AGFORWARD
Agroforestry for Europe

Research and Development Protocol for Bocage Agroforestry in France

Project name	AGFORWARD (613520)
Work-package	2: High Natural and Cultural Value Agroforestry
Specific group	Bocage agroforestry in Brittany
Milestone	Milestone 4 (2.3) Part of experimental protocol for WP2
Date of report	19 June 2015
Authors	Claudine Thenail, Valérie Viaud and Stéphanie Aviron, INRA, Rennes, France
Contact	Claudine.thenail@rennes.inra.fr; Valerie.viaud@rennes.inra.fr; stephanie.aviron@rennes.inra.fr
Reviewed	Gerardo Moreno (20 June 2015) Paul Burgess (23 July 2015)

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AGFORWARD (Grant Agreement N° 613520) is co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD. The views and opinions expressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.

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.

This report contributes to the second objective. It contributes to the initial research and development protocol (Milestone 4 (2.3)) for the participative research and development network focused on the use of agroforestry of high natural and cultural value.

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). Even if the presence of hedgerows was practised in the Middle Ages (or even earlier), the main period of expansion of this agroforestry system was from the 18th Century to the end of the 19th Century. This expansion accompanied the successive separation and redistribution of parcels linked to inheritance. In a landscape that was already relatively poor in terms of forests, such hedgerows provided important sources of firewood and timber. At this period, regulations applied to rural leases included rules for hedgerows management by tenant farmers (e.g. the type of management according to the tree shape and purpose). From the 1950s, the process of agricultural modernization and intensification, accompanied with collective land reallocation programs, led to a general decrease of hedgerow density and their reduced importance in farming management. In the area, agriculture has tended to evolve toward intensive dairy and grain-based meat production. At the same time, the regulation of hedgerow management within rural leases has reduced. The density of hedgerows varies substantially across Brittany (see Figure 2, in report initial stakeholders meeting (Thenail et al 2014)), and between farms in the same area. There are also variations in the interest amongst farmers to integrate hedgerows with grassland and arable land in their production system.

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. Although the schemes have had a changing focus, most have tended to support the establishment of new hedgerows (using “ready-made” models) rather than a focus on long term management. The farmers of "Terres et Bocages" group started their association in 2008 to promote novel multi-functional hedgerows that were adapted, over the long-term, to their farming systems and the cultural and landscape contexts. The initial meeting organized in 2014 with the association confirmed this principle, and subsequent meetings have identified individual technical innovations, systemic technical innovations and organizational innovations. Discussions with the farmers of the association and other local stakeholders led to the identification of a specific systemic innovation for testing

One organizational innovation concerned the objective of "Terres et Bocages" Group to build up a "cooperative machine and skill pool". It was agreed that this innovation would be advanced outside of the AGFORWARD project.

In terms of technical innovations, we identified individual techniques such as types of mulch and types of tree pruning. However the most interesting development was the way that the individual techniques were combined to address a diversity of farming systems, landscapes, and to provide a range of ecosystem services. We termed this systemic technical innovation as the "3D adaptive design and management of hedgerows". The first principle of this innovation is that hedgerows are not designed from a static model but by combining a range of elements in 3 dimensions (*e.g.*, the establishment sequence, the shaping and maintenance, the type of ground and vegetation structure, the mixing of species and of trees of high and medium stems, the number of lines, the connections between hedgerows) which needs to be adapted in 3 dimensions. The second principle is to follow an adaptive and cost-effective management of hedgerows which can follow different trajectories over time according to changing circumstances (e.g. light cut of branches, reshape trees if necessary, minimize underneath vegetation cutting, use of cutting residues for mulch, promoting natural regeneration of trees).

Hence the key innovation is the adaptive design and management of hedgerows to allow multiple ecosystem services within an evolving agricultural and landscape context. The objective we set up in partnership with Terres & Bocages Group was to identify a set of ecosystem services that were expected from this innovation, and to test how far these hedgerows expressed these services, given their design and management and degree of integration with field management, when compared with other old-hedgerows systems. The "expected ecosystem services" were identified in three domains (Table 1): 1) support and regulation services associated with biodiversity, 2) support and regulation services associated with soil and water, 3) provisioning services.

