Lessons learnt -
Agroforestry with ruminants 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.

This report contributes to Objective 2, Deliverable 5.14: Report describing the results of innovations related to agroforestry for livestock farmers. This includes technical as well as socio-economic aspects, and based on that, an overview of how the main findings might be disseminated.

2 Background

Integration of trees with crops and/or livestock production (agroforestry) has been identified as a sustainable way to increase the productivity of land and to provide a number of ecosystem services and environmental benefits compared to disaggregated agricultural and woodland systems (Jose 2009). In cattle production systems agroforestry may also improve animal welfare and provide additional fodder from trees and shrubs leaves (Broom et al. 2013). Trees could also extend the seasonality and spatial distribution of the understorey production, by buffering the microclimate (Ryan et al. 2010) and by generating an uneven spatial distribution of nutrient deposition.

At present, agroforestry systems constitute only a minor part of ruminant husbandry in France. Before adopting agroforestry, farmers need more information in regard to the following issues (Pottier and Novak, 2014): i) the nutritive value of trees and shrubs, ii) the protection of newly established trees, iii) the spatial organization of trees, and iv) forage production in the alleys. They also need information on the way to simplify and limit the additional work created by trees.

To answer these demands, a demonstration plot was designed (with the involvement of 10 stakeholders) in December 2014 to test options related to 1) diversification of tree uses, 2) the spatial organization of trees, and 3) protection of trees against livestock (Novak et al. 2015). We also evaluated the nutritive value of various fodder trees resources for ruminants, according to the tree species, management and stage (Emile et al. 2016). We also quantified the impact of trees on the flora and on the production of the grassland between tree rows.

This report complements the results already presented in previous reports (Novak and Emile, 2015; Novak et al. 2016). It highlights the results obtained on the demonstration plot (until 30 June 2017) and the main lessons learnt. It also gives key messages on the nutritive value of fodder trees and on the impact of trees on the grassland between tree rows.

3 Innovations tested on the demonstration plot

3.1 Field measurements

Cattle behaviour and tree damage, pasture composition and productivity, as well as workload and the establishment costs of the tested agroforestry options were assessed on the demonstration plot during the grazing seasons of 2015, 2016 and until 30 June 2017.

3.2 Description of the system investigated

A description of the specific case study system is provided in Table 1.

Table 1. Description of the specific case study system

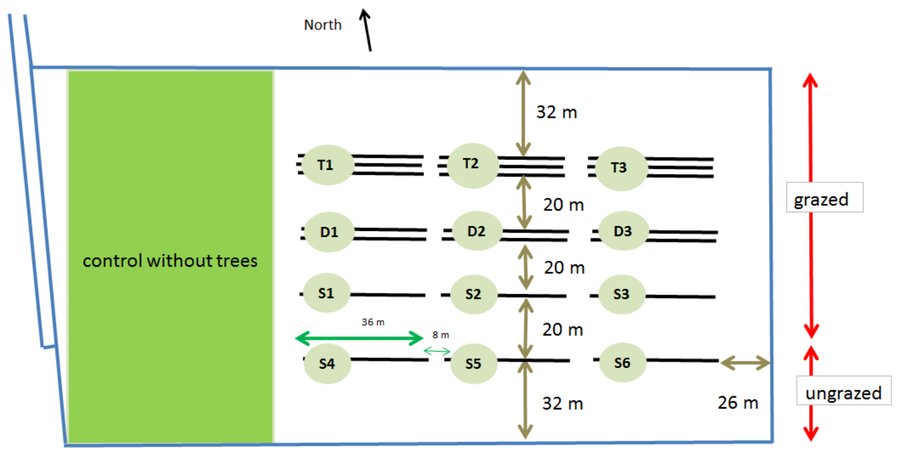
Specific description of site	
Area	The demonstration plot is a 3.0 ha paddock located at the experimental facility of INRA in Lusignan, Vienne, France. The plot is part of the grazed acreage of the OasYs system experiment (Novak et al. 2016) and is engaged in a rotation consisting of five years of temporary pasture and two years of annual forage crops. The total experimental farm area is 90 ha including 16 paddocks (48 ha), 3 of them being planted with rows of trees or shrubs.
Co-ordinates	46°25’12,91”N; 0°07’29,35”E
Site contact	Sandra Novak
Site contact email	sandra.novak@inra.fr
Example photograph	 Figure 1. Cattle in the silvopastoral system June 2015

Map of system

Figure 2 Aerial view of the fields involved in the OasYs system experiment hosting the silvopastoral demonstration “G14” paddock, which was designed with stakeholders in the frame of the AGFORWARD project (Novak et al. 2015).

In green, the other agroforestry fields of the OasYs system experiment (M2, M3 in the grazed acreage and V12, not grazed).

Figure 3. Aerial view of the silvopastoral “G14” paddock (source: Google satellite).



S=single row set ; D = double row set ; T = triple row set

Schematic representation of one 36 m unit

Pol	HS	Pol	Pol	Pol	HS	Pol	Pol	Pol	Pol

Pollard
High stem tree

Figure 4. Silvopastoral system design of the "G14" paddock, INRA Ferlus, La Gralière, Lusignan, France (not to scale)
The detailed experimental design is given in Annex A.

Climate characteristics	
Mean monthly temperature	11.6 ± 0.5°C (1991-2010)
Mean annual precipitation	804 ± 148 mm (1991-2010)
Details of weather station (and data)	A weather station at the experimental INRA facility since April 1988.

