Lessons learnt: Bocage agroforestry in France

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1 Context

The AGFORWARD research project (January 2014 - December 2017), funded by the European Commission, is promoting agroforestry practices in Europe that will advance sustainable rural development. The project has four objectives:

1. to understand the context and extent of agroforestry in Europe,
2. to identify, develop and field-test innovations (through participatory research) to improve the benefits and viability of agroforestry systems in Europe,
3. to evaluate innovative agroforestry designs and practices at a field-, farm- and landscape scale, and
4. to promote the wider adoption of appropriate agroforestry systems in Europe through policy development and dissemination.

Within the participative research and development networks of the AGFORWARD project, there were ten stakeholder groups focused on agroforestry systems of high natural and cultural value. This report contributes to the second objective of the project and Deliverable 2.5, which describes the lessons learnt from innovations within the stakeholder group focussed on the bocage hedgerow systems of France.

2 Background

The hedgerow systems of Brittany in France are ancient agroforestry systems comprising lines of high- and medium-stem trees (Antoine and Marguerie 2008). The main period of expansion of this agroforestry system was from the eighteenth century to the end of the nineteenth century. From the 1950s, the process of agricultural modernization and intensification led to a general decrease of hedgerow density and their reduced importance in farming management. From the 1990s, hedge planting schemes have been implemented but these have not compensated for hedgerow losses over the same period (Le Dû et al. 2008; Thenail et al. 2014). The objectives in hedgerow planting include the maintenance of the cultural landscape and the regulation of nitrate and phosphorus pollution.

The research developed in work-package 2 of the AGFORWARD project focuses on recent hedgerow networks planted in the 2000s, promoted by the farmers of ”Terres et bocages” group, and designed and managed with an adaptive strategy to allow multiple ecosystem services. The objective is to quantify the ecosystem services provided by such systems in three domains: 1) support and regulation services associated to biodiversity, 2) support and regulation services associated to soil and water, and 3) provisioning services from the hedgerows and associated fields.

Three research questions were addressed:

(1) What is the ecological added value of these recent hedgerow networks?
(2) What is the contribution of management practices to the added value of recent hedgerow networks?
(3) How do farmers perceive hedgerows and how does this perception impact their management strategy?

3 Description of the evaluation study

3.1 Description of case study systems and update on the evaluation study

Our research is based on a pseudo-trial, i.e. a comparison of four sites where hedgerows have been planted in the 2000s and that can be compared from a limited set of varying factors. This evaluation study, initially planned on two sites - La Motte ("Les Ecoupées") and St Barnabé ("Coacavec") - was extended to two supplementary sites (Loudéac and Plumieux) in order to maximize the number of evaluated hedgerows and therefore the robustness of innovation assessments (see Figure 1 for the location of the four sites). A description of the specific pseudo-trial case study systems is provided in Table 1.

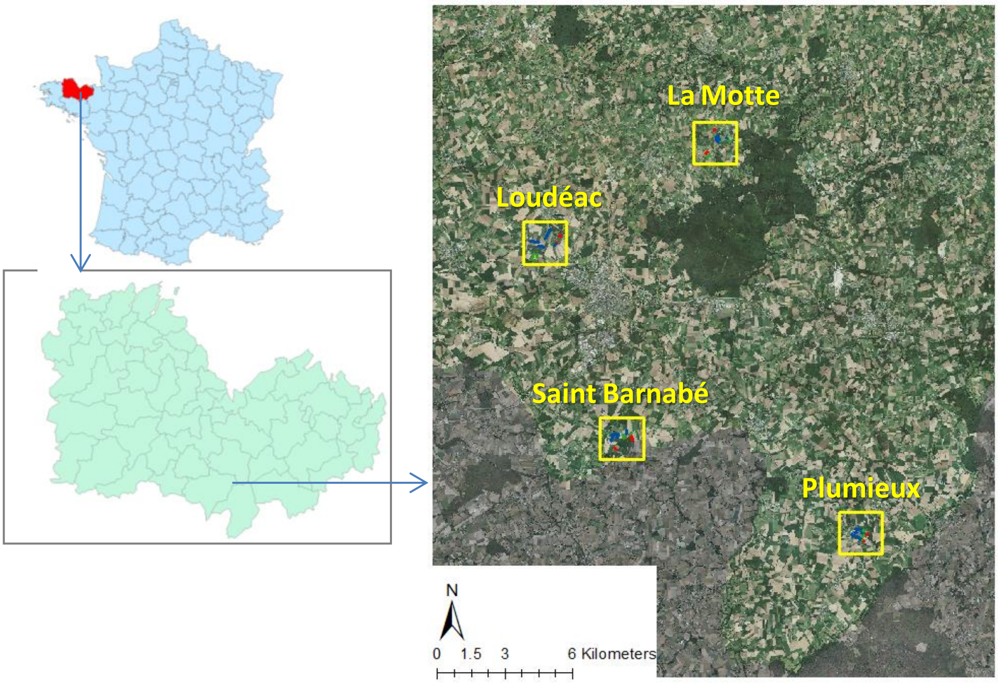

Figure 1. Location of the four study sites: Loudéac, La Motte, Saint Barnabé and Plumieux

3.2 Description of surveys

Field measurements and field to farm surveys, carried out within the framework of the AGFORWARD project and described in the research and development protocol (Thenail et al. 2015) were conducted from spring to autumn 2016.

3.2.1 Surveys of services related to biodiversity

The objective was to quantify ecosystem services related to biodiversity i.e. support services (habitat provisioning, conservation of patrimonial or flagship biodiversity), and regulation services (pest control, pollination). At each site, biodiversity measurements were undertaken on four new planted hedgerows and four traditional field margins (two old traditional hedgerows and two herbaceous field margins) i.e. on a total of 16 new planted hedgerows, 8 old hedgerows and 8 herbaceous field margins (Figure 2). For some biodiversity groups (plants, carabid beetles and pollinators), sampling was also conducted in the field adjacent (at one side) to each studied margins.

Figure 2. Location of studied hedgerows and fields margins in the four study sites. In blue: new planted hedgerows, in red: old hedgerows, in green: herbaceous margins.

3.2.2 Support services

Figure 3 summarizes the whole sampling design regarding biodiversity sampling. Diversity of vascular plants, diurnal butterflies (*Rhopalocera*) and ground beetles (*Carabidae*) was monitored to assess potential services of habitat provisioning (plants) and of flagship species conservation (butterflies, forest ground beetles) fulfilled by new planted hedgerows compared to traditional ones.

For each margin, the presence and percentage of area covered by tree and shrub plant species (Braun-Blanquet Index) were sampled once on a 60 m length along the margin. Presence and percentage of ground covered by herbaceous plant species were sampled once in two 1 m² quadrats (0.5 m x 2 m) distributed along the margin and a distance of 15 m, and in two 1 m² quadrats (1 m x 1 m) located in the adjacent field, at 15 m from the edge.

Species and individuals of adult butterflies were counted during two 10 minute observation periods in June and July, on a 60 m long and 5 m wide transect along each margin (Pollard and Yates 1993). Carabid beetles were sampled using two pitfall traps placed in each margin and distant of 15 m. Traps were open continuously during two weeks and collected three times (May, June, September). The sampling periods were designed to encompass the two main seasons during which carabid beetles emerge (Kromp 1999). Carabid species were identified following Roger et al. (2010).

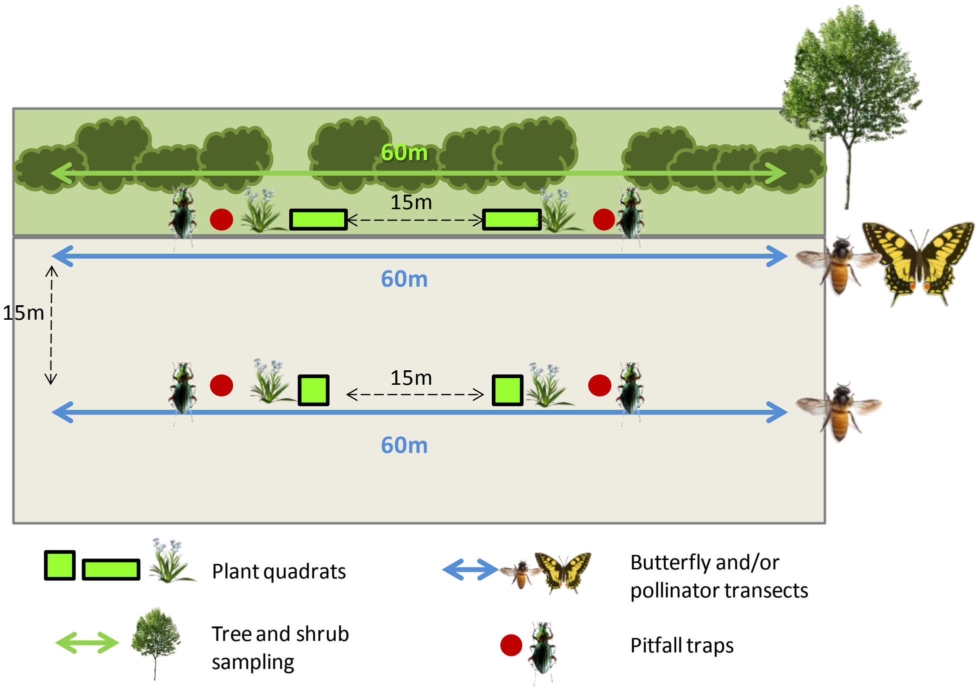

Figure 3.Sampling design of plants, butterflies, pollinators and predatory ground beetles in study field margins and adjacent fields

3.2.3 Regulation services

The potential for regulation services was assessed by monitoring predatory carabid beetles (abundances and diversity of carabid species) that are assumed to play an important role in biological pest control (Kromp 1999), and by monitoring pollinators (abundances of honey and solitary bees, bumble bees, and hoverflies) in field margins and adjacent fields.

In addition to carabid sampling in field margins (cf. previous paragraph on support services), two additional pitfall traps placed in the adjacent field, 15 m from the edge. Again, traps were open continuously during two weeks and collected three times (May, June, and September) and carabid species were identified following Roger et al. (2010).

Pollinating insects were surveyed by the mean of visual counting of individuals according to four categories: honey bees, solitary bees, bumblebees and adult hoverflies. As for butterflies, counting was realized during two 10 minute observation periods in June and July, on a 60 m transect along each margin and on a 60 m long and 5 m wide transect in the adjacent field, parallel to the edge.

3.2.4 Description of the landscape context of sampled margins

Aerial ortho-photographs and field surveys were combined to digitize land-uses (grassland, annual crops, woodland, urban areas) and hedgerows for each sampled margin in a 1000 m diameter circle centered on each sampled margin. Previous studies have shown that this spatial extent allows to detect responses of carabid beetles, butterflies, or plants (see e.g. Davis et al. 2007, Duflot et al. 2015). Several metrics describing landscape composition and configuration were calculated within 1000 m diameter circles: (i) the percent cover (%) of land-covers and land-cover diversity (Shannon index) as descriptors of landscape composition, and (ii) hedgerow density (m), edge length (m) between crops and grassland and edge length (m) between crops and hedgerows, as descriptor of landscape configuration.

