



Lessons learnt: Weed survey in Mediterranean silvoarable agroforestry

Project name	AGFORWARD (613520)
Work-package	4: Agroforestry for Arable Systems
Specific group	Mediterranean silvoarable agroforestry – Weed survey
Deliverable	Contribution to Deliverable 4.11 Lessons learnt from innovations within agroforestry for arable farmers
Date of report	30 January 2018
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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 field-, farm- and landscape scales, 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 in that it contains results of the studied innovations from the silvoarable stakeholder group in Mediterranean France, which forms part of the participative research and development network in work-package 4 which focuses on agroforestry for arable systems. Together with other reports, this document will contribute to Deliverable 4.11 on lessons learnt from agroforestry for arable farmers. Similar reports exist for agroforestry of high nature and cultural value, agroforestry with high value trees, and agroforestry for livestock systems.

2 Weeds and the management of the tree understorey in silvoarable agroforestry

Arable agriculture provides large quantities of food, but it can be associated with reductions in soil and water quality, biodiversity, and the release of greenhouse gases. Some of these negative effects can be addressed by the integration of trees. Two of the innovations that the silvoarable stakeholder group in Southern France selected for further study were the creation of new durum wheat varieties adapted to agroforestry, and the challenge of managing the herbaceous vegetation in the tree line to avoid weed problems in the crop (Gosme 2014). This report addresses the second challenge focused on weeds. For the results of the plant breeding, please refer to Gosme and Desclaux (2017).

2.1 Why weeds are more concerning in agroforestry systems?

In France, all the stakeholder groups focusing on silvoarable systems, i.e. the groups for Mediterranean, Southern, Western or Northern France, mentioned weeds as an issue for crop management (Gosme 2014; Cirou and Hannachi 2014; Malignier et al. 2014; Wartelle 2014).

Weed management is important both to minimize the reduction in current crop yields (Oerke 2006) and to prevent weed infestations in future years (Macé et al. 2007), and it is a particular concern in silvoarable agroforestry (Burgess et al. 2003). In particular, farmers raise two concerns:

- Cultivation of the tree-rows is not possible because this would damage the trees and, as is the case with field boundaries, this uncultivated vegetation could be a source of potential weeds for the crops of the interrow (Marshall, 1989; Marshall and Moonen, 2002). Thus the question (as illustrated in Figure 1a) is whether this understory strip acts as a reservoir of arable weeds for crops?
- For tree row spacings of 13 to 30 m, the uncropped tree strips can comprise 3 to 8% of the field area. Another concern is that weed dispersion from the tree row could also be favored by the potential low efficiency of weeding (chemical or mechanical) and tillage on the edge of crop alley compared to the center of the alley (margin effect) (Figure 1b).

- A third reason why weed management may be more problematic in agroforestry than in an open crop is that trees modify the microclimate (e.g. available light, temperature, soil moisture) (e.g. Gosme and Desclaux, 2017). The low light levels and moderated temperatures could favor weed species relative to the crop which has been selected for an open environment. It can be argued that many weeds have a higher morphological plasticity than crops (e.g. Munier-Jolain et al., 2014) and a given weed species could be more competitive against crop in agroforestry compared to pure crop system (Figure 1c).