Soil type	
Soil type	Dystric cambisol
Soil depth	90 cm
Soil texture	Loamy (25.3 % sand, 57.8 % silt, 16.9 % clay)
Additional soil characteristics	Developed from loamy parent material of unknown origin over red clay; characterized by vertical tongues
Aspect	Flat

Tree characteristics	
Species and variety	High stem trees: pear, honey locust, service tree Pollards: white mulberry, Italian alder Coppice: goat willow, field elm, black locust, grey alder
Date of planting	17 February 2015
Tree row set (width)	Single (2 m) , double (6 m) or triple (10 m)
Intra-row spacing	4 m between high stem trees or pollards; 1.3 m when coppice is considered
Inter-row spacing	20 m
Tree protection	Single or double line of electric fence, electric fencing tape, metal or plastic fences, olfactory repellents, barrier tape
Typical tree yield	No harvest to date
Typical increase in tree biomass	Not determined

Crop characteristics	
Species	This plot is included in a crop-grassland rotation. Grassland sown in April 2014 including lucerne (15 kg ha^{-1}), tall fescue (5 kg ha^{-1}), cocksfoot (5 kg ha^{-1}), perennial rye-grass (5 kg ha^{-1}), spring barley (20 kg ha^{-1}), white clover (2.6 kg ha^{-1}), birdsfoot trefoil (2.5 kg ha^{-1}), chicory (2 kg ha^{-1}), lentil (9.8 kg ha^{-1})
Management	The ungrazed part of the field was mown three times in 2015 and 2016, and twice until 30 June 2017. The paddock was grazed nine times in 2015, six times in 2016 and thee times until 30 June 2017.
Fertiliser, pesticide, machinery and labour management	
Fertiliser/pesticides	Dung and urine during the grazing of dairy cows; no pesticides
Machinery	Tractor and mower, tedder, roundballer and trailer for the part being cut. Crusher for the refusals and roller chopper for the maintenance of tree rows Tree rows were subsoiled 10 February 2015. Trees were irrigated on 27 and 28 July 2015 using a water bowser.
Manure handling	Not necessary in the field
Labour	Animals checked daily when in field
Fencing	Field has hedge and barbed wire fence on two sides, and barbed wire fence on other two sides. Several fencings were erected along each tree row prior to cattle entering field (see above “tree protection”).
Livestock management	
Species and breed	Holstein, Holstein x Jersey and Holstein x Red Scandinavian crossbred dairy cows.
Description of livestock system	The herd is part of an agroecological system experiment with rotational grazing on 16 paddocks.The dairy cattle graze from March to December depending on weather and soil conditions. When the grassland growth is low, the animals only graze half-time, *i.e.* they stay in the cowshed during the daytime in summer or during the night (after the last milking) in late autumn. When they are not grazing, the animals are fed at the cowshed with silages of maize, sorghum or cereal-legumes mixtures, and concentrates.
Animal health and welfare issues	None. The hedges could provide shelter from wind and shade in the summer, but the just planted trees will have no shelter effects.
Requirement for supplementary feed	When the animals grazed half-time, they received silage at the cowshed (between 3.2 and 6.4 kg DM cow^{-1} d^{-1} in 2015, between 5.7 and 12.5 kg DM cow^{-1} d^{-1} in 2016, none until 30 June 2017) and concentrates (between 0.4 and 0.9 kg cow^{-1} d^{-1} in 2015, between 0.9 and 1.7 kg cow^{-1} d^{-1} in 2016, none until 30 June 2017).
Technical data, livestock	
Production volume	The milk delivered respectively in 2015 and 2016 was 443 733 and 436 611 litres, with an average production of 19.6 and 19.4 litres per day and per cow.
Feed consumption	Not determined. The grassland biomass available for grazing is estimated to be around 8400 and 7100 kg DM ha^{-1} on the entire period of grazing respectively in 2015 and 2016, and permitted to feed a total of 1028 and 815 cows x days of grazing respectively in 2015 and 2016.
N-balance	At the scale of the entire OasYs system experiment, the N-balance (including N fixation by legumes) was estimated at 14 kg N ha^{-1} in 2014.
Financial and economic characteristics	
Costs	At the scale of the entire OasYs system experiment, the production costs have been assessed in 2014 at 406 € per 1000 l milk, compared to an average of 444 € per 1000 l milk for dairy farms of Poitou-Charentes, which represent a cost price of 326 € compared to an average of 348 € per 1000 l milk.

3.3 Results

As mentioned previously, the G14 paddock was specifically designed with stakeholders to provide technical and economic references in relation to the diversification of tree uses, spatial organization, and tree protection from cattle. Three spatial organizations of trees were tested with either single, double or triple-rows with an inter-row spacing of 20 m. Two types of pruning techniques of fodder trees will be tested: pollards of *Morus alba* and *Alnus cordata*, and coppices of *Salix caprea*, *Ulmus minor*, *Robinia pseudoacacia* and *Alnus incana*. These trees are intended to be browsed in a couple of years but also to provide wood chips. High stem trees (*Pyrus communis, Gleditsia triacanthos, Sorbus domestica*) were also planted mixed with various layouts with pollards and coppices, as farmers wanted to test the diversification of tree uses. To restrict the browsing of the newly established trees, seven types of tree protections were tested, i.e. single or double lines of electric fence, electric fencing tape, metal or plastic fences, olfactory repellents and barrier tape. Another option included excluding the paddock from grazing, and mowing the grassland during the first years of the establishment phase. The reported results concern the **period February 2015-June 2017**.