3.2.5 Data analysis

Generalized Linear Mixed Models (GLMm) were used to test the effects of field margin type (new planted hedgerow, old traditional hedgerow, grassy field margin) and landscape metrics on the diversity of carabid beetles, butterflies, pollinators and vascular plants. Diversity was described by total number of arthropod and plant species (species richness) and total arthropod abundance or activity-density (in the case of carabid beetles). Correlations between landscape metrics were examined in order to avoid collinearity (Spearman correlation $|r_s| \geq 0.7$) in analyses. Percent cover of crops was negatively correlated with percent cover of grassland (r_s = -0.95). Land-cover diversity was positively correlated to percent cover of woodland (r_s = 0.76) and grassland (r_s = 0.76) and negatively correlated to the percent cover of crops (r_s = -0.89). The length of edges between hedgerows and grassland was negatively correlated with the percent cover of crops (r_s = -0.88), and positively correlated with percent cover of grassland (r_s = 0.90), land-cover diversity (r_s= 0.78) and hedgerow density (r_s= 0.73). The final landscape metrics included in analyses were: percent cover of grassland and woodland, hedgerow density and edge length between crops and hedgerows.

Multi-model inference (Burnham and Anderson, 2004) was used to build all possible combinations of explanatory variables and to rank the resulting models according to Akaike's information criterion (AICc) (MuMIn 1.9.13 package; Barton, 2013). Because focusing on the best model (with the lowest AICc) can result in the rejection of alternative relevant models (Johnson and Omland 2004), we determined the average of the models presenting similar relevance (ΔAICc < 2) when several similar models were identified in multimodel inference procedure (model.avg function in the MuMIn package) (Burnham and Anderson, 2004).We standardized quantitative explanatory variables (Mean = 0, SD = 1) to make the effect strength (or relative importance) of the coefficients comparable across different variables (Smith et al. 2011).

3.2.6 Surveys of services related to soil and water quality

The objective was to quantify regulation ecosystem services related to soil and water quality: climate regulation by measuring soil organic carbon stocks, water quality regulation by measuring nitrate concentration in soil, and water quantity regulation by measuring chloride concentration in soil solution as a proxy of water uptake by trees (Grimaldi et al. 2009; Hao et al. 2015). At each site, soil measurements were realized on a subset of the hedgerows sample for biodiversity.

We have put emphasis on the newly planted recent hedgerows: nine recent hedgerows and three old ones were sampled. The recent hedgerows were selected to cover the variability of hedgerows design in the agroforestry bocage network recently planted in this area. The old hedgerows corresponded to field boundaries with a bank and mature trees planted more than 50 years ago (Table 1).

Table 1. Main characteristics of the hedgerows sampled for soil analyses

Study site	Age	Hedgerow setting	Land-use in the adjacent plots		Local slope
La Motte	Recent (2005)	Two rows of trees, no bank	Permanent grassland	Permanent grassland	13%
	Recent (2005)	One row of trees, no bank	Permanent grassland	Permanent grassland	13%
Saint Barnabé	Recent (2000)	One row of trees, no bank	Maize	Wheat	9%
	Recent (2000)	One row, a bank built using a spade, a ditch	Wheat	Grassland	10%
	Recent (2007)	One row, a bank built using a plow	Grassland	Road	5%
	Old	One row, a bank	Grassland	Maize	7%
Plumieux	Recent (2000)	One row, no bank	Grassland	Maize	3%
	Old	One row, a bank	Maize	Wheat	3%
	Recent (2002)	One row, a bank built using a mechanical shovel	Maize	Grassland	9%
Loudéac	Recent (2003)	One row, no bank	Maize	Wheat	10%
	Old	One row, a bank	Maize	Wheat	10%
	Recent (2002)	Four rows of trees, no bank	Maize	Maize	7%

3.2.7 Soil sampling strategy for each hedgerow

For each hedge, soil samples were collected along three transects perpendicular to the hedgerow up to 18m on both sides of the hedgerow. The transects were about 1.5 m apart to capture the local variability of soil properties. Seven points were sampled per transects at -18 m, -6 m, -3 m, -1 m, 3 m, 6 m, and 18 m from the hedgerow, where soil profiles were sampled in three increments (0-30, 30-60, 60-90 cm) using a manual auger. The distances of the sampling points from the hedgerow are denoted as negative on the up slope side of the hedgerow and positive on the down slope side. The negative distances correspond to soil sampled upstream the hedge. The samples were collected in April and May 2016. Soil samples were bulked by layers and by distances to obtain 21 composite samples representing each distance and increment. Additional undisturbed soil samples were taken for bulk density determination at the same soil depth intervals, using a manual core sampler of 15-cm height and 8-cm internal diameter. The objective was to evaluate the impact on SOC stock, nitrate and chloride concentration by direct measurement next to the hedge as compared to reference stocks and concentration in the middle of the field.

Figure 4. Collection of soil samples

3.2.8 Soil analyses

The composite samples were sieved at 2 mm. A 100 g subsample was used to measure the soil moisture content, by first weighing in a wet state and then after drying at 105°C (AFNOR ISO11465). Another 100 g wet subsample was used for extracting soil solution for the analysis of dissolved constituents. After addition of 100 mL ultra-pure water, the mixture obtained was agitated for 1 h, filtered at 2.5 mm after settling of soil particles, and then again at 0.45 mm. The anions NO_3 and Cl were analyzed by liquid-phase ion chromatography (DX 100 DIONEX, AFNORISO 10304–2) at the UMR SAS laboratory (Rennes). The precision for NO_3analysis was 3%, while the detection limit was 0.1 mg NO_3 L^{-1}. The precision for Cl analysis was 5%. In cases where soil-solution constituents could not be extracted immediately after sampling, the sieved soil subsample was frozen. The results are expressed in mg kg^{-1} of dry soil or mg L^{-1} of the extracted soil solution. A third subsample was milled to 10 µm for organic C (SOC) determination. Carbon concentrations were determined by dry combustion (TrueSpec CNS Analyzer; LECO Co., St. Joseph, MI, USA). Soil was free of carbonates and organic C was equal to total C. Carbon and N contents were expressed as concentration and C stocks as cumulative mass computed for an equivalent soil mass (Mg C ha^{-1}) (Wendt and Hauser 2013).

3.2.9 Surveys of farming practices at field and farm levels

This study was based on interviews, conducted in Autumn 2016, of farmers who managed pairs of fields and field margins in the four study sites. Two types of interviews were performed.

The first type of interviews concerned the technical operations that farmers implemented in 2015-2016 on the fields and field margins sampled for the survey of the ecosystem services related to biodiversity, soil and water. The aim of these interviews was to identify factors related to farming practices that may mitigate or enhance the potential of ecosystem services provided by new planted hedgerows, and also by older hedgerows and herbaceous flat field margins in comparison. A total of 11 farmers (among 15) were interviewed in this frame. They were asked about 1 to 3 pairs of field-field margins located in their farms and in the study sites. A total of 24 pairs of field-field margin were described in this way, including 13 pairs of type "field-new planted hedgerow", 5 pairs of type "field-old hedgerow", and 6 pairs of type "field-herbaceous field margins". From a former methodology (see next paragraph) we notably used graphic representations of the growth of several crops, to help farmers to point the technical operations they implemented on field and adjacent field margin.

The second type of interviews concerned the integration of field margins in the farm management system. All types of field margins on farms were considered, including new planted hedgerows, old hedgerows, and other structures like banks, ditches and flat herbaceous field margins. The interviews concerned i) the overall organization of the work dedicated to field margins in farms, ii) the assets and contraints related to these different kinds of field margins that farmers perceived in the frame of their management systems. The aim of these interviews was to identify the ecosystem services (or "disservices") that are taken into account by farmers, and the obstacles farmers perceived to further develop and manage new planted hedgerows, finally the related services. Among the 11 farmers that have been asked about their practices at field-field margin level, 6 farmers could participate to the survey at farm level.Therefore the results should be considered as a study case description. Nevertheless, they could be compared to the results obtained in 2003-2004 on a similar topic[1], from 81 interviews, some of them being conducted in the area. From the former methodology, we notably remobilizedtwo principles: i) photographies to help the farmers to identify and talk about the different types of hedgerows and other field margins in their farms, ii) methods for assessing the work organization at a farm level.

4 Results and discussion: farming practices

The farmers that were interviewed in this first sequence managed dairy cattle (four farms), dairy and other cattle (two farms), dairy and other cattle and granivorous livestock (two farms), or granivorous livestock and large crops (two farms).

4.1 Agricultural cover and crop successions bordered by the different types of field margins

Figure 5a describes the type of agricultural cover bordered by the studied field margins (we did not separate the types of grassland in this graph), and Figure 5b describes the crop successions. Farmers implemented a diversity of agricultural covers and crop successions on fields bordered by the new hedgerows. In eight cases of new planted hedgerows among 13, the hedgerows bordered temporary grassland of 2-5 years or permanent grassland (Figure 5b). To categorize crop successions we distinguished sown grasslands according to their duration before being ploughed: this partition is consistent with the functions farmers dedicated to the different grassland types (e.g. short duration grassland primarily dedicated to silage and hay production, versus long duration sown grassland primarily dedicated to pasture).

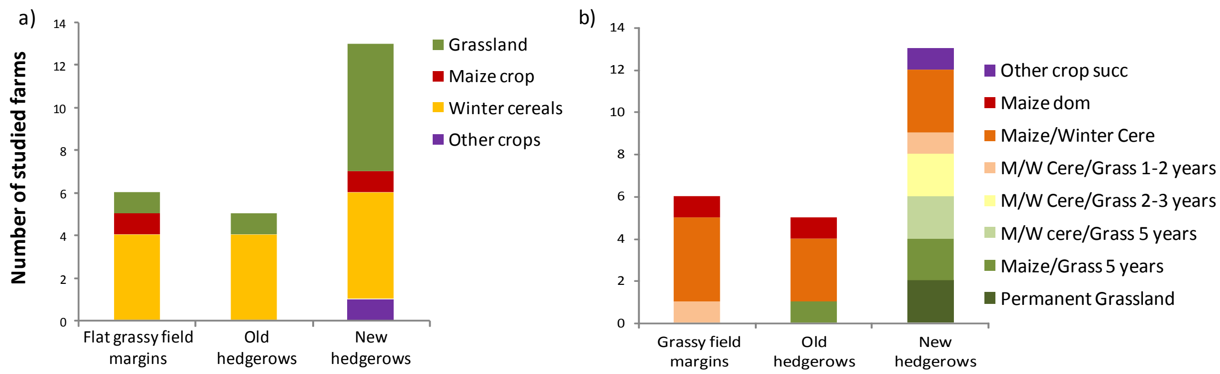

Figure 5. Crops and crop successions bordered by the studied field margins in 2015-2016.

4.2 Coordination of field and field management operations

Firstly, to give an idea about how far the operations of management of the crops or grasslands may affect - or may be affected by - the bordering field margin, we asked farmers about the distance they keep between the cultivated border or the fence location and the middle of the field margin (the trees for a hedgerow). Figure 6 illustrates this distance according to the type of field margin (Figure 6a) or the crop rotation of the field they border (Figure 6b). We observed that farmers keep a distance of tilling or fencing of at least 50 cm from the new planted hedgerows (Figure 6a). In addition, the distance also depends on the crop succession on field (Figure 6b). The distance is more important at the interface between field margins and grassland (permanent or temporary), than at

[1]Thenail, unpublished data. Also see Le Du et al. (2008).

the interface between field margins and successions of annual crops (in this case tilling is also used to reduce the width of the vegetation cover of the field margins).

