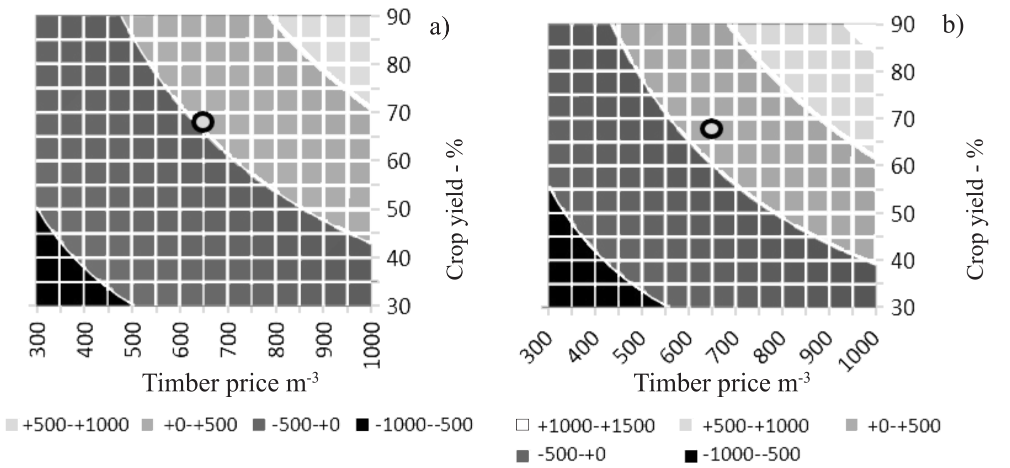

Figure 1. Profitability of AC scenario: with 140 plants/ha tree density and barley crop (a) and with 227 plants/ha tree density and wheat crop (b).

the default values used in the model, positive results were only slimly achieved, however a hypothetical slight reduction of the timber price to 600 € m^{-3} or of the crop yield production to 65% could produce negative economic results. Figure 1b shows a greater economic robustness of agroforestry systems in association with a wheat crop. In this case, positive economic results were guaranteed even when the price of timber was reduced to 550 € m^{-3} and when agricultural production was reduced to 60%. However, in both scenarios it would be difficult to generate a significant increase in profits.

Figures 2a and 2b show the sensitivity analysis results for the biomass component of RB1 and RB4 scenarios, referred to a 0.07 ha surface. In both cases, the results obtained with the default values were negative and a very high biomass yield production and price would be necessary to achieve economic viability of this crop. In the scenario without irrigation (Fig. 2a) it was difficult to assume an increase in production, and the biomass price would have to exceed 85 € m^{-3} in order to achieve a positive economic result. In the case with irrigation (Fig. 2b), the break-even point was only reached in the upper right-hand area, assuming a production greater than 11.3 Mg (dry matter) rotation^{-1} 0.07 ha^{-1} and prices higher than 75 € Mg^{-1}. As a result, it does not seem possible to achieve positive economic results with this method.

Discussion

As stated by Sereke *et al.* (2016), there is a lack of studies focussing on the socio-economic aspects regarding profitability of agroforestry farming. The present study assessed the profitability of agroforestry at plot scale, as an income opportunity for farmers located in rural areas with environmental problems.

In fact, one of the main drivers of abandonment and decline of rural areas is related to agriculture