3.3.1 Pasture productivity and flora composition of the grazed pasture vs the hay meadow

Results of the 2015, 2016 and 2017 biomass productivity and flora composition of the grazed grassland and of the ungrazed part are given respectively in Table 2 and Table 3.

Table 2. Pasture production and composition of the grazed agroforestry paddock

Extent of the grazing season	Total number of grazing days	Mean cattle number	Stocking = cattle number x grazing duration	Estimated grassland DM yield (t DM ha^{-1})	Legume (%)	Grass (%)	Chicory (%)	Weeds (%)
8 April- 21 Dec. 2015	17	62	1060	8.4	31	18	51	0
25 Mar-23 Oct 2016	13	62	815	7.2	31	31	38	1
16 Mar-4 Jun 2017 (until 30 June)	9	66	599	3.7	21	36	42	1
Total	**39**		**2475**	**19.3**				

Figure 5. Cattle grazing the G14 paddock

Table 3. Pasture production and composition in the ungrazed part of the agroforestry paddock

Year of cut	Number of cuts	Grassland DM production (t DM ha^{-1})	Legume (%)	Grass (%)	Chicory (%)	Weeds (%)
2015	3	9.4	27	11	62	0
2016	3	6.9	40	14	45	1
Until 30 June 2017	2	5.5	49	25	26	0
Total	**8**	**21.8**				

During the 3-year-period, the grazed grassland was grazed 39 days which represents a biomass productivity of **19300 kg DM ha^{-1}**. During the same period, the eight cuts of the ungrazed part of the grassland represented a biomass of **21800 kg DM ha^{-1}**. The grazed grassland was mainly composed of chicory in summer and autumn. Clover and lucerne were the main legumes, and the grass species were mainly perennial rye-grass and to a smaller extent, tall fescue, and cocksfoot. The proportion of legumes increased during the three years in the ungrazed part of the grassland and represented 49% of the composition (mainly represented by lucerne) in 2017 (Figure 6).

Figure 6. The grazed (left) and ungrazed (right) parts of the G14 paddock

3.3.2 Tree mortality due to wildlife

Overview considering tree damage: for the overall newly established paddock and after 2 years of establishment, 17% of the high stem trees and future pollards were damaged and only 5% died due to wildlife, whereas 20% of the future coppiced trees were damaged and 35% died (Table 4), willow and black locust being the most damaged species.

Table 4. Damage and mortality of trees due to wildlife

	Future pollards and high stem trees		Future coppice	
	Dead and replanted (%)	**Damaged** (%)	**Dead** and replanted (%)	**Damaged** (%)
December 2015	4	11	21	14
December 2016	1.5	6	14	6
Total of the 2 years	**5**	**17**	**35**	**20**

In 2015, voles cause high damage to the trees: they injured 10% of high stem and pollard trees (from 0 to 23% depending on trial) and 15% (from 0 to 36%) of the coppice. At the level of the paddock, they were responsible for 20% of tree mortality and 76% of tree injuries. To prevent this damage, all the trees replanted since 2016 were protected with a plastic collar (as used for electric cable). In 2016, deer seem to be responsible of the majority of tree deaths and injuries.

During the first two years of establishment, mechanical control of the vegetation on the tree row, poor initial establishment of tree seedlings and, to a less extent, hare damage also contributed to tree mortality. Dairy cows only contributed to the tree mortality in one trial (see below). The response in March 2017 was to install stronger mesh guards and stakes for the coppice, in order to limit the damage caused by deer, to prevent them flying away in strong wind conditions, and also to make them more visible during the mechanical control of vegetation.

3.3.3 Workload and costs of the agroforestry plot

Workload: planting the trees (including the installation of protection against deer) was the most time-consuming operation during the year of establishment of the agroforestry plot (February 2015), the second one being almost equally split between the mechanical control of the vegetation on the tree rows and the establishment of tree protections against livestock (Table 5).

During the two years after plantation, the main workload was due to the replacement of dead trees (and in 2017 of the tree protections of coppice) and the mechanical control of vegetation on the tree rows. The other time-consuming operations were the irrigation of trees (8 hours during the very dry summer 2015), their pruning (6 hours in summer 2016, not yet done in summer 2017) and to a lesser extent checking tree damages.

Table 5. Workload on the demonstration plot

Workload (hours)	Plantation and installation of tree protections against deer	Mechanical control of vegetation on the tree row	Installation of tree protections against livestock
2015 (establishment of the demonstration plot)	48	10	10
2016	12	10	1
2017 (until 30 June)	17	17	0
Total	**78**	**37**	**11**

Costs: At the level of the overall new established paddock, tree protection against livestock (including stakes) was almost as expensive as planting costs (including plant seedlings and mesh guards against wildlife) (almost 2600 euros for each of them) (Table 6). However there are high differences between trials depending on the amount and type of tree seedlings and on the type of protection.