Table 1. Ecosystem services expected by the stakeholders of Terres & Bocages to promote the "3-D adaptive design and management of hedgerows"

Three domains of ecosystem services	Detailed expected effects on ecosystem services *Does the innovation "3D adaptive design and management of hedgerows", in synergy with field management, favour:*
1. Support and regulation services associated to biodiversity	1.1. local specific bocage biodiversity? 1.2. pollination? 1.3. natural control of pests?
2. Support and regulation services associated to soil and water	2.1. buffering of nitrate leaching? 2.2. soil conservation? 2.3. the limitation of excess water and/or adequate water availability?
3. Provisioning services from hedgerows and associated field	3.1. shelter for grazing cattle from wind and inclement weather? 3.2. crop or grass production in the field 3.3. diversified production from trees

Cultural services were also considered by stakeholders (see Milestone 2.2; Moreno et al 2015). The cultural elements considered by Terres & Bocages facilitators in their hedgerows design and management with farmers include: i) individual management of high stem trees, ii) planting historic tree species present in old local hedgerows (*e.g. Fagus sylvatica*), iii) building a bank for the plantation, iv) establishing "connector" open hedgerows to benefit the landscape scenery.

3 Description of sites and systems

Considering the time span of AGFORWARD, we could not propose a new trial of hedgerow planting and management. However we could rely on the set of trials already started over recent years on the farms of the Terres & Bocage group of farmers.

We aimed at performing a pseudo-trial, *i.e.*, we chose novel agroforestry sites that can be compared in terms of a limited set of factors. We chose two continuous land areas that have been divided into several fields planted with novel hedgerows in 2005 (Site 1, Les Ecoupées Farm, la Motte) and 1999-2000 (Site 2, Coacovec Farms, Saint-Barnabé). Figures 2 and 3 give an aerial picture of the two sites describing the ground structure, the lines of the hedgerows, and the topography. Tables 2 and 3 give further descriptions of the two sites.

Site 1 was visited during the first stakeholder meeting (Thenail et al 2014)). It is managed as part of Les Ecoupées Farm (La Motte Municipality), and the management is regulated (*e.g.*, compulsory allocation to grassland and limited stocking rate and fertilization). This is because the site is a water intake site and the property of the Inter-municipalities Water-Supply Association of Trévé and La Motte.

Site 2 occurs across two farms (Coacovec Farms) and the land use is not regulated. The crop rotations and field management are representative of local farms (*e.g.*, rotations with silage maize, cereals with or without grassland). The ecosystem services produced are not solely a result of hedgerow design and management, but also the interactions between the hedgerow and field design and management. Hence it is important to compare bocage agroforestry with contrasting cropping systems. At both two sites, the fields are used for dairy, crop, and meat production (either cattle or pigs).

Site 1 is situated at about 15 km north-east of Site 2. The climate at both sites is similar. Sites 1 and 2 are both situated on a hill side of similar slope, and include new hedgerows running perpendicular to the slope and new hedgerows running parallel to the slope. Hence a grid is formed which connects the hedgerows to each-other and to other hedgerows and woods in the landscape. Hence the spatial organization of the agroforestry system is similar at both sites.

Regarding the ecosystem services depending on physical-chemical fluxes, another interest of comparing the two sites is that hedgerows located perpendicular to the slope present several combinations of ground structure (with or without banks) and vegetation structure in width (e.g. one or double-line of trees) so that different degrees of buffering effects may be envisaged. This diversity of ground structure and vegetation structure in different contexts of cropping system is also interesting to assess the factors at play in the diversity and biomass of products harvested from trees (see next section).

Some old hedgerows (including, *e.g.*, *Castanea sativa*, *Quercus pedunculata, Fagus sylvatica)* are situated close by in the farms and are also managed in relation to fields: therefore comparisons can be done between the new agroforestry systems implemented in the 2 sites and the existing ones with old hedgerows. Such comparisons are important to establish since we know that processes at play in ecosystem services change with the aging of trees and of the overall hedgerows ground and vegetation structure.