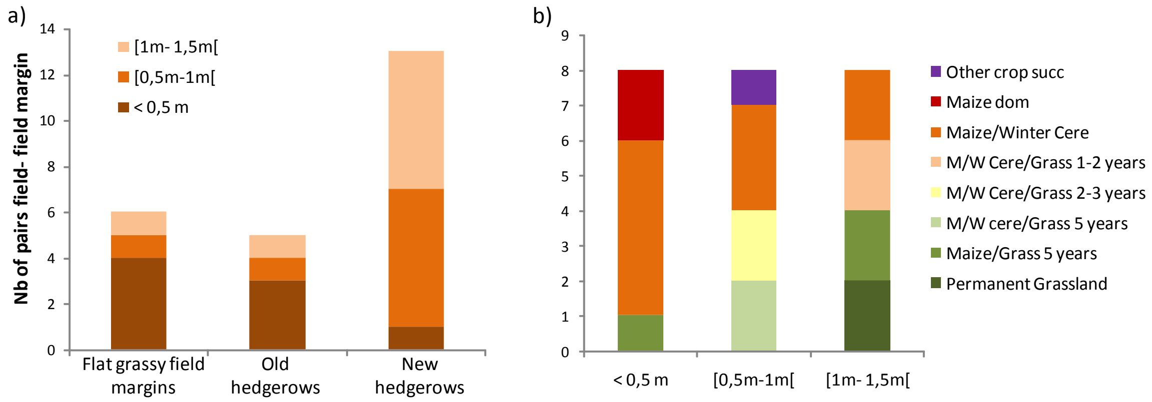

Figure 6. Distance between tilling border or fence location and field margins (and trees for hedgerows), a) according to the type of field margin, and b) according to the crop rotation

Figures 7 and 8 present the operations on field margins alongside the different agricultural cover, with the detail of crop management operations on winter wheat and grassland. Figure 7 describes the results for the first three months of 2016 (January to March), and, for a comparison, Figure 8 gives the results for the second set of three months in 2016 (April to June).

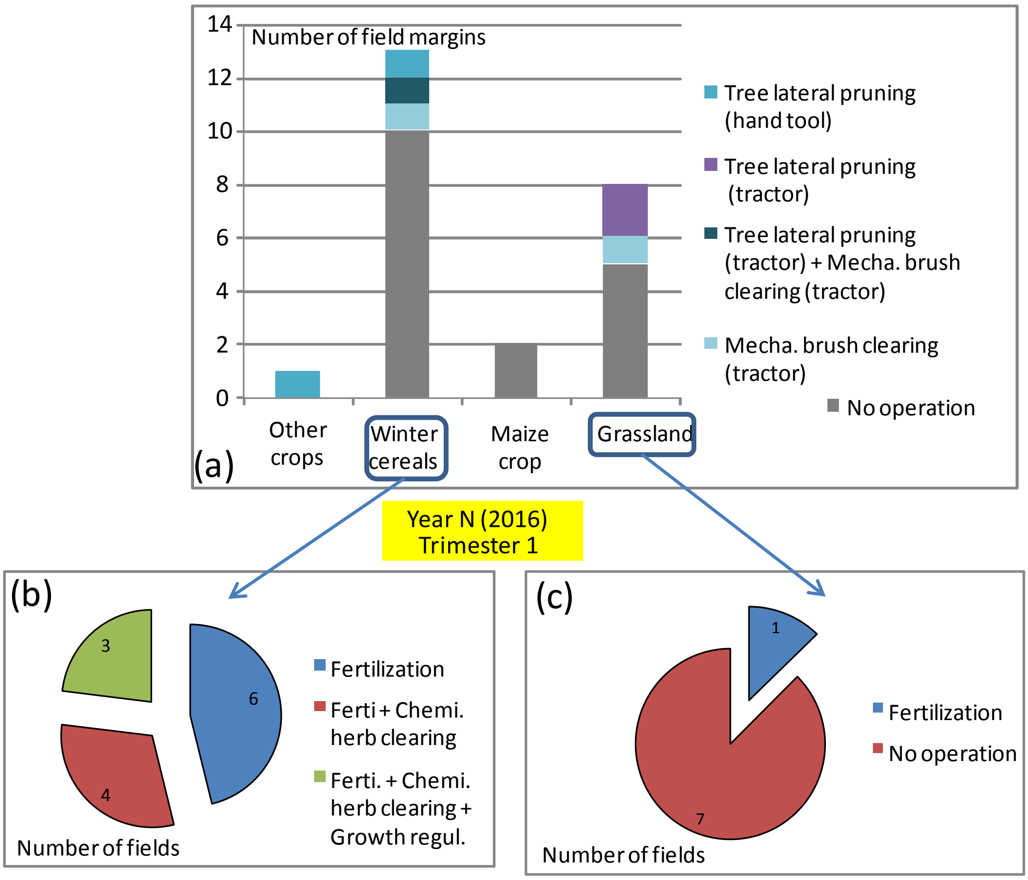

Figure 7. Technical operations (a) on field margins alongside four categories of crops, and the operations within (b) winter cereals and (c) grass crops: January to March 2016 (Trimester 1). Legend: "tractor" means "operated with tractor-mounted tools"; "hand tools" means "operated with hand tools".

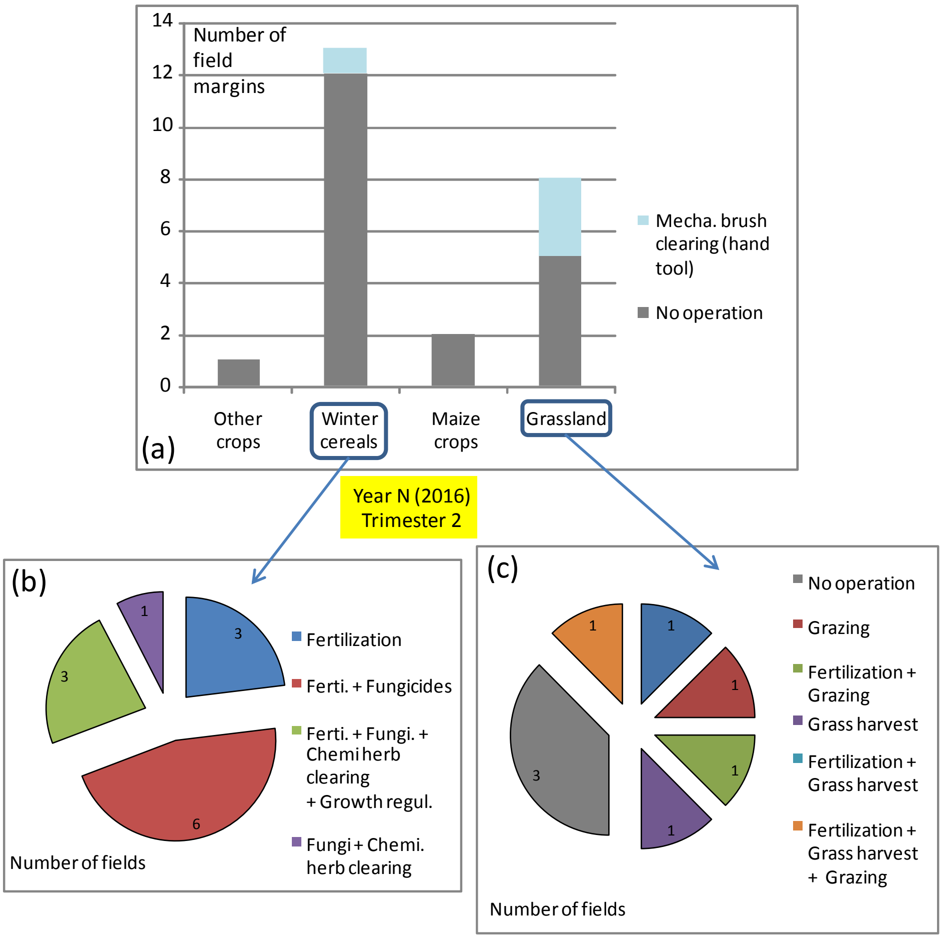

Figure 8. Technical operations (a) on field margins alongside four categories of crops, and the operations within (b) winter cereals and (c) grass crops: April to June 2016 (Trimester 2). *Legend: "tractor" means "tractor mounted tool"*

To facilitate the reading at this stage, we have pooled the management operations by trimester. Among the 24 studied field margins, only two received no management between the 1st trimester of 2015 and the 4th trimester of 2016 (one old hedgerow and one newly planted hedgerow). Farmers have made one to two operation(s) on each of the 22 other field margins. As in former studies, we distinguished for hedgerows and other field margins four main types of operations: tree pollarding, tree lateral trimming, mechanical brush clearing and chemical brush and herb clearing. No specific shape pruning was registered for newly planted hedgerows during the period of study. No tree pollarding was registered on old hedgerows during the period.

The results confirm that, at a field level, farmers organize in time the management operations on field margins according to i) the organization in time of the operations of crop or grassland management (also the availability of the fields), and ii) the plant rest period (i.e., tree pruning and brush mechanical clearing in autumn and winter)(Thenail, unpublished).

The operations on field margins during the first trimester, 2016 were lateral pruning of trees and mechanical brush clearing of new planted hedgerows. Alongside winter wheat crops (Figure 7a), these operations on field margins have been made early in the trimester, before starting the crop management operations (applications of fertilizers, of growth regulator and chemical herb clearing on fields). In January and early February, farmers could still use tractor-mounted equipment at the edge of wheat crops, for a light pruning (e.g. tractor-mounted hedge trimmer) or brush clearing. Heavy field works of, for example, tree pollarding cannot be conducted at this time: farmers perform such operations mainly the winter before a maize crop (a spring crop) in the rotation (also see results at farm level). In the majority of cases, pastures are enclosed with mobile electric fences because grass forms part of the crop rotation and also because field patterns are spatially fragmented and dispersed. This is therefore a major issue for livestock producers that the fences function properly. The operations of pruning and mechanical brush clearing alongside grassland are made before cattle are brought to pasture: the aim is to avoid branches and brushes touching the electric fences (Figure 7a).

The operations on field margins during the second trimester, 2016, were mechanical brush clearing of flat field margins and new planted hedgerows, by the mean of hand tools such as operator-carried brush cutters (Figure 8b). At this period, alongside wheat fields, it is not possible anymore to manage field margins with tractor-mounted tools without affecting the crop, and the more appropriate period for tree mechanical management is over. Cattle are often brought to first pasture at this period: just before this, farmers prepare the fences by cutting the brush and herbs that have grown underneath, with a hand tool which is the most appropriate in this situation.

4.3 Wheat yield according to nitrogen fertilization and the type of margin alongside

The wheat yield in 2016 registered for the studied fields ranges from 7 to 8.1 t/ha (Figure 9a). Figure 9b shows there is no simple relationship between wheat yield and the fact that the field is bordered by a flat herbaceous field margin, an old or a newly planted hedgerow.