Table 6. Costs (€) for planting and protecting trees from wildlife or livestock

Costs	Planting seedlings	Protection against wildlife	Protection against livestock
2015 planting	1873	724	2549
2016 replanting	149	0	43
2017 replanting	115	316	43
Total costs	**2137**	**1040**	**2635**

Planting costs were much higher for *future* pollards and high stem trees than for coppice (Table 7), whether for plant seedlings (between €1.5 and €11.9 each for *future* pollards and high stem trees, and between €1.2 and €1.6 each for coppice) or for protecting them from wildlife (mesh guard and stake for €2.8 compared to €0.5 for coppice). The stronger protection installed in March 2017 for coppice were more expensive (€1.3 each compared to €0.5).

Table 7. Costs (€) for planting and protecting future pollards or high stem trees *vs* coppice.

Costs	*Future* pollards and high stem trees			*Future* coppice		
	Planting seedling	Protection against wildlife (mesh guard + stake)	Total	Planting seedling	Protection against wildlife (mesh guard + stake)	Total
2015 planting	1330	551	1881	542	173	715
2016 replanting	27	0	27	122	0	122
2017 replanting	36	1	37	79	315	394
Total costs	**1393**	**552**	**1945**	**743**	**488**	**1231**

3.3.4 Efficacy of tree protection against livestock

To restrict the browsing of the newly established trees, seven types of tree protections were tested, i.e. single or double line of electric fence, electric fencing tape, metal or plastic fences, olfactory repellents or barrier tape. Another option included excluding the paddock from grazing, and mowing the grassland during the first years of the establishment phase.

- Electric fence, electric fencing tape and metal fence were very efficient in protecting trees from cow damage during the 2015, 2016 and 2017 (until 30 June) grazing periods.
- The plastic fence was damaged by cows on a corner from the first day of grazing in 2015 and it was tattered at two places from the 4th grazing period (1 July 2015). It was mended with a piece of string at each grazing which prevented the cows from entering into the tree rows up to the 6th period of grazing which occurred in mid-September 2015. During the 7th grazing period (12 to 14 October 2015), two cows went under the tattered fence and they broke two tree stakes and browsed the top of two trees (one white mulberry and one alder). Before the 8th grazing period in 2015, the tattered areas were strengthened with a strip and the cattle did not go any more into the tree rows. In 2016, two strips were attached under the plastic fence, and this protection was effective all year round and also during the first semester of 2017.
- Four olfactory repellents were tested in 2015 on the **tree row S2** (see experimental design in Annex A): garlic essence, spirit vinegar, a repellent for deer used by hunters (which is a mixture

of spices and NPK fertilizer) and fresh cow dung. They turned out to be ineffective from the first day of grazing, either when they were sprayed directly on the trees (at the first grazing) or on the wood chips around trees (at the second grazing period). Observations showed that the cattle were attracted by the stakes which they used as rubbing posts, and they also played with the mesh tree guards. As a result, 77% of trees were damaged at the end of the second grazing period. The removal of stakes and mesh tree guards on this tree line, and the installation of two poles with brushes to be used as rubbing posts and of barrier tape along the tree row were effective at preventing the cows from damaging the trees from the third grazing period (at the beginning of June 2015) until the last grazing in December 2015. At the end of 2015, tree mortality was 29% for garlic essence, 43% for spirit vinegar, 57% for fresh cow dung, and 71% for the deer repellent, with the cows being responsible for 82% of this mortality. Voles and hares (as the mesh guards were removed) also damaged some trees.

In 2016, all trees in this S2 tree row were replanted and equipped with new stakes and mesh guards. A new repellent called "trico" based on sheep fat and used against wild deer was applied on the half of this tree row (the other part being untreated). A barrier tape was reinstalled along the tree row. During the 2016 grazing period, some cows played with mesh guards and browsed some branches of few trees (essentially on the part without repellent) but no tree was considered to be damaged at the end of 2016. The cows frequently used the two poles equipped with brushes as rubbing posts and apparently they did not use the stakes anymore for rubbing in 2016.

The protection of trees with a barrier tape was reintroduced on this S2 tree row during the first semester of 2017: in March and April, the barrier tape was installed along the tree row as in 2016, and in June, it was attached on plastic and metal stakes like those used for electric fence. Nevertheless cows damaged all the trees during the first three grazing periods in March, April and June 2017 (Figure 7) and 10% of *future* pollards and high stem trees and 17% of coppice apparently died.

Figure 7. Damage on trees protected by a barrier tape in June 2017

In terms of cost, olfactory repellents or barrier tape were the cheapest among the tested protection method, but as mentioned above, they turned out to be ineffective. The metal fence costs nearly half the price of electrified fences and is less expensive than the plastic fence which is also less durable. The solar charger represents the largest item of expenditure in relation to the electrified fences (€300) but it can be reused on another paddock if necessary.

In terms of workload, the row with olfactory repellents or barrier tape requires less mechanical control of the vegetation on the tree row (grazed directly by cows) and less time to protect trees against livestock. Electric fence and electric fencing tape were also quickly installed and have the advantage of facilitating the mechanical control of the vegetation on tree row, as the access to the tree row can be easily opened. The wires need only to be retightened before the new grazing period begins.

The installations of plastic and metal fences are respectively 1.5 times and twice as long as electric fence and these protections also complicate the control of the vegetation of tree rows. As said above, the plastic fence also needed to be strengthened during the first two years. However the metal fence could offer the opportunity to be used as trellis for lianas.

Excluding the paddock from grazing, and mowing the grassland during the first years of the establishment phase, has the advantage of incurring no additional cost for protecting them from cattle.

3.3.5 Effect of the spatial organization of trees

The establishment of tree rows incurs a loss of grazed surface area that increases with the number of rows in the set, and that will only be recovered when the trees will be exploitable.