Figure 1. Photos of Site 1, Les Ecoupées Farm, La Motte (water intake site of Trévé-La Motte)

Figure 2. Photos of Site 2, Coacovec Farms, Saint-Barnabé

Table 2. Description of Site 1, Les Ecoupées Farm, La Motte (with characteristics of location, soil and topography, climate, plantations, and land use)

Site characteristics	
Area: Co-ordinates: Site contact: Site contact email address:	20 ha 48.245868°N, 2.695410°W Claudine Thenail Claudine.thenail@rennes.inra.fr
Characteristics of soil and topography	
Altitude: Slope: Soil type and description: Soil texture	200-220 m 2-6% Soil unit n°308. Moderately deep to deep soil produced from micaschist, sometimes altered (scale 1/250000, source http://www.sols-de-bretagne.fr/). Clay-loam
Climate characteristics	
Mean monthly temperature: Mean annual precipitation: Details of weather station :	10.7°C (Mean min: 7.3°C; mean maxi: 14.1°C) 735 mm Loudeac Station / MeteoFrance
Characteristics of tree plantation (also see Figure 2)	
Tree species: Structure of hedgerows: Ground structure: Date of plantation:	Non-exhaustive list: *Castanea sativa*, *Fagus sylvatica*, *Pinus sylvestris*, *Quercus pedunculata*, *Quercus sessiliflora*, *Carpinus betulus*, *Coryllus avellana*, *Acer campestre*, *Prunus cerasifera*, *Crataegus monogyna*. Both one line and two lines hedgerows (see Figure 2); one potential high stem tree every 2 meters along double-line hedgerows (plantation in quincunx). Plantations on flat ground, novel or old bank (see Figure 2) 2005
Field land-use characteristics	
Cropping system: Livestock system:	Permanent grassland (since 2005) Dairy heifers

Table 3. Description of Site 2, Coacovec Farms, Saint-Barnabé (with characteristics of location, soil and topography, climate, plantations, and land use)

Site characteristics	
Area : Co-ordinates: Site contact: Site contact email address:	30 ha 48.123801°N, 2.739273°W Claudine Thenail Claudine.thenail@rennes.inra.fr
Characteristics of soil and topography	
Altitude: Slope: Soil type and description: Soil texture:	100-150 m 2-6% Soil unit n°4031. Moderately deep to deep soil produced from soft shale, often altered (scale 1/250000, source http://www.sols-de-bretagne.fr/). Clay-loam
Climate characteristics	
Mean monthly temperature: Mean annual precipitation: Details of weather station :	10.7°C (Mean min: 7.3°C; mean max: 14.1°C) 749 mm Loudeac Station / MeteoFrance
Characteristics of tree plantation (also see Figure 3)	
Tree species:	Non-exhaustive list: *Castanea sativa*, *Fagus sylvatica*, *Pinus sylvestris*, *Quercus pedunculata*, *Quercus sessiliflora*, *Carpinus betulus*, *Coryllus avellana*, *Acer campestre*, *Prunus cerasifera*, *Crataegus monogyna*, *Ligustrum vulgare*, *Prunus spinosa*, *Viburnum* sp.
Hedgerows vegetation structure:	Both one line and two lines hedgerows (see Figure 3); one potential high stem tree every 4 or 6 m along hedgerows (plantation in quincunx).
Ground structure:	On flat ground, novel or old bank (see Figure 3) Plantations on flat ground
Date of plantation:	1999-2000
Field land-use characteristics	
Cropping system: Grazing livestock on site:	Silage maize / cereals / grassland rotations Suckler cows and dairy cattle

4 Effect of innovation on ecosystem services

Table 4 repeats the two columns of Table 1, *i.e.*, the list of ecosystem services potentially influenced by the agroforestry innovation, and displays a third column, which presents what we will observe or measure as indicator of these services.

Table 4. Set of ecosystem services the stakeholders of Terres & Bocages expect to promote with the innovation "3 dimensions adaptive design and management of hedgerows"

Three domains of ecosystem services	Detailed expected effects on ecosystem services (ES). *Does the innovation "3D adaptive design and management of hedgerows", in synergy with field management:*	What will be observed or measured to indicate the effect of the innovation on ecosystem services
1. Support and regulation services associated to biodiversity	ES 1-1. favour local specific bocage biodiversity?	Flora species characteristics of forest-edges and low fertile grassland; forest ground beetles
	ES 1-2. favour pollination?	Broadleaf flora; non specialized butterflies.
	ES 1-3. favour natural control of pests?	Weed flora; open-field ground beetles, spiders
2. Support and regulation services associated to soil and water	ES 2-1. buffer nitrate leaching?	NO_3^- content in soil
	ES 2-2. favour soil conservation?	C content in soil
	ES 2-3. limit excess of water and/or favour water availability?	Indicator accounting for hedgerows configuration and water table height
3. Provisioning services from hedgerows and associated productive field	ES 3-1. shelter grazing cattle from wind and inclement weather?	Animal behaviour; structure of hedgerows vegetation and orientation
	ES 3-2. favour, or avoid to disadvantage, the crop or grass production on field	Abundance of quality fodder species in grassland; crop yield compare to farm references
	ES 3-3. favour a diversified production from trees	Indicators of biomass: i) potential for timber, ii) produced for firewood, iii) produced for mulch