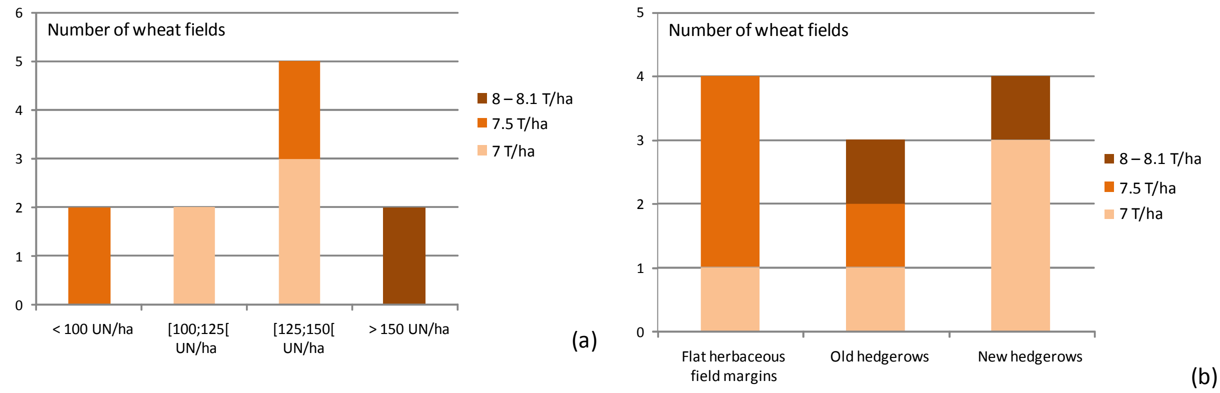

Figure 9. Wheat yield according to (a) nitrogen fertilization and (b) type of field margins alongside. *Legend: The Nitrogen fertilization is given by number of N units per hectare (UN/ha).*

Farmers observe a decrease in the yield mainly within 6-8 m of the field edge, if the hedgerow is oriented so that it shades the crop (also see results at a farm level). However this is not perceptible at a field scale in the situations we encountered. Figure 9a shows that the most fertilized wheat fields (>150 nitrogen units/ha) are the most productive (8 - 8.1 t/ha). Farmers considered that the deviation from the average wheat yield in their farm is primarily due to the diversity of soils (also see results at farm level).

5 Results and discussion: services related to biodiversity

5.1 Overview of sampled biodiversity

Overall, 60 carabid beetle species (4051 individuals), 18 butterfly species (204 individuals) and 117 plant species (1441 occurrences) were sampled in studied margins and adjacent fields. Concerning pollinators, 223 individuals were observed. In most cases, observed species were found in both new planted and traditional hedgerows (Figure 10). However newly planted hedgerows harbored butterflies (5 species), carabid beetles (7 species) and plants (37 species) that were not recorded in traditional field margins. Some arthropod and plant species were also exclusively found in traditional margins (Figure 10).

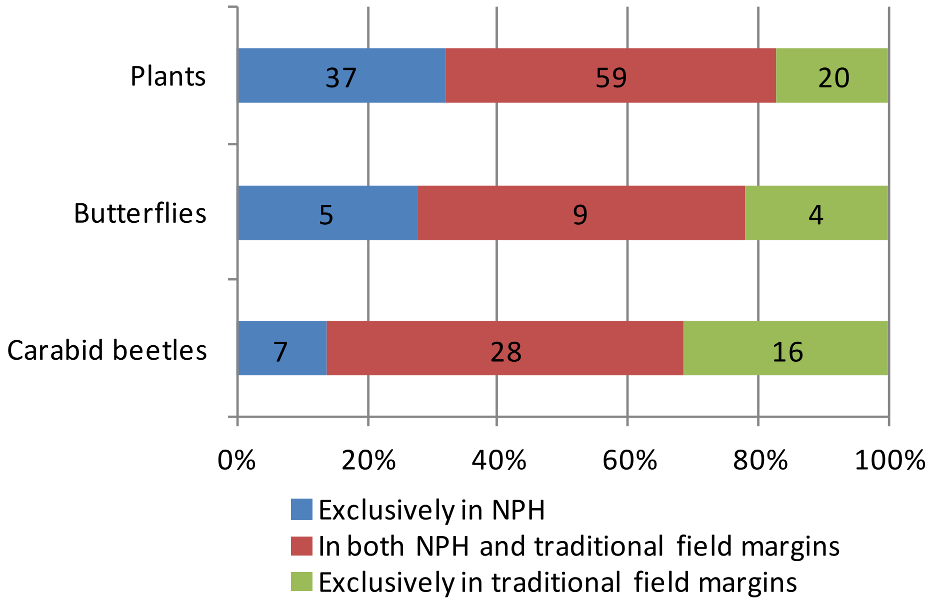

Figure 10. Distribution of arthropod and plant species in new planted hedgerows (NPH) compared to traditional field margins. NPH: new planted hedgerows.

5.2 Habitat provisioning: diversity of vascular plants, butterflies and carabid beetles

5.2.1 Plant diversity in new planted hedgerows and other field margins

New planted hedgerows had similar numbers of herbaceous plant species compared to traditional old hedgerows or grassy field margins (Table 2, Figure 11). However they harbored significantly more tree and shrub species than old traditional hedgerows (Table 2, Figure 11). These differences in tree and shrub diversity are probably related to the initial high diversity of species planted in new planted hedgerows.

Table 2. Significant environmental variables obtained in averaged models (from multimodel inference on GLMm) testing the effects of margin type and landscape variables on species richness of herbaceous, shrub and tree species. NPH: new planted hedgerows, OTH: old traditional hedgerows.

	Estimate	Adj. SE	Z	P
Herbaceous plant species richness				
(Intercept)	2.07	0.06	34.81	< 0.001
Hedge density	0.12	0.06	2.21	0.027
Tree and shrub plant species richness				
(Intercept)	1.89	0.08	25.18	< 0.001
Hedge type (NPH vs. OTH)	-0.54	0.15	3.60	< 0.001

Est.: estimate; Adj. SE: adjusted standard error; Z: z-value; P: P-value.

Local species richness of herbaceous plant species in margins further increased with hedgerow density in the surrounding landscape (1000 m) (Table 2, Figure 11). This finding is in concordance with existing results on plant diversity (Le Coeur et al. 1997; Billeter et al. 2008).

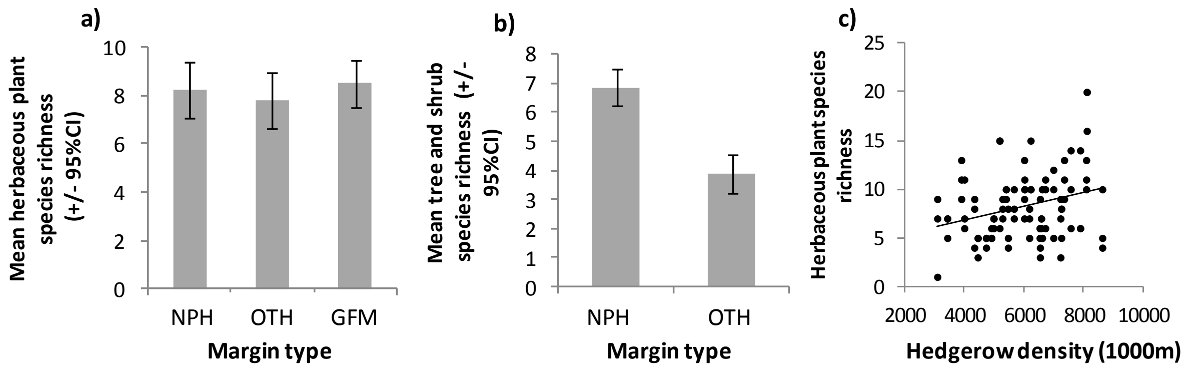

Figure 11.Variation in plant species richness in studied field margins. Average species richness (± 95% CI) of a) herbaceous plants and b) of trees and shrubs respectively, according to margin type, (c) total species richness of herbaceous plants according to landscape context of field margins (hedgerow density in a 1000 m diameter circle). NPH: new planted hedgerows, OTH: old traditional hedgerows, GFM: grassy field margins.

5.2.2 Plant diversity in fields adjacent to new planted hedgerows and other field margins

The analyses of herbaceous plant diversity in agricultural fields showed that plant species richness in fields did not differed according to adjacent margin type (Table 3). It only varied according to field use, and was higher in grasslands than in annual crops (Table 3, Figure 12).

Table 3. Effect of field use and adjacent margin type on herbaceous plant species richness in agricultural fields (unique best model obtained from GLMm). NPH: new planted hedgerows, OTH: old traditional hedgerows, GFM: grassy field margins.

	Estimate	Adj. SE	Z	P
(Intercept)	0.97	0.17	5.64	< 0.001
GFM / NPH	0.04	0.21	0.20	0.842
OTH / NPH	-0.09	0.20	-0.44	0.662
Grassland/Crop	0.62	0.24	2.61	0.009

Est.: estimate; Adj. SE: adjusted standard error; Z: z-value; P: P-value.

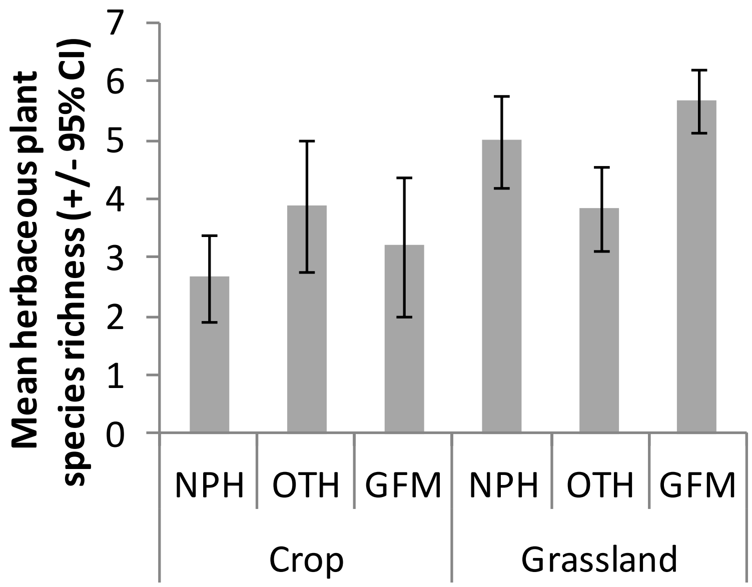

Figure 12. Variation in plant species richness (average ± 95% CI) in agricultural fields according to field use and adjacent margin type. NPH: new planted hedgerows, OTH: old traditional hedgerows, GFM: grassy field margins.

5.2.3 Biodiversity conservation: diversity of diurnal butterflies

Butterfly diversity did not differ significantly between new planted hedgerows and other existing field margins (Table 4, Figure 13). The low number of species (18) recorded during our study was similar to species numbers found in other studies in agricultural landscapes of Brittany (Ouin and Burel 2002). Although differences were not significant, butterfly species richness and abundances were however slightly higher in old traditional and new planted hedgerows compared to grassy field margins (Figure 13).

Butterfly abundance was significantly higher in field margins located in landscapes with high percent cover of woodland (within 1000 m) (Table 4, Figure 13). This positive effect might be related to woodland edges, which can provide important nectar and flowering resources for insects.

Table 4. Significant environmental variables obtained in averaged models (from multimodel inference on GLMm) testing the effects of margin type and landscape variables on butterfly species richness and abundance in field margins

	Est.	Adj. SE	Z	P
Butterfly species richness				
No significant variable	-	-	-	-
Butterfly abundance				
(Intercept)	1.57	0.26	5.95	< 0.001
% Woodland	0.30	0.00	89.96	< 0.001

Est.: estimate; Adj. SE: adjusted standard error; Z: z-value; P: P-value.