As indicated in Table 4, during the first two years of establishment, the mortality of coppice was seven times higher than for future pollards and high stem trees. As the seedlings of coppice were planted closer than pollards or high stem trees (1.3 m compared to 4 m), they may have been more susceptible to damage by deer and voles, attracted by the hay litter surrounding the seedlings. They may also have incurred greater damage during the brushing of the vegetation along the tree row in 2015 and 2016, particularly before February 2017 as the tree protection was of lower quality (60 cm high with bamboo stakes compared with 120 cm high mesh guards protections with chestnut stakes) which could fly away with the wind and easily be destroyed during mechanical control of the vegetation on tree row. This high coppice mortality generated a workload in terms of checking for tree damage, replanting and it will also delay the exploitation of the trees. Clearing the vegetation was also trickier for coppice planted between two tree rows of high stem trees and pollards, all the more since the grassland included chicory which grows higher and faster than trees.

Planting costs were higher for triple row sets, than for double and single row sets (Table 8), and were related to the amount, type and species of tree seedlings, with prices varying from €1.15 to €11.90 per tree seedling.

The duration of mechanical control of vegetation on tree rows and planting costs were higher for triple row sets, than for double and single row sets (Table 9). However when considered relative to the number of tree seedlings, double and triple row sets become more beneficial than single row sets, if we set aside the single row set S2 with repellents (mainly done directly by cattle) and the double row set with no coppice.

The double and triple row designs open opportunities not offered by single row set, for instance the mix of different tree uses. For example, we plan to plant liana beside pollards next year in the triple row sets (in the place called “fodder hedge”).

Table 8. Costs for planting and protecting trees depending on the spatial organisation

Spatial organisation		Type of protection against cattle	Planting costs (including protection against wildlife) (€)	Protection against cattle (€)	Total (€)
Single row set					
S4	Pollards x high stem trees x coppiced trees	No protection (not grazed)	160	0	160
S5			151	0	151
S6			147	0	147
S1		Electric fencing tape	150	354	504
S2		Olfactory repellents, barrier tape	193	187	380
S3		Electric fence (single line)	157	333	490
Double row set					
D1	Pollards x high stem trees	Electric fence (single line)	190	335	525
D2	Coppiced x high stem trees		206	335	541
D3	Pollards x high stem trees x coppiced trees		368	335	703
Triple row set					
T1	Pollards x high stem trees x coppiced trees x future fodder hedges	Plastic fence	470	260	730
T2		Electric fence (first single and then double line)	488	345	833
T3		Metal fence	496	152	647

Table 9. Workload depending on the spatial organisation

Spatial organisation		Type of protection against cattle	Workload		
			Planting (hours)	Mechanical control of vegetation on the tree row (hours)	Protection against cattle (hours)
Single row set					
S4	Pollards x high stem trees x coppiced trees	No protection (not grazed)	4	2	0
S5			3	2	0
S6			3	2	0
S1		Electric fencing tape	3	2	1
S2		Olfactory repellents, barrier tape	7	1	2
S3		Electric fence (single line)	3	2	0
Double row					
D1	Pollards x high stem trees	Electric fence (single line)	2	4	1
D2	Coppiced x high stem trees		8	4	1
D3	Pollards x high stem trees x coppiced trees		10	5	1
Triple row					
T1	Pollards x high stem trees x coppiced trees x future fodder hedges	Plastic fence	11	6	2
T2		Electric fence (first single and then double line)	11	6	1
T3		Metal fence	12	6	2

4 Nutritive value of fodder trees and shrubs

4.1 Measurements

The nutritive value of various fodder trees resources for ruminants was evaluated according to the tree species, management (pollarding or not) and season (spring, summer, autumn). Resources were collected in 2014, 2015 and 2016 at our experimental site (tree collections, agroforestry plots, hedges) and also in the neighborhood since the agroforestry trees were only planted in February 2014. The main data collected, from sampling to chemical and biological evaluations, are given in Table 10.

Table 10. List of data collected on the nutritive value of fodder trees

Process step	Data collected
Sampling	Location (geo-referencing), photo Date of sampling Weather conditions Stage of growth Type of management
	Description of the organ visual sanitary aspects photo Dry matter content (DM)
Pre-treatment	Drying parameters Lyophilization conditions Grinding parameters
Chemical composition	Crude protein (CP) content (Dumas method) Fiber content (ADF, NDF and ADL content) van Soest method Condensed tannins content (HCl-butanol method)
In vitro digestibility	Enzymatic digestibility (Aufrère method)
Ruminal degradation kinetics	2 to 72 hours incubation in ruminal fistulated dairy cows Organic matter and protein kinetics parameters

The nutritive value is expressed through the chemical composition, the *in vitro* digestibility (enzymatic method) and the ruminal degradation kinetics. Particular attention is paid to the protein content and fiber content (ADF-NDF-ADL) and the content of condensed tannins.

Figure 8. White mulberry and lime managed as pollards

Leaves were sampled on at least 3 individuals of each species (Figure 8 and Figure 9): Italian alder (*Alnus cordata*), ash (*Fraxinus excelsior*), chestnut (*Castanea sativa*), field elm (*Ulmus minor* x *resista*), hazel (*Corylus avellana*), lime (*Tilia platyphyllos*), black locust (*Robinia pseudoacacia*), white mulberry (*Morus alba*), holm oak (*Quercus ilex*) and vine rootstock (*Vitis* sp). Lucerne (*Medicago sativa*) was also collected (three samples on a 500 m² plot) as herbaceous forage control, harvested after six weeks of regrowth.