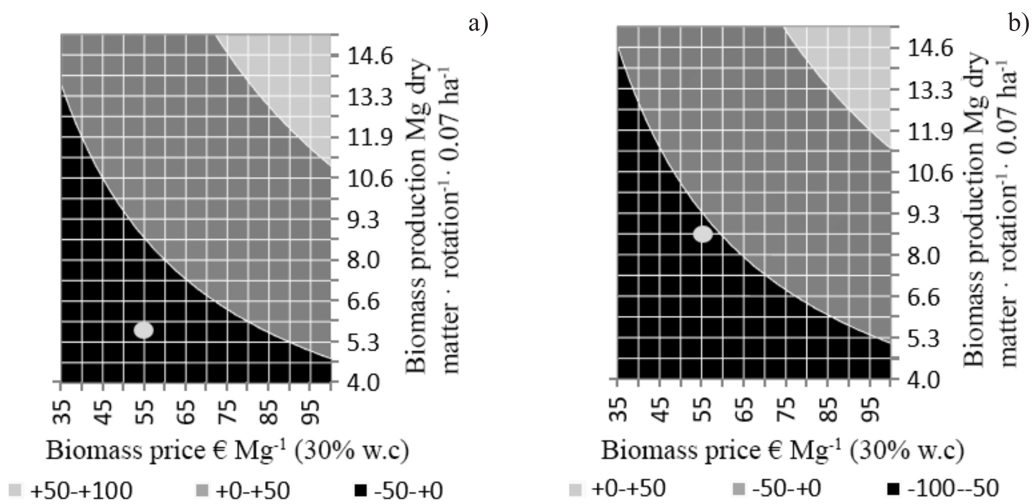

Figure 2. Profitability of RB scenario with a 10,000-tree density plantation without irrigation (a) and with a 20,513-tree density plantation with irrigation (b).

profitability (Breustedt & Glauben, 2007; Renwick *et al.*, 2013), hence, the first motivation for farmers to start agroforestry practices is of economic nature. Therefore, agroforestry could represent an interesting opportunity, useful to stimulate rural areas by providing additional revenues and employment opportunities (Rancane *et al.*, 2014; Rois-Díaz *et al.*, 2017). With reference to the Mediterranean area, the main drivers for practicing agroforestry are: diversification of products, improving the environment, life quality and subsidies (Mosquera-Losada *et al.*, 2017; Rois-Díaz *et al.*, 2017).

Many authors (*i.e.*, Graves *et al.*, 2017b) state the negative perceptions of silvoarable systems due to intercrop production and timber quality. In our simulation, the results in alley-cropping scenarios confirmed the sharp decline of the agricultural crop component after 20 years, and these results would only be offset by the profits from the tree component at the end of the rotation. Furthermore, agroforestry only appeared to be applicable advantageously in AC with barley, while the scenarios with wheat indicated negative results. Moreover, the results show that to achieve high profitability of the tree component, the objective is not high productivity but rather high-quality timber, such as veneer.

Other authors point out that, in a European environment, agroforestry systems become economically interesting by reducing the number of plants per hectare and with crops lasting between 30 and 60 years (Sereke *et al.*, 2015), in other environments the agroforestry system is economically viable over 20 years (Martinelli *et al.*, 2019). It is therefore necessary to highlight that the economic results of the agroforestry system examined in this study are strongly influenced by the ecological and regulatory function for which this type of activity is undertaken. The sensitivity analyses indicated that both AC scenarios only become a competitive option, compared to traditional crops, when agricultural production is reduced by 40-45% and with higher timber prices at 800-850 € m^{-3}. These conditions present a pessimistic scenario for the agricultural component and optimistic for the tree component, however when compared to the experience gained in other contexts it could be considered realistic (Valdivia *et al.*, 2012; Rancane *et al.*, 2014).

Graves *et al.* (2017b) highlight that farmers could possibly perceive the advantage of systems located in a Mediterranean context, where the annual crops are obtained from the trees (*i.e.* firewood). In this study, the economic results for the RB scenarios indicated that high-density crops involved high production costs that were not offset by the biomass yield. These results are in line with those obtained by Faasch & Patenaude (2012), who also achieved similar results in Central Europe, reporting high production costs not offset by revenues, and highlighting the importance of subsidies to encourage this type of agricultural activity. The sensitivity analyses conducted for the two RB scenarios also expressed the difficulty of obtaining positive economic results.