Using the knowledge we have acquired about old hedgerows, we assume that new hedgerows will help the colonization of specific bocage biodiversity, which otherwise rare in these landscapes: these are species of forest edges and low fertile grassland (see ES1-1.). We expect that the density of plantation in hedgerows, their connections to other old hedgerows and woodlots in the landscape, but also the management of field margins by farmers (cattle grazing without trampling, and / or light mechanical clearing) would favour the development of such flora and fauna species at the bottom of hedgerows. However, the time span of 10-15 years from planting may be insufficient for the colonization of forest-edge flora species, which is very slow (several decades). These flora species are also involved in regulation services, such as broadleaf species providing complementary or supplementary resources for pollinators (ES 1-2). Regarding natural control of pests, we will make an assessment by observing both flora that farmers wish to control (weeds) and predatory insects and spiders (open-field species) that can help controlling weeds (ground beetles) and/or pests such as aphids (beetles and spiders). For instance we assume that the different strategies employed to cover the ground structure of new hedgerows at planting and afterward (sowing, mulch addition), but also the density of planting within the hedgerows, would control the weed development at the bottom of the hedgerows. Still, we know that the drift of herbicides, fertilizers from field, and/or the soil mechanical degradation under and along the hedgerow, would favour the development of weeds on field margins and into the field: we shall examine this possible antagonist interaction. By contrast, we also know there are synergies between hedgerows and crop rotation systems for the cycles of open-field ground beetles that are generalist predators: this will be assessed as well.

We assume that some combinations of characteristics of the new agroforestry systems will also be beneficial for soil-related services in terms of buffering nitrate leaching (ES 2-1) and protecting soil (ES 2-2), under the hedgerows and into the field. In this respect, we will examine those services regarding the combination between the cover of the hedgerows bottom, the density/width of the planting, in interaction with the cropping system and field margin management. Regarding water-related services (ES 2-3) we assume that the 3D pattern of new hedgerows will both slow down the surface and sub-surface fluxes of water in the landscape, and avoid extremes of too much or too little water in fields. However it is also known that problems of extreme water flows may occur with some patterns and ground/vegetation structures of hedgerows (*e.g.*, ground structures "blocking" water fluxes, dried-out soil under some old hedgerows).

The principle of multifunctionality of hedgerows in Terres & Bocage Group also concern provisioning services from both trees and fields. We will account for the services of shelter grazing cattle from wind and inclement weather (ES 3-1): this is notably the argument given by the farmer who managed Site 1, when he proposed to develop the parcel with hedgerows plantations (see report of the first stakeholders meeting (Thenail et al 2014)). Today, this farmer observes that the group of heifers in pasture indeed takes advantage of the network of hedgerows. This is why we will rely on recurrent observations of grazing cattle behavior to assess this service. We will also describe the orientation and vegetation structure of the hedgerows in terms of hedgerows references and local climate features to understand this sheltering service. Regarding field production, we shall focus on plantings on fertilized land on intensive farms. Here the issue is about i) maintaining crop and grass production when the cropping system remained unchanged after the plantation, or ii) maintaining or even favoring crop and grass production when farmers have extensified their cropping systems after planting (this is the case for Site 1). The farmers' group do not expect to optimize any particular hedgerow product but they would like to maintain the capacity of the hedgerows to produce a diversity of valuable / recoverable products. We identified three kinds of such products: i) firewood (mainly logs), ii) mulch (“Ramial Chipped Wood”), and iii) timber (from high stems trees selected in time). Compared to old hedgerows or shelterbelts, it is assumed that the "3D design and management innovation" of hedgerows (e.g., planted species, density of plantation, use of mulch, adaptive management including individual tree shaping) will better allow such multifunctional production.

5 Design of observation, measurement and on-farm survey

From this list of ecosystem services and assumptions of driving factors, we proposed a design of observation, measurement and on-farm surveys. Table 5 presents the principles of this design that will be implemented in both sites.