Figure 9. Black locust and chestnut leaves (4 August 2014)

4.2 Results (Emile et al. 2017)

The main characteristics of the leaves of woody plants collected from 3 to 10 August 2015 are given in Table 11. The leaf dry matter (DM) content ranges from 284 g kg^{-1} in black locust to 573 g kg^{-1} in holm oak. The crude protein (CP) concentration varies from less than 85 g kg^{-1} in holm oak to more than 200 g kg^{-1} in black locust, chestnut and white mulberry. The ADL concentration varies from less than 30 g kg^{-1} in mulberry to more than 150 g kg^{-1} in Italian alder and ash. The highest condensed tannin concentrations ($P < 0.001$) are observed in black locust, vine and holm oak (respectively 168, 94 and 52 g kg^{-1}). The *in vitro* DM digestibility (IVDMD) ranges from less than 50% in holm oak to 76% in ash and 84% in white mulberry.

Table 11. Chemical composition (g kg^{-1} DM), in vitro DM digestibility (IVDMD, %), and effective degradability of DM (EDDM, %) and of nitrogen (EDN, %) of woody species leaves during summer 2015

Species	DM	Ash	CP	NDF	ADL	Condensed tannin	IVDMD	EDDM	EDN
Alnus cordata	412	60	173	373	172	13[cd]	61	57	45
Fraxinus excelsior	545	95	141	251	157	2[a]	76	75	66
Castanea sativa	300	55	207	408	62	2[ab]	64	45	33
Ulmus minor x resista	463	130	148	354	33	30[e]	64	63	45
Corylus avellana	449	68	153	334	44	8[bc]	55	46	17
Tilia platyphyllos	311	119	183	380	72	23[de]	58	59	60
Robinia pseudoacacia	284	53	245	333	64	171[h]	57	48	36
Morus alba	372	123	204	173	28	2[a]	84	81	79
Quercus ilex	573	39	82	528	117	52[f]	47	40	30
Vitis sp	296	60	128	158	30	94[g]	62	52	24
Medicago sativa **(control)**	355	85	176	389	66	1[a]	64	68	81

Values within a row with the same superscript letter do not differ significantly.
CP= crude protein; NDF=neutral detergent fibre; ADF acid detergent fibre; ADL=acid detergent lignin.

The DM and CP degradation curve kinetics highlight the large differences between species. EDDM ranges from less to 50% in holm oak, chestnut, hazel and black locust to 75% in ash and 81% in mulberry. EDN varies from less than 25% in hazel and vine, to 79% in mulberry and 81% in lucerne. The lower EDN of locust, vine and holm oak could be linked with their high levels of condensed tannins reducing protein availability for ruminal microbes. However chestnut and hazel have few condensed tannins but low EDN suggesting that other compounds are responsible of this effect. The most effective compromise between DM digestibility, protein concentration and protein degradability is obtained with mulberry and ash, which are species traditionally fed to cattle respectively in oceanic and Mediterranean conditions. Hazel, vine rootstock and holm oak seem to be of poor nutritive quality for ruminants, at least for feeding high producing animals.

5 Impact of trees on the herbaceous forage production

5.1 Field measurements

The impact of trees on the herbaceous forage production was measured depending on the season and climate. Experiments were conducted on three mature fields in the development of agroforestry trees and on controls without tree so as to assess the grassland productivity for two whole years. An assessment of the effects on flora was also performed.

On each plot three zones of exclosure were installed (Figure 10) and in each four samples were collected to specific distances rows of trees (Figure 11). A similar system was set up on the control. In total, 16 samples were made to each sequence for each device.

Figure 10. Example of agroforestry plot (left) and control (right)

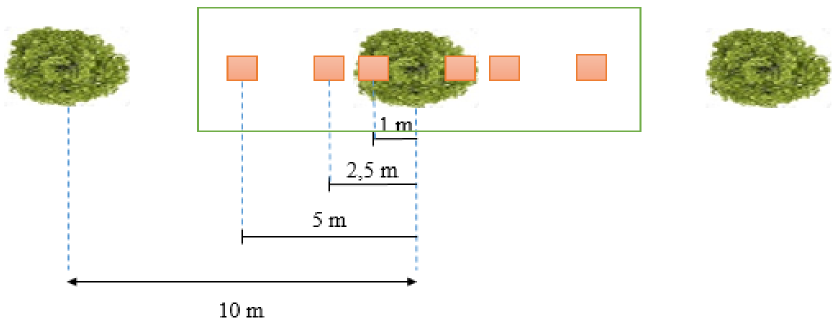


Figure 11. Diagram of sampling devices on agroforestry plots

The samples were collected five times a year at specific times: in spring, the measurement was made on the basis of the sum of temperature reached, in order to capture the growing momentum; in summer and autumn, to characterize the regrowth time with a minimum grass height of 8 cm; in winter at the end of January.

At each sampling date simplified composition measurements were made in quadrats at the four areas identified (grass proportions and various legumes, and grasses stages of development). Grass samples were collected in four frames on each zone. Grass heights are measured before and after each sampling. Each sample is then stored for purposes of analysis of forage values. Each sample was dried for conservation (60°C for 72h).