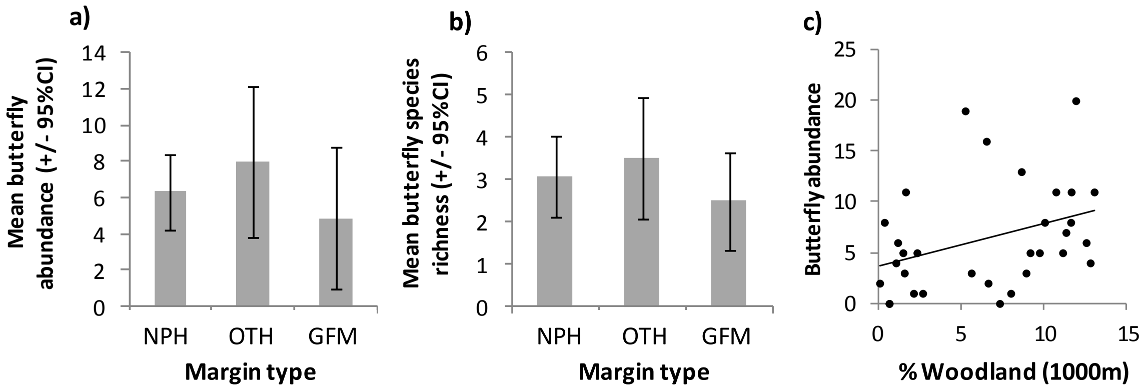

Figure 13.Variation in butterfly species richness and abundance in field margins. (a) and (b): average species richness and abundance (± 95% CI) respectively, according to margin type, (c) total butterfly abundance according to landscape context of field margins (percent cover of woodland in a 1000m diameter circle). NPH: new planted hedgerows, OTH: old traditional hedgerows, GFM: grassy field margins.

5.2.4 Forest carabid diversity

Eight carabid species classified as forest species in the literature (Neumann et al. 2016) were recorded during the study, but at very low abundances (26 individuals trapped): *Abax parallelepipedus* (Piller & Mittterpacher), *Pterostichus madidus* (Fabricius), *Leistus fulvibarbis* (Dejean), *Notiophilus palustris* (Duftschmid), *Stomis pumicatus* (Panzer), *Carabus auratus* (Linné), *Carabus violaceus* ssp. *Purpurascens* (Fabricius), *Notiophilus rufipes* (Curtis).

Three carabid forest species (*L. fulvibarbis*, *N. palustris*, *S. pumicatus*) were exclusively trapped in old traditional hedgerows, whilst two species were only trapped in new planted hedgerows (*C. auratus, N. rufipes)*. However, the very low abundances of these species do not allow concluding about differences or similarities between new planted hedgerows and other field margins.

5.3 Regulation services: diversity of predatory carabid beetles and pollinating insects

5.3.1 Carabid diversity in new planted hedgerows and other field margins

Carabid communities were dominated by six species (representing more than 70% of trapped individuals) that are commonly found in cropped habitats in agricultural landscape in Brittany: *Pterostichus melanarius* (Illiger), *Bembidion lampros* (Herbst), *Pterostichus cupreus* (Linné), *Trechus quadristriatus* (Schrank), *Loricera pilicornis* (Fabricius), and *Agonum dorsale (Pontoppidan).* Carabid diversity did not differ between new planted hedgerows and traditional field margins (Table 5, Figure 14).

Table 5. Significant environmental variables obtained in averaged models (from multimodel inference on GLMm) testing the effects of margin type and landscape variables on carabid diversity

	Est.	Adj. SE	Z	P
Carabid species richness				
(Intercept)	1.71	0.07	22.93	< 0.001
Hedge density	-0.18	0.07	2.61	0.009
% Woodland	-0.15	0.07	2.13	0.033
Carabid activity-density				
(Intercept)	2.39	0.10	24.95	< 0.001
Hedge density	-0.28	0.11	2.45	0.014
% Woodland	-0.37	0.10	3.55	< 0.001

Est.: estimate; Adj. SE: adjusted standard error; Z: z-value; P: P-value.

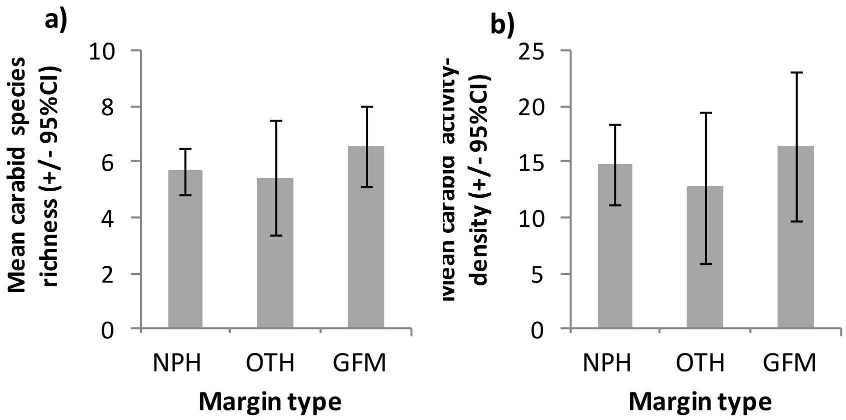

Figure 14. Variation in carabid diversity in field margins. (a) and (b) average species richness and activity-density (± 95% CI) respectively, according to margin type. NPH: new planted hedgerows, OTH: old traditional hedgerows, GFM: grassy field margins.

Although differences were not statistically different, new planted hedgerows tended to have intermediate levels of carabid species richness and activity-density compared to old hedgerows and grassy field margins (Figure 14).

By contrast, carabid species richness and activity-density varied significantly according to the landscape context of field margins (Table 5, Figure 15). Local carabid species richness decreased with increasing percent cover of woodland and hedgerow density within 1000 m. These results are contradictory with existing literature showing a positive impact of the amount of semi-natural habitats on carabid diversity (e.g. see Billeter et al. 2008). Previous studies in the same region have shown that the presence of carabid species associated with cropped habitats (such as *P. melanarius)* is enhanced in open landscapes but reduced in dense hedgerow network landscapes (Aviron et al. 2005). This negative effect of hedgerow density might be related to the higher availability of cropped habitats in open landscapes in our study area. It might also reflect filter or barrier effects of hedgerows to the movements of crop species (Mauremooto et al. 1995; Thomas et al. 1998).

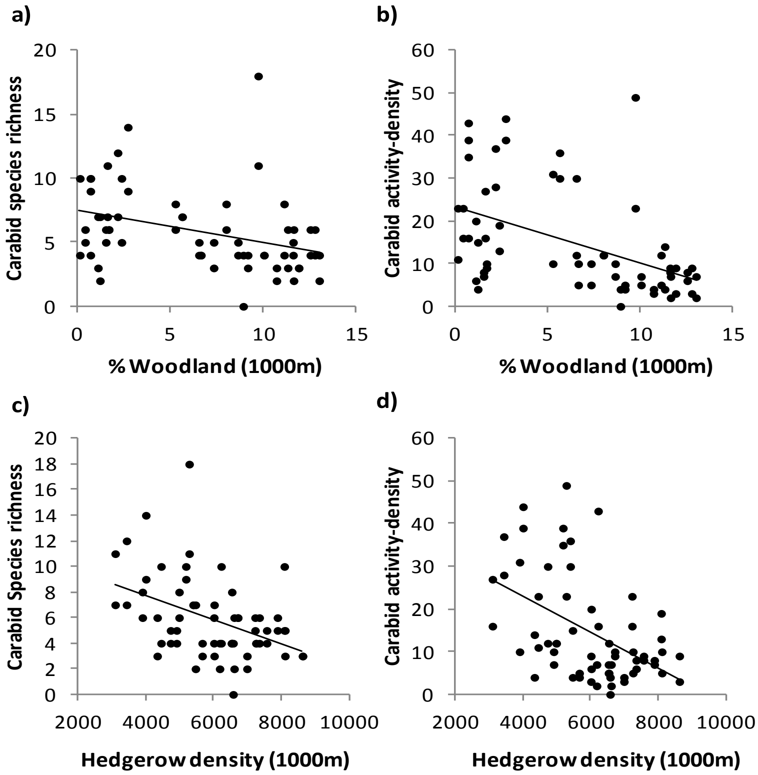

Figure 15. Variation in total carabid species richness and abundance in field margins according to landscape context of field margins (within a 1000 m diameter circle). (a) and (b): species richness and activity-density respectively, according to percent cover of woodland, (c) and (d) species richness and activity-density according to hedgerow density.

5.3.2 Carabid diversity in agricultural fields

Species richness and activity-density of carabid beetles in agricultural fields did not vary according the type of adjacent field margin (Table 6, Fig. 15). They differed according to field use, and were higher in annual crops than in grasslands (Table 6, Fig. 15). Although differences were not significant, carabid activity-density were, however, slightly higher in annual crops adjacent to new planted hedgerows. The higher activity-density of carabid beetles in annual crops is probably related to high abundances of the dominant crop species *P. melanarius.*

Table 6. Effect of field use and adjacent margin type on carabid diversity in agricultural fields (best GLM model). NPH: new planted hedgerows, OTH: old traditional hedgerows, GFM: grassy field margins.

	Est.	Adj. SE	Z	P
Carabid species richness				
(Intercept)	2.11	0.11	19.90	< 0.001
GFM / NPH	-0.02	0.15	-0.14	0.890
OTH / NPH	0.11	0.14	0.76	0.449
Grassland/Crop	-0.38	0.14	-2.66	0.008
Carabid activity-density				
(Intercept)	3.97	0.28	14.17	< 0.001
GFM / NPH	-0.27	0.29	-0.94	0.347
OTH / NPH	-0.27	0.28	-0.98	0.330
Grassland/Crop	-1.08	0.30	-3.56	< 0.001

Est.: estimate; Adj. SE: adjusted standard error; Z: z-value; P: P-value.

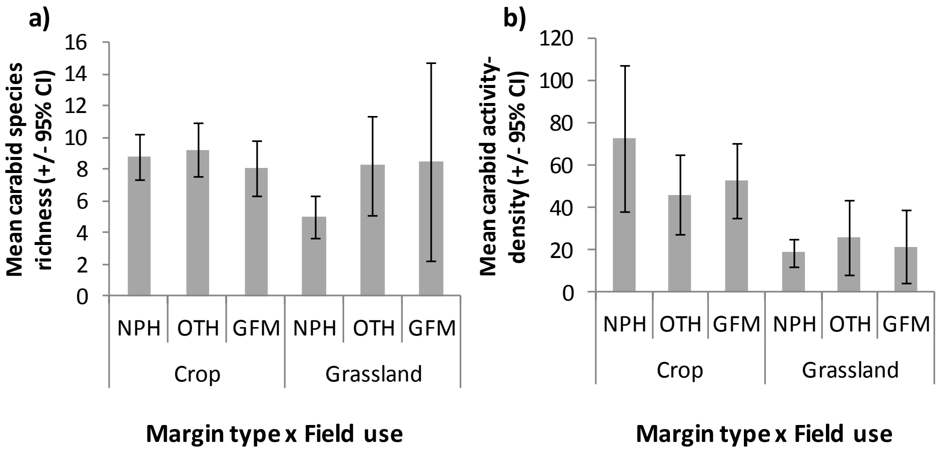

Figure 16. Variation in carabid diversity in agricultural fields. (a) and (b) average species richness and activity-density, respectively, according to field use and adjacent margin type. NPH: new planted hedgerows, OTH: old traditional hedgerows, GFM: grassy field margins.

5.3.3 Pollinator abundance in new planted hedgerows and other field margins

The pollinating insects that were counted during the study were mainly hoverflies (118 individuals), domestic bees (61 individuals), bumble bees (25 individuals) and solitary bees (19 individuals). These low abundances are explained by the non-destructive method used to characterize pollinator abundances (visual counting).