Table 5. Description of design for the collect of data necessary i) to assess factors that may interact and influence ecosystem services, ii) to indicate the influenced ecosystem services

Design of observation plots and on-farm surveys	Registered data		Related ecosystem services
	Data used to describe factors that may interact and influence ecosystem services	Data used for indicating the influenced ecosystem services	
1. Transect of observation plots from hedgerows perpendicular to slope, toward the center of fields	Location of the plot in the landscape. Descriptors of vegetation structure and signs of practices at plot scale.	Exhaustive sampling of flora; collect of ground beetles and spiders by the mean of pitfall traps; sampling of butterflies by visual observations.	Biodiversity-related services (ES 1-1; ES 1-2; ES 1-3)
			Abundance of quality fodder species in grassland (provisioning service ES 3-2)
		Measurements in soil samples at different depths	Services related to the buffering of nitrate-leaching and the conservation of soil (ES 2-1.; ES 2-2)
2. Succession of observation plots in and alongside hedgerows (about 25 m-long segments of field margins)	Location of the plot in the landscape. Descriptors of vegetation structure and signs of practices at plot scale.	Exhaustive sampling of flora; collect of ground beetles and spiders by the mean of pitfall traps; sampling of butterflies by visual observations	Biodiversity-related services (ES 1-1; ES 1-2; ES 1-3)
3. Further description of hedgerows ground and vegetation structure	Measurements of, e.g., width of the ground structure, of the canopies, tree height, bank height.		Biodiversity-related services (ES 1-1; ES 1-2; ES 1-3)
			Water and soil related services (ES 2-1.; ES 2-2; ES 2-3)
		Indicator based on the structure of hedgerows vegetation and orientation	Provisioning service / cattle sheltering (ES3-1.)
4. Mapping of the landscape structure and topography	Indices of hedgerows density, of structural connectivity at a landscape level.	Indicator taking into account hedgerows configuration and water table height	Water-related services (ES 2-3).
		Descriptors of landscape structure as Indicators of services when upscaling	Biodiversity, soil and water-related ecosystem services (ES 1-1. to ES 2-3)
5. Detailed survey of management practices and harvests at the hedgerow and field scale, in sites	History and current management: e.g., for hedgerows: dates and types of cut, details of mulch deposit. e.g., for field: stocking	Measurement of harvested biomasses of firewood and mulch; estimation of potential for timber from high stem trees frequency and trunk diameters.	Provisioning services / productions from trees (ES 3-3.)

	rate on grassland, crop and grassland fertilization.	Assessment with farmers of crop and grass yields compare to farm comparable references (e.g. similar soils)	Provisioning services / productions from fields (ES 3-2)
		Observations with farmers of grazing cattle behavior	Provisioning services (ES 3-1)
			Biodiversity, soil and water-related ecosystem services (ES 1-1. to ES 2-3)

The same design of observation plots will be implemented for several indicators, so that synergies or antagonisms in agroforestry systems of Site 1 and Site 2 can be discussed regarding the different targeted ecosystem services. This is the case for instance with the design of observation plots (design 1 and 2 in the left column), where both data feeding indicators of biodiversity-related and soil-related services will be registered.

Facilitators and farmers will help with estimated and effective yield evaluation of tree products. Farmers will help with answering a survey of management practices at hedgerows and field scale. For mulch and firewood products: it is possible to rely on harvests assessments made by the farmers and facilitators. Timber production remains a potential given the age of hedgerows: this will be assessed by measuring the structure of the high-stem trees that were initially designated for potential timber.

We will also conduct a systemic description of farm territory management, by interview and mapping (farm level). The objective will be i) to evaluate the role of the developed land parcel of site 1 or 2 in the overall farming systems, and ii) to compare the management practices and yields of the land parcel of site 1 or 2, to the management practices and yields of other comparable land parcels in farms (including hedgerows and cropping systems). This will be useful to build with farmers some indicators of provisioning services (e.g., observation of cattle grazing behavior, references of yield variability across fields). This will also be useful to assess if and how farmers used indicators of ecosystem services in their management decisions, related to their existing and novel agroforestry systems.

6 References

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7 Acknowledgements

The AGFORWARD project (Grant Agreement N° 613520) is co-funded by the European Commission, Directorate General for Research & Innovation, within the 7th Framework Programme of RTD, Theme 2 - Biotechnologies, Agriculture & Food. The views and opinions e-pressed in this report are purely those of the writers and may not in any circumstances be regarded as stating an official position of the European Commission.