Table 10. List of measurements

Variable	Measurements
Production	Grass height Biomass, Dry matter
Flora	Gramineae, legumes, or other Phenological stage
Climate	Air temperature, precipitation, wind speed etc. are automatically recorded every hour at an adjacent meteorological station

5.2 Results

During the two years, the grass protection structures faced problems especially in autumn. During these periods of low fodder production, destruction by the animals prevented measurements. Hence the production results presented relate only to the spring and summer periods.

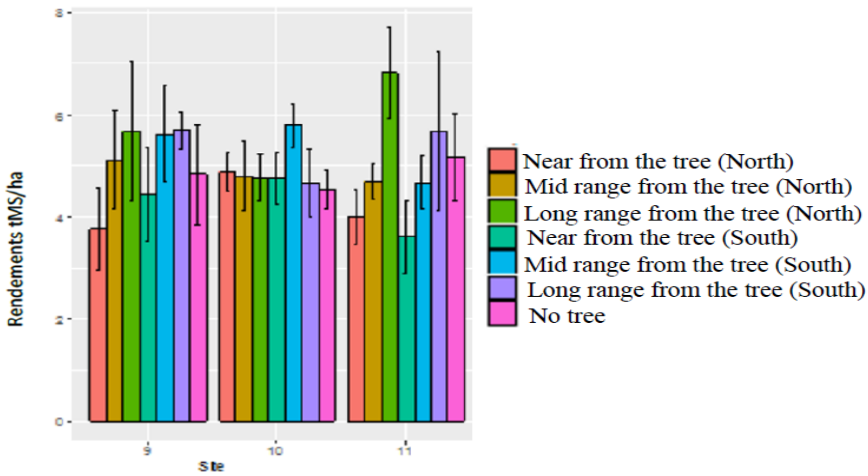


Figure 12. Impact of the tree on forage production measured at the three study sites

The lowest yields were measured closest to the trees (Figure 12). The highest yields are generally found in the sunniest areas, the control and the inter-row zones of agroforestry plots. However, these results should be considered in their context, with control areas sometimes not representative of the agroforestry meadow. In a plot-based approach, by using average production over the three tree distances, the overall production of agroforestry meadow appears very close to the control meadow (Figure 13).

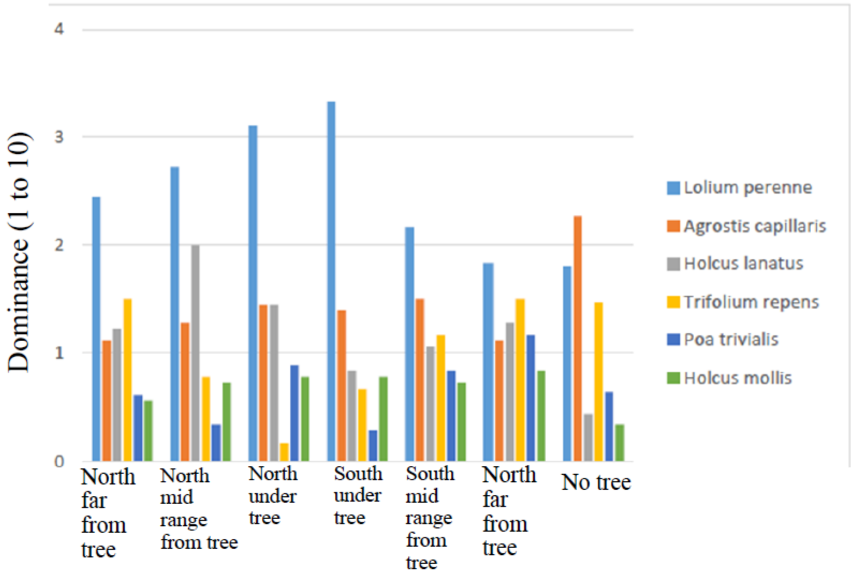


Figure 13. Effect of the tree on the floristic composition of the sward

These observations are valid for both the early and late spring measurements and show some amplification for the second survey period. In terms of vegetation composition (Figure 13), there is a tendency for a decrease in the proportion of legumes (*Trifolium repens* clearly dominant) in shaded areas and mainly under trees where they are virtually non-existent. A slowing effect on prairie grass phenology is also observed in spring.

6 Lessons learnt

6.1 Demonstration plot with multipurpose trees

How to protect young trees from cattle?

Several types of protection can be used, depending on the farmer preferences in terms of cost, installation time and facility of the mechanical control of the tree row. Electric fence and electric fencing tape are quick installed and facilitate the mechanical control of the vegetation, but they are relatively expensive (333 to 354 euros/module) though reusable. The metal fence is cheaper (152 euros/module) and offers the opportunity to be used as trellis for lianas but it needs more time to be installed and it complicates the control of the vegetation on the tree rows.

Olfactory repellents such as garlic essence, spirit vinegar, a repellent for deer used by hunters, and fresh cow dung are not efficient in protecting trees from cow damage.

Installing poles with brushes (to be used as rubbing posts) and a barrier tape along the tree row was effective in preventing cattle from damaging the trees of single row set in 2016 but not in 2017.

Another interesting option is if the farmer has the possibility of excluding the paddock from grazing during the first years of the establishment phase, because it has the advantage to involve no additional cost to protect trees from cow damage.