Our results show that abundance of pollinating insects did not differ significantly according to margin type (Table 7, Figure 17), although they were slightly higher in grassy field margins than in new planted or traditional hedgerows.

Table 7. Significant environmental variables obtained in averaged models (from multimodel inference on GLMm) testing the effects of margin type and landscape variables on pollinator abundances.

	Est.	Adj. SE	Z	P
(Intercept)	1.4672	0.1803	8.138	< 0.001
Edge length crop-hedges	0.3599	0.1636	2.201	0.028
% Woodland	0.708	0.1888	3.751	< 0.001

Est.: estimate; Adj. SE: adjusted standard error; Z: z-value; P: P-value.

Pollinator abundance increased significantly according to increasing percent cover of woodland in the landscape context of field margins (within 1000 m) and to the length of edges between annual crop fields and hedgerows (Table 7, Figure 17). The amount of semi-natural habitats is known to promote diversity of pollinating insects (Billeter et al. 2008; Le Feon et al. 2010). These landscape elements, which include wooded edges, can provide nesting sites and food resources for pollinating insects.

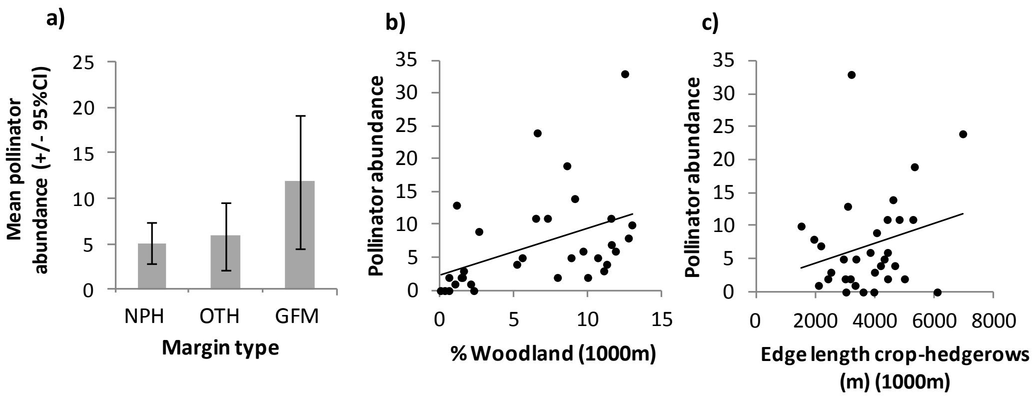

Figure 17. Variation in pollinator abundance in field margins. (a) average abundance according to margin type, (b) and (c) total abundance according to landscape context of field margins (percent cover of woodland and edge length between crops and hedgerows respectively, within a 1000 m diameter circle). NPH: new planted hedgerows, OTH: old traditional hedgerows, GFM: grassy field margins.

5.3.4 Pollinator abundance in agricultural fields

Only 55 individuals were recorded in sampled agricultural fields. This low abundance did not allow the statistical testing of the effect of adjacent margin type on pollinator abundance in fields.

5.3.5 Conclusions regarding biodiversity and associated services

Support services

Our findings on plant diversity suggest that, if we only consider the number of plant species, new planted hedgerows have a comparable (herbaceous species) or higher (tree and shrub species) contribution to habitat provisioning for biodiversity than existing field margins, 15 years after their plantation. However, further analyses are needed to analyze the functional composition of plant communities which probably strongly differs in the different margin types.

New planted hedgerows and traditional field margins seemed to harbor comparable diversity of flagship species (butterflies and forest carabid species). This diversity was rather low, suggesting that the potential contribution of new planted hedgerows to biodiversity conservation is limited, as for traditional field margins.

Regulating services

Our results showed that new planted hedgerows exhibit a similar potential than old traditional hedgerows and grassy field margins, in terms of diversity of predatory carabid beetles. Similarly, the plantation of new hedgerows did not result in a significant increase in the diversity of carabid beetles in adjacent fields. However, the trend to higher carabid activity-densities in annual crops adjacent to new planted hedgerows suggests that they might contribute to pest regulation services, but over the longer term. Additional surveys are needed to confirm or infirm this hypothesis.

Regarding pollinating insects, we could not demonstrate any additional value of new planted hedgerows compared to other field margins, probably because of the low abundances of these insects during our survey.

Importance of the landscape context of field margins

We found significant and strong effects on the diversity of all studied biological groups, of the amount or configuration of semi-natural woody habitats (hedgerow density, woodland area, or edge length between hedgerows and crops), in the landscape context of field margins. We found, however, synergistic or antagonistic effects of similar landscape properties depending on the biological groups: the presence of semi-natural habitats in the landscape context of field margins seemed to enhance the local diversity of plants, butterflies, and pollinators, but it decreased the diversity of carabid beetles. These findings highlight the importance of integrating spatial issues at the landscape scale in the design of hedgerow plantation and in the evaluation of their contribution to ecosystem services. Such concern is taken into account in actual hedgerow plantation programs leaded by the association Terres & Bocage.

6 Results and discussion: services related to soil and water quality

6.1 Soil organic content (SOC) and stocks

For the old hedgerows, although the differences were not statistically significant, mean SOC contents were higher at -6, -3 and -1 m than at the other locations along the transect (Figure 18). These observations are consistent with previous quantification of SOC content in old bocage network, where high SOC contents were explained by high carbon inputs by tree biomass (including roots) and C-rich sediments retained by hedgerows. For the new planted hedgerows, differences in SOC contents between the distances to the hedgerows were smaller, but the highest SOC content were always observed at -1 m from the hedgerows (Figure 19). Average SOC stocks for recent hedgerows are presented in Table 8.

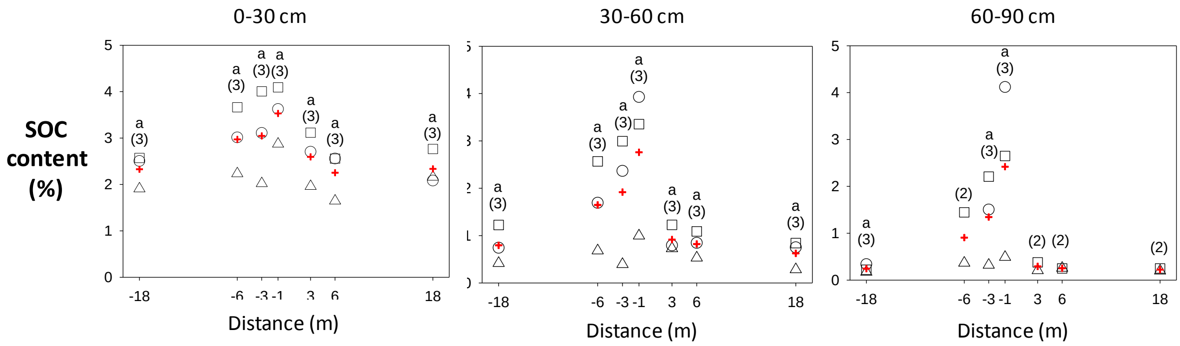

Figure 18. Soil organic content (SOC) as a function of distance to the old hedges, for the three soil layer (0-30, 30-60, 60-90 cm). The red crosses correspond to mean SOC content.

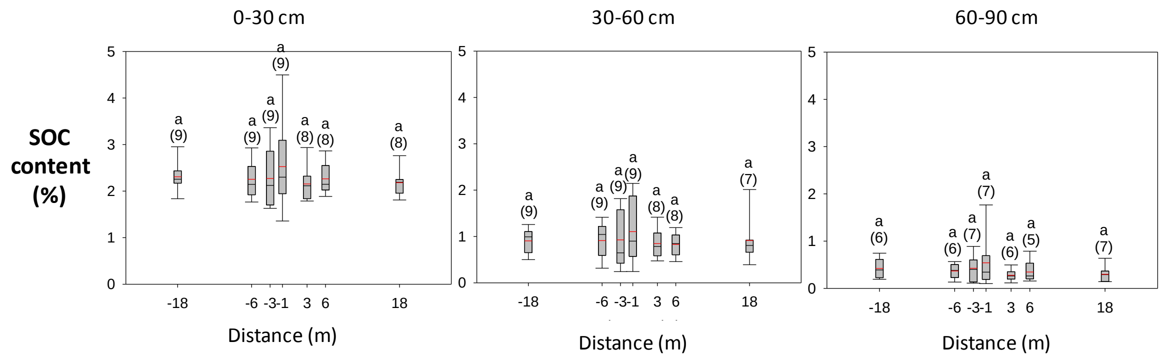

Figure 19. Soilk organic content (SOC) as a function of distance to the recent hedges, for the three soil layer (0-30, 30-60, 60-90 cm). The red line corresponds to the mean SOC content.

Overall, we observed a high variability in SOC concentrations and stocks irrespective of hedgerows age, which probably results from a combined influence of very local conditions (e.g. land use history and local topography). SOC contents and stocks tend to be higher next to the hedgerow (-1 m) in the surface layer that in the other locations for the recent hedgerows: SOC are beginning to be marked by the impact of the hedge but its impact is still limited.

Table 8. Average stocks (standard-deviation) for equivalent soil mass for recent hedgerows

Reference soil mass (Mg ha^{-1})	Average depth to reference soil mass (cm)	Distance to hedgerows (m)						
		-18	-6	-3	-1	3	6	18
2500	24.2	68.0	69.9	66.9	70.2	63.5	67.0	62.4
		(8.3)	(18.6)	(15.5)	(23.7)	(12.4)	(11.3)	(13.5)
5000	44.8	94.0	94.4	92.5	100.3	88.7	90.8	88.2
		(12.2)	(17.4)	(27.9)	(40.2)	(11.0)	(15.1)	(18.5)
7500	64.3	110.2	112.6	116.0	122.2	110.5	112.9	106.0
		(19.3)	(25.0)	(41.2)	(60.9)	(14.8)	(23.9)	(24.8)
10000	84.5	120.1	124.1	126.7	134.6	118.6	123.4	113.1
		(23.3)	(30.1)	(46.1)	(72.5)	(17.1)	(27.7)	(26.8)

6.1.1 Nitrate and chloride concentrations in soil solution

Nitrate and chloride concentrations were affected by the land use of the plot adjacent to the hedgerows: nitrate and chloride concentrations were significantly higher in maize than in the other land use, likely because of the fertilization of maize in spring. Therefore, concentrations under maize had to be analyzed separately from the rest of the dataset. Under grasslands or wheat, regardless the soil sampling depth and the age of the hedgerows, soil chloride concentrations were higher in the vicinity of the hedgerows (up to + or - 6m) than at a distance of the trees (+ or - 18m)(Figure 20). These differences may reflect the higher water uptake by trees, especially by old trees, during the past growing season as compared to crops. No differences were observed under maize, probably because of the impact of fertilization on chloride concentrations.