Farmers consider that the major benefits of silvoarable systems would be environmental (Pannell, 1999) and previous studies have demonstrated the environmental and social benefits of agroforestry (Palma *et al.*, 2007). Both silvoarable agroforestry systems studied, in addition to being a business opportunity, provide habitats and refuge zones for birds and other animals, and ensure ecological functions. However, RBs provide important environmental functions, and the loss of profits may be comparable to the cost of deployment of other systems for N pollution reduction (*i.e.* reduction at source and treatment of slurry, artificial drainage). This solution could have a positive reception, particularly in rural areas and where water is readily available.

As highlighted, no decrease is expected for the number of stabled animals in the Mediterranean area, and several manure management solutions are needed, moreover farmers with environmental problems are more receptive to the adoption of silvoarable agroforestry (Graves *et al.*, 2017b). Hence, for farmers located in Mediterranean area, the mitigation of groundwater contamination and N leaching could be transformed from an environmental problem to an opportunity.

The main threats to the implementation of the examined practices appear to be high insecurity and dependence on EU subsidies. As also reported by Mosquera-Losada *et al.* (2017), in order to make this possible, agroforestry has to be supported by policy and actions, bearing in mind that agroforestry is a land management option that delivers market and non-market goods and services. In both the examined agroforestry categories, it appears that direct payments of subsides for annual crops are fundamental for the success of agriculture in rural contexts. Unlike other six Spanish regions, Catalonia has not activated grants for agroforestry within its Regional Rural Development Programme (sub-measure 8.2) within Pillar II of the CAP. In this regard, Spain operates as a federal state in agricultural management and policies, meaning that Catalonia has the authority to develop its own policy. Thus, support in the form of an annual grant would be justified by the potential of agroforestry systems to reduce N leaching. More generally, the access to forms of subsidies, such as payments for ecosystem services, could be key to encouraging farmers to provide environmental service benefits.

In Pillar I of the CAP, agroforestry is eligible for basic payments, where the density of trees with a crown diameter larger than 4 m is below 100 trees ha^{-1} (Coello *et al.*, 2018). Moreover, agroforestry practices are eligible to receive payments linked to greening, as they have been activated by Spain as an eligible Ecological Focus Area. Thanks to our simulation, an additional subsidy to that already granted, equal to 122 € ha^{-1} year^{-1}, could be sufficient to make AC economically viable, where the annual crop is wheat, and a subsidy of 137 € ha^{-1} year^{-1} for RBs. A similar picture emerges in other contexts (Buchholz & Volk, 2013), where the profitability of this type of cultivation is strongly affected by incentive programs. Therefore, agroforestry can represent an opportunity in rural areas, where the value of agricultural land is low. Furthermore, searching for a compromise through tree density reduction would reduce costs, without losing significant profits and at the same time, limit the negative impact on agricultural production.

Considering the limitations in comparing the eight scenarios, which involve rotations of 12 and 50 years, to conventional farming, we can expect that agroforestry will ensure a comparative advantage in the future, whereby wood prices are not expected to collapse and the demand for biomass energy will probably grow. The choice of agroforestry practices creates great risks for the farmer, as climatic factors are particularly relevant in determining the capability of forestry species to grow successfully at a specific site. Moreover, in 12 and 50-year scenarios, it is difficult to predict what risks these crops will be challenged by, and additionally, these systems must consider the willingness of the farmers to accept the risk of not seeing an income before 12-50 years, against the typical annual revenue of agricultural crops. In fact, the poor cash flow during most of the rotation could be a demotivating factor for many farmers.

The limitations that emerged from this study are still linked to the lower flexibility that agroforestry guarantees, when compared with annual crops and the lack of awareness of farmers of the opportunities that agroforestry presents. Undoubtedly, agroforestry is able to reduce nitrogen leaching, but in our experimental plots, the timescale was too short to demonstrate this ability. However, from an economic point of view, the results are encouraging, in fact, with a minimum of aid provided by an annual grant, farmers located in NVZ areas could undertake this activity in a profitable way, guaranteeing important environmental benefits.

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