In all cases it seems necessary to use strong (e.g. mesh guards) individual tree protections and chestnut stakes to limit the damage of deer. The additional use of wild deer repellents (e.g. trico) is also recommended.

Which spatial organization of the tree rows?

Grazing is not complicated by the tree rows, but the establishment of trees induces a loss of grazed surface area that increases with the number of rows in the set, and that will only be recovered when the trees are exploited. However when considered relative to the number of tree seedlings, double and triple row sets could become more beneficial in terms of time needed to control the vegetation on the tree rows and on costs. Double and triple row sets also open opportunities not offered by single row set, for instance the mix of different tree uses.

Further recommendations

To limit the control of vegetation on the tree rows, it is recommended to plant the tree seedlings in a sward composed by species with low growth (chicory is not recommended).

The first years of establishment of the agroforestry plot place demands on the farmer in terms of workload, costs, learning, and loss of grazed surface area, without any advantage in terms of animal welfare, forage resource and wood products that will only come apparent after several years. Hence the farmer needs then to have a long term view.

6.2 Nutritive value of tree leaves

Leaves from hedgerows, coppices, shrubs, or pollarded trees may become a forage resource for livestock during periods of low grasslands production (summer and autumn), either directly by browsing or fed after cutting. However the lack of data on the nutritive value of this unusual forage is an important limitation to their adoption in forage systems of the Atlantic agro-climatic region.

A large variation between species

The composition, nutritive value and ruminal degradability of leaves from woody resources collected during the summer exhibit large variation between species (Emile et al. 2016 and 2017). The crude protein concentration varies from less than 85 g kg^{-1} in holm oak to more than 220 g kg^{-1} in black locust, chestnut, ash and white mulberry (Figure 14). The digestibility ranges from less than 50% in holm oak and black locust to more than 75% in ash and white mulberry.

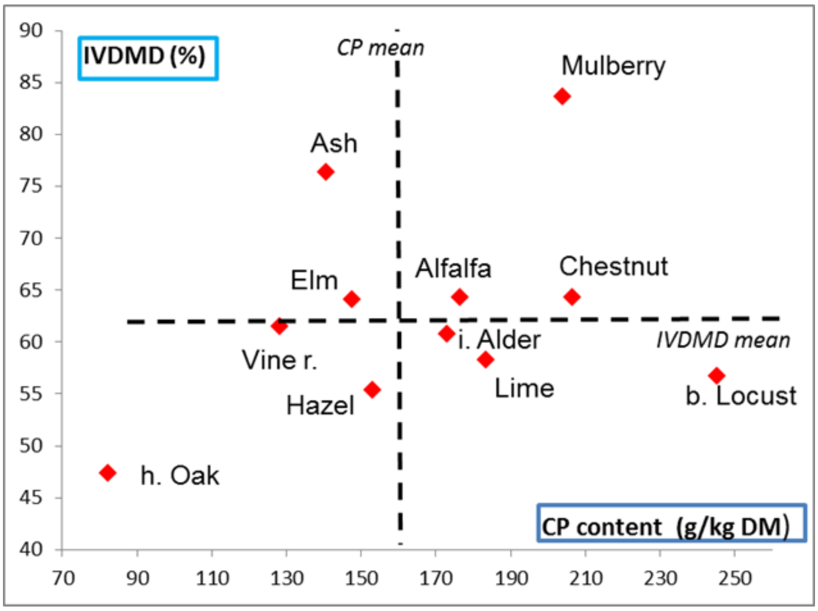


Figure 14. *In vitro* digestibility (IVDMD, %) and crude protein content (g/kg) in leaves of woody plants and lucerne collected in summer 2015 (Emile et al*.* 2017)

There are large differences in minerals, un-degradable fibres and anti-nutritional compounds contents between species.

Some trees are of higher quality than classical forage

White mulberry (*Morus alba*) and common ash (*Fraxinus excelsior*) have sufficient digestibility and nitrogen degradability to be included in the diet of lactating cows in mixed crop-livestock systems. Their quality is higher than those of grasses or lucerne in summer! Other species such as lime, elm, Italian alder, chestnut and black locust seem also potentially interesting to feed less producing ruminants.

The type of management of the tree affects its feeding value

For some species, the nutritive value of the leaves of fodder trees depends on the pruning technique (pollarded or coppiced trees *vs* high stem trees). The effect of season has a lower impact on trees than on herbaceous forage.

Direct browsing of fodder trees would then be a promising management mode to gain value from these leaves while saving time and energy. However it implies to be vigilant on the way to protect the tree from an excessive defoliation.

6.3 Impact of trees on the herbaceous forage production

At the end of the two-year follow-up on a limited number of plots, the measurements show no significant depressive effect on the grassland, the lower production measured near the trees in spring are partly compensated in the zones far away and the middle of the agroforestry alley. Differences in floristic composition and in particular the relative proportions of grasses and legumes can be explained by the incidence of trees on light interception which primarily penalizes legumes. In this study it was not possible to distinguish the respective and direct effects of the tree from the indirect effects of the tree via the behavior of the animals (parking for example).

7 Acknowledgements

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Annex A. detailed experimental design of the demonstration plot

T1	T2	T3
D1	D2	D3
S1	S2	S3
S4	S5	S6

High stem tree
Pollard
Coppiced tree

S = single row set
D = double row set
T = triple row set

P pear
F honey locust
C service tree

M white mulberry
A italian alder

s goat willow
o field elm
r black locust
b grey alder