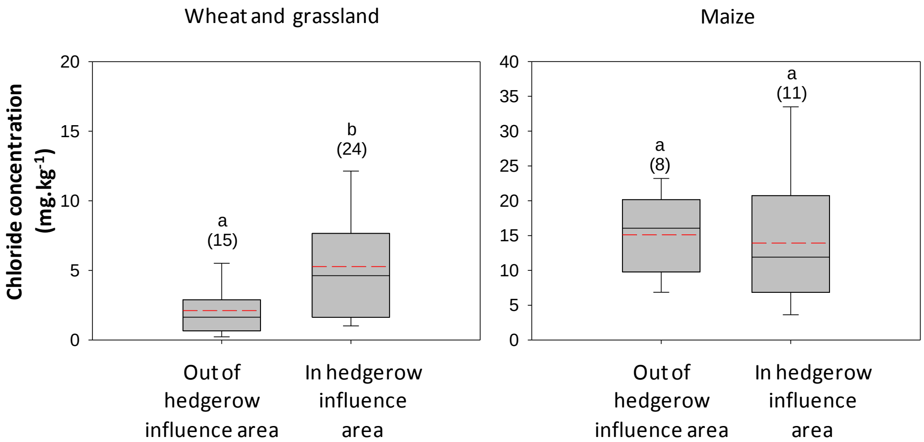

Figure 20. Chloride concentration in soil solution, out of hedgerow influence area (sampling distance: +/– 18 m) or in hedgerow influence area (sampling distances: +/- 6, 3, 1 m), under maize and under wheat or grassland. The red line corresponds to the mean SOC content.

Nitrate concentrations did not show any specific patterns: they were highly variable and they not lower in the vicinity of hedges, contrary to what we could expect. This could be partly explained by the sampling period, favorable to soil organic matter mineralization, especially in SOC-rich areas. The soil nitrate concentration results however from the balance between several processes and fluxes including denitrification, mineralization, plant uptake, and leaching which are highly variable at the field scale.

6.2 Farmers' management and perceptions of assets and constraints of field margins at a farm level.

The six farmers that were interviewed in this second sequence ran the same diversity of production systems than the one described in Section 4.1. One farm is of 20-50 ha, two farms are of 50-100 ha, one farm is of 100-150 ha, and two farms are of 150-200 ha.

6.2.1 Farm-level field margin management: activities, labour and equipment

New planted hedgerows had been planted on four farms among the six that have been studied. In three of these farms, farmers were involved in the project of plantation, in one farm the land owner was commited in the project of plantation but not the farmer. After the plantation, shape pruning have been operated on new planted hedgerows. Then, the management activities were lateral pruning and mechanical brush clearing. Only one farmer also operated chemical brush clearing.

Figure 21 presents the main management activities performed by farmers on the "old types" of field margins at a farm level. All six farmers have old high-stem hedgerows (including notably oaks and chesnuts trees), and five farmers have old medium-stems hedgerows (including notably willows). These hedgerows are managed by tree pollarding (coppicing for willows), or tree lateral pruning, or both (Figure 21). All six farmers have flat herbaceous field margins, three have banks covered by brushes, and three have simple ditches (herbaceous or covered by brushes). Only one farmer operate chemical brush clearing; in contrast mechanical brush clearing is operated in all farms and on all type of field margins (Figure 21).

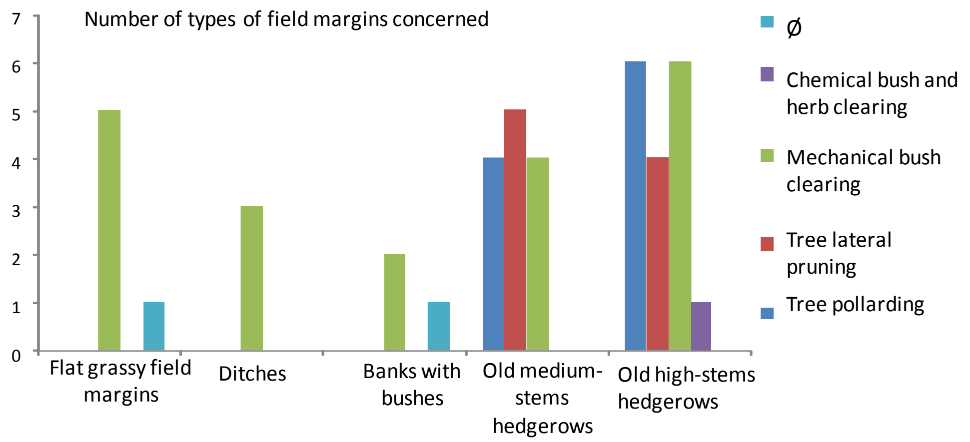

Figure 21. Main management activities operated on old types of field margins

Figure 22 gives an evaluation of the whole working time per year, dedicated to each of the four main management activities on field margins, namely i) tree pollarding for old hedgerows, ii) tree lateral pruning for old and new planted hedgerows, iii) mechanical brush clearing and iv) chemical herb and brush clearing.

It was not possible to assess this working time specifically for each type of field margin, because farmers have generally an organization by field work and not by type of field margin : in one field work of one or several days, they will go through the whole set of field margins that need to be managed in their farms.

To make the assessment of working time feasible with farmers, we asked them to consider the number of days of 5 hours (i.e., out of the hours of compulsory tasks, e.g., for livestock feeding) spent on the activity by a working team, independently of the number of workers in the team. This evaluation of the working time include the mobility of workers from field to field and back to farmstead to store the wood. We asked independently about the number of workers by team of field work, and their origin, as well as the types of equipements/tools and their origin.

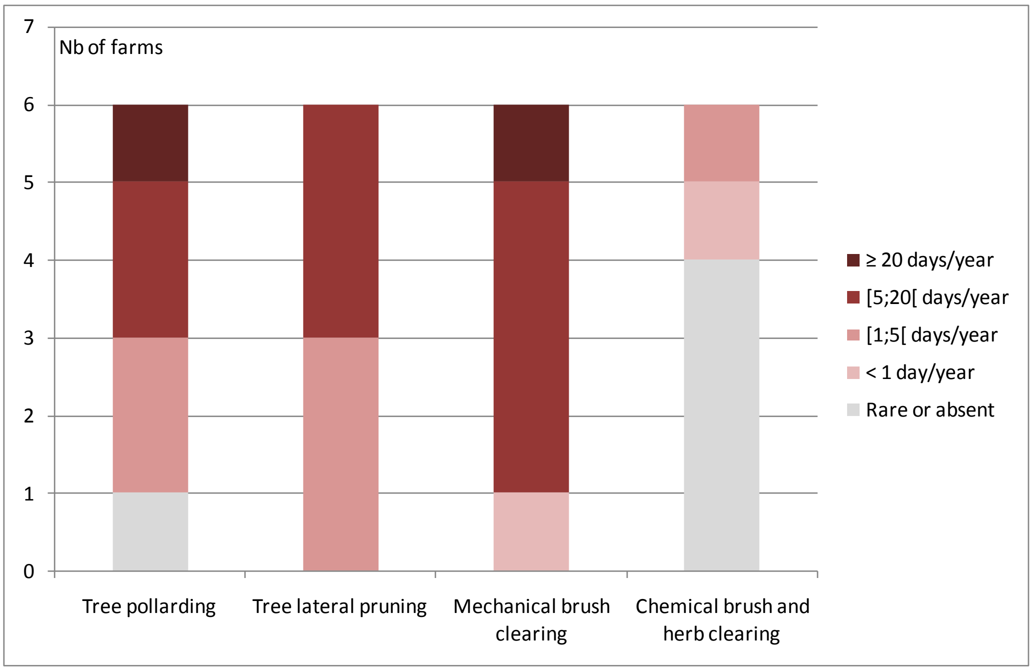

Figure 22. Evaluation of the number of days dedicated to the management of field margins in each farm by year. NB. One day of work correspond to a day of 5 hours by working team (of one to three persons the case arise)

Tree pollarding, tree lateral pruning and mechanical brush clearing are time consuming activities: each of them often need more than 5 days of work each in the studied farms (Figure 22) with a working team of 2-3 persons for tree management. The management of hedgerows by tree pollarding requires to prune the trees one by one with a hand tool from an elevator and to remove the branches out of the hedgerow. The working team is formed by 2-3 persons: the farmer(s) with family in three cases, and the farmer(s) with in- or out-farm workers in three other cases (including workers from cooperative machine pools). The management of hedgerows by lateral tree pruningalso requires a team of 2-3 persons for cutting the branches and cleaning the field. It is operated with a tractor-mounted hedge trimmer in three farms (workers: the farmer and the driver of the machine for instance), or with a chain saw with or without elevator in three other farms (workers: the farmer(s) and family). Mechanical brush clearing is operated in five farms by one person (a farmer) and in one farm by 2 persons (farmer and family): it is operated with a tractor-mounted tool in threefarms (tractor-mounted mower or flail), with a hand tool in one farm (operator-carried brush cutter), and with both in two farms. Chemical brush clearing is operated with an operator-carried sprayer: it is used in one farm ponctually (< 1 day/year) but in another quite heavily (2-5 days/year).

The choice of these different techniques and equipment by farmers is related to the shape of the hedgerows, the objectives of wood production, the availability of tractor-mounted equipement, of workforce, and also the accessibility of the field margins (this last aspects explains the use of operator-carried sprayer or brush cutter). There is no clear relationship in the sample of farms between the working time on the different activities of field margin management and the farm area and average field size. All farms except one have dairy cattle: there is no differences between farms related to the presence of grazing livestock on farm or not.

6.2.2 Farmers perception of newly planted hedgerows and other field margins

For a comparison, we present in this point i) the assets (Figure 23) and the constraints (Figure 24) farmers perceive about the old hedgerows and the other old field margins in their farms, and ii) the goals that farmers have targeted for their new planted hedgerows and that they consider as achieved today (Figure 25), as well as the remaining constraints of these new planted hedgerows.

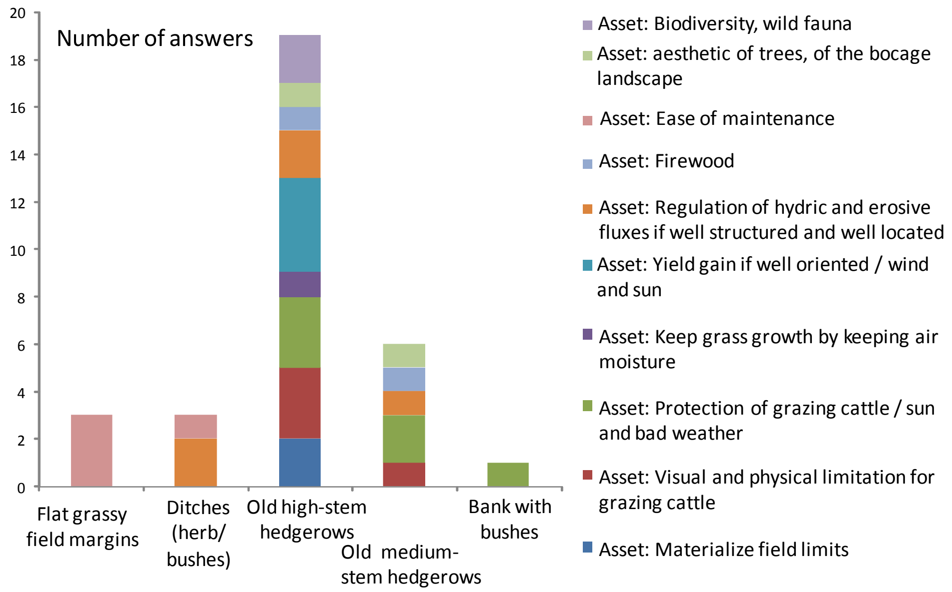

Figure 23. Assets perceived by farmers about their old types of hedgerows and other field margins

The assets that farmers perceived for their old field margins are very diversified (Figure 23), and the old high-stem hedgerows are the most frequently mentionned by farmers from a positive viewpoint (19 answers). The assets relative to the protection of crops and cattle are the most frequently mentionned. Still, biodiversity, aesthetic aspects, regulation of hydrological and erosive fluxes, as well as the structuring of field limits were also mentioned. The ease of maintenance is logically mentioned for herbaceous flat field margins and ditches. Being a source of firewood was spontaneously mentioned only twice as an asset of hedgerows. Nevertheless, all households (except one household without firewood heating) have a consumption of at least 10 m^3 of firewood per year, which corresponds to a principal heating source. This firewood is principally wood logs from old hedgerows, because wood production has just started on new planted hedgerows and because they still constitute a low percentage of the hedgerow network in farms. The fact that farmers did not mentioned the asset of the firewood resource is maybe due to the fact that they need to get wood logs anyway because of their heating systems but all perceive acutely the constraints of tree management to get these wood logs (see Figure 24).

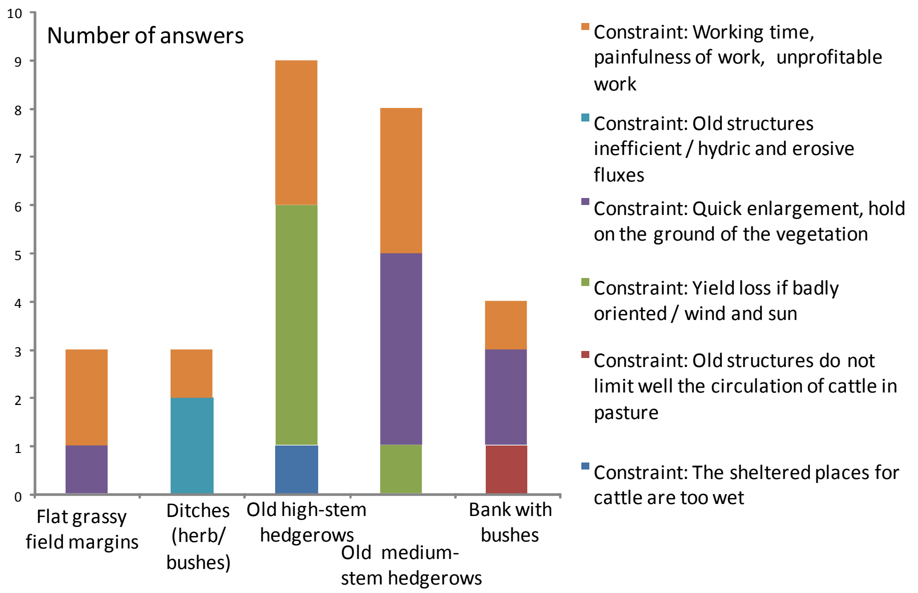

Figure 24. Constraints perceived by farmers about their old types of hedgerows and other field margins

The constraints percieved by farmers about their old types of field margins are less diverse than assets but more recurring among farmers (Figure 24). The working time, painfulness of work and feeling of unprofitable work is the negative perception that is the mostly shared among farmers. As earlier mentioned, this perception concerns the tree management of old high-stem hedgerows, but also the management of the willows or brushes enlarging in luminous environment (herbaceous banks, flat field margins or ditches) and/or under the fences. In fact these constraints of quick enlargement of the vegetation is the second most frequently mentioned by farmers. Another important constraint is the yield loss due to the hedgerows if they are badly oriented regarding the sun and dominant wind (mentioned by five farmers among six for old high-stem hedgerows). However there was also the opposite perception, i.e., the yield gain due to a favorable orientation of the hedgerows was also common (mentioned by four farmers among six for old high-stem hedgerows). When asking farmers about the reasons of gaps in their farms between their average crop yield and the yield they obtain in certain fields, the first reason they mentioned is the soil quality. They perceived that the gain or loss of yield because of hedgerows is on the first 6-8 m from the field margin and is compensated at the farm level by the different orientations of the combinations of hedgerows and fields. The other constraints mentioned are due to the fact that old structures have lost some of their functionalities, for instance their capacities to regulate the erosive and water fluxes, or to limit the circulation of cattle.

Figure 25 concerns the farmers that have been commited into the project of plantation of new planted hedgerows in their farms. The graph presents farmers' objectives of plantation, which they considered, from their observations, as achieved today.

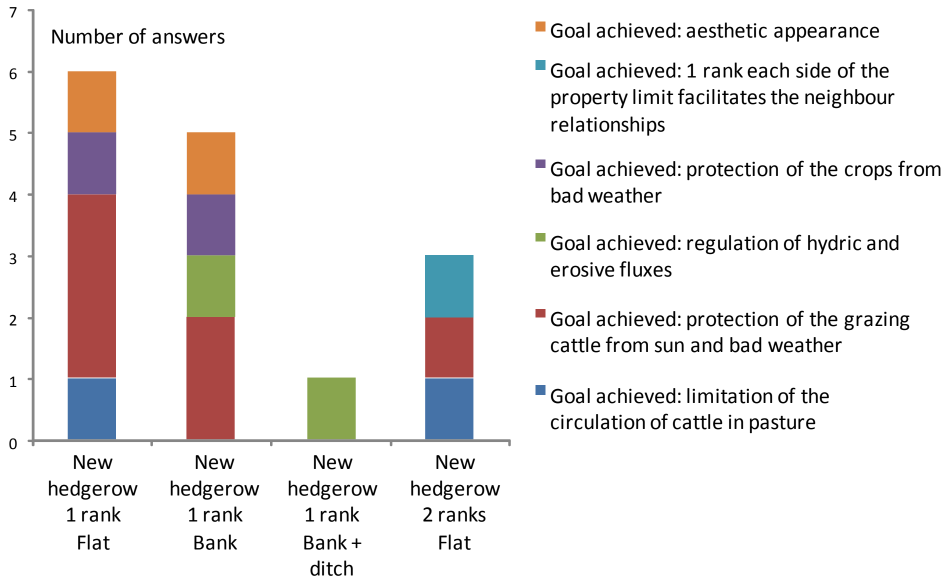

Figure 25. Farmers' identification of the goals achieved by new planted hedgerows

As for old high-stem hedgerows, livestock farmers all anticipated protection of their cattle in pasture (protection against sun and bad weather, and visual, physical limitation of cattle circulation): they considered this goal as achieved by observation of the behaviour of their animals. The farmers who have planted new planted hedgerows with trees planted in quincunx on two rows, particularly point the effectiveness of the hedgerow as a shelterbelt. The observation of a yield gain in the first meters from the well oriented new planted hedgerow was also expected and was observed by farmers in two cases. The regulation of hydrological and erosive fluxes was expected in two cases: the farmers observe today that the gully has disappeared in one case, and that the water is in fact channeled in winter by the ditch in the other case. The aesthetic aspect was also part of the objectives of plantation of some farmers who were already sensitive to this aspect with old hedgerows: these farmers appreciate the new planted hedgerows that combine high-stem and medium-stem trees with a reference to old hedgerows by the chosen species. A functional way to materialize property limits was also expected in the farms where double-row hedgerows were planted: farmers notice it is indeed favourable for neighbour relationships: each farmer can manage his own side without considering the overlap of one hedgerow on the other property. In fact, the old hedgerows were planted at the property limit, and fully belong to one of the two properties. Today, the newly planted hedgerows that will exceed 2 m in height shall respect a distance of 2 m from the property limit. The double-row hedgerow straddling the property limit may therefore be considered as one functional answer to this issue of enlargement of the hedgerow to the other side of the property limit.

Farmers also mentioned two new assets of the hedgerows that were not part of their initial objectives. Some farmers who are also hunters mentioned the great interest of the double-row hedgerows for protecting wild fauna (they reinforce this function by storing cut branches in between the two rows). Other farmers mentioned that the new planted hedgerows have started to take over the old hedgerows for firewood production. Lastly the constraints of management of these hedgerows and the loss of yield the first metres at the "bad side of the hedgerow" were also mentioned by two farmers.

7 Lessons learnt

- **Our evaluation of the biodiversity and services** of newly planted hedgerows (15 years after their plantation) highlights that new hedgerows harbour at least comparable levels of biodiversity of conservation interest (vascular plants, butterflies, forest carabid beetles) or of predatory arthropods (carabid beetles) potentially involved in biological control of crop pests. The trend to higher abundances of predatory arthropods in annual crops adjacent to new planted hedgerows suggests that they might contribute to pest regulation services, but over the longer term. Our assessment further underlined synergistic or antagonistic effects of similar landscape properties (presence of semi-natural habitats in the landscape context of hedgerows) depending on the biological groups. These findings highlight the importance of integrating spatial issues in the design of hedgerow plantation and in the evaluation of their contribution to ecosystem services.

- **Soil** carbon storage and the pattern of soil carbon stock distribution measured in the context of AGFORWARD study for old mature hedgerows was similar to that measured in former studies in Brittany. For the recent hedgerows planted 15 years ago, different soil organic carbon and chloride contents was observed in the top 0-to-30-cm soil layer up to 1 to 3 m from the hedgerows. This suggests that soil organic carbon storage started to increase in the vicinity of recent hedgerows, but as carbon dynamics can be a slow process, it may still be far from its potential. Hedgerows must be maintained for several decades to significantly contribute to carbon storage in soil at the landscape scale. As expected, a high variability in soil nitrate concentrations was observed, probably due to the variability of soil management practices in the fields, and no impact of old nor recent hedgerows was detected in this exploratory study. A more reliable evaluation of recent hedgerows impact on water quality would involve further sampling on a longer time period. We did not find any impact of the hedgerow structure on soil properties.

- **Farming practices at a field/field margin level**. (1) New hedgerows may be affected by a diversity of field operations as they border permanent grassland, rotations including grassland and annual crop rotations. Nevertheless, farmers keep a distance of cultivation or fencing of at least 50 cm from the bottom of the new planted hedgerows - at least 1 m if alongside long duration or permanent grassland - which is more than for herbaceous field margins and old hedgerows. (2) Maintenance practices, i.e., tree pollarding, tree lateral pruning, brush mecanical clearing (no brush/herb chemical clearing in the observations) are undertaken by farmers on new hedgerows as on old hedgerows and herbaceous field margins. At a field level, these practices are chosen according to the type of field margin and organized according to i) the organization in time of the operations of crop or grassland management (e.g. brush clearing close to fences prior to grazing period), and ii) the cropping rest period (e.g. tree pruning and brush mechanical clearing in autumn and winter). (3) At a field level, there is no immediate relationship between wheat yield and whether the wheat was bordered by flat herbaceous field margins, old and/or new planted hedgerows: the highest wheat yields were linked to the mostly intensive crop management systems.

- **Farmers' management and perceptions of new hedgerows at a farm level.** (1) According to the interviewed farmers, the new hedgerows have reached targeted objectives such as: protection and limitation of cattle in pasture, regulation of hydrological and erosive fluxes, improved aesthetics of trees and landscape, and the designation of field limits. Firewood production and the protection of wild fauna were mentioned as supplementary benefits. (2) Farmers notice that the yield is different from each side of hedgerows (within the first meters), according to the hedgerows orientation regarding sun and wind conditions. According to them, these differences are compensated at field to farm scales, and the yield differences at a farm level is rather due to the differences of soil quality. (3) The labour required for hedgerow maintenance remains a challenge for the farmers, with some of them reporting up to 10-20 days - of 5 hours- per annum being spent on all tasks (brush clearing, tree pruning). Further innovation is required to reduce these labour demands and thus ensure the sustainability of the *bocage system*.

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