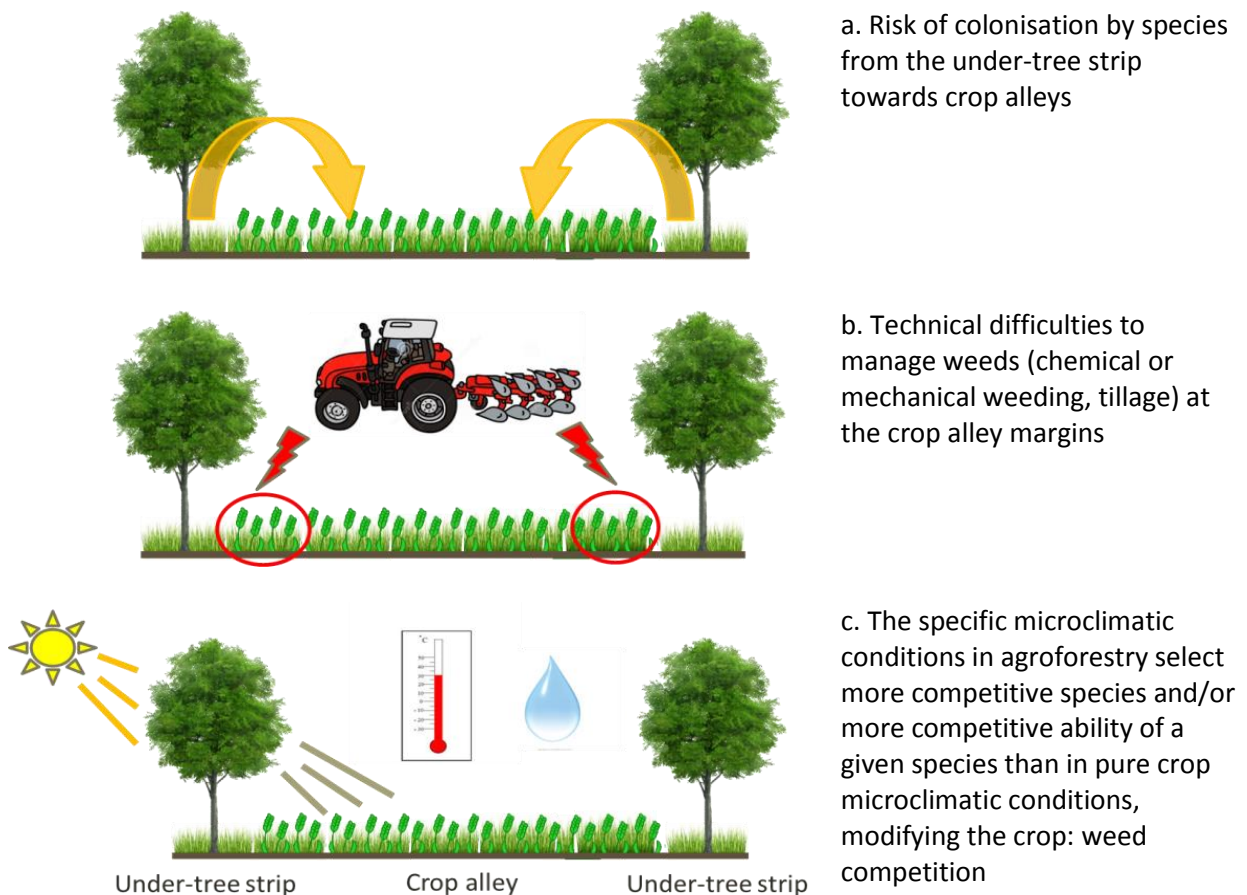


Figure 1. Three potential reasons why agroforestry weed communities may be different and more complex to manage than weed communities in open crops

3 Objectives

The objective of this two-year trial was to assess the effect of the understory strip on weed community of the crop alleyways in alley cropping. Key questions included:

- Is the weed community of arable crops different (richness, abundance, composition) in silvoarable systems compared to conventional arable systems?
- Is the understory vegetation responsible for increasing weed infestation in crops of the alleyways in a conventional alley cropping system?
- Are the shading conditions responsible for changes in weed composition and abundance?
- Does weed pressure for crops change in silvoarable systems compared to arable systems?

Alongside these objectives, the hypotheses were:

- The arable weed community in silvoarable systems is different in terms of species composition and richness (more shade-tolerant species, more perennials in agroforestry, increased species richness) and abundance (similar to field border, where abundance is generally increased, because of the presence of understories): (i) because some of the species of the understories can spread to the crop alleys and (ii) because of the specific conditions (e.g. shading) of agroforestry.
- The different structure and composition of weed community in silvoarable systems (compared to pure crop systems) result in a different effect on the crop.

4 Methodology

4.1 Site description

The trial was set up in two fields, at the Restinclières experimental site, 15 km north of Montpellier (43°43' N, 4°1' E, 54 m a.s.l.), in South-East of France. This site was chosen because the fields are amongst the oldest alley cropping agroforestry systems in France and because of a pure crop control (i.e. a field without trees, with exactly the same crop management and in the same pedoclimatic context). Figure 2 shows the localisation of the fields in the Restinclières site. The trial focused on two fields (A and B) as described in Table 1.

Field A is a 6 ha field (Figures 2 and 3), divided in two parts (crop management has remained constant for the past 20 years). The field comprises 4 ha of alley cropping part, with 20 year-old hybrids of walnuts (*Juglans x intermedia*), and arable crop (13 m across tree rows, with barley in 2015 and pea in 2016), and a 2 ha pure cropping part with barley or pea in 2015 or 2016 respectively.

Field B is a 1 ha field (Figures 2 and 3) divided in two parts (crop management has remained constant for the past 20 years). The field comprises 0.5 ha of a well-shaded alley cropping part, with 15 year-old poplars (*Populus spp.*), and arable crops (13 m across tree rows, with pea in 2015 and durum wheat in 2016), and 0.5 ha of an unshaded area with poorly-developed 20 year-old sorb trees (*Sorbus domestica*) and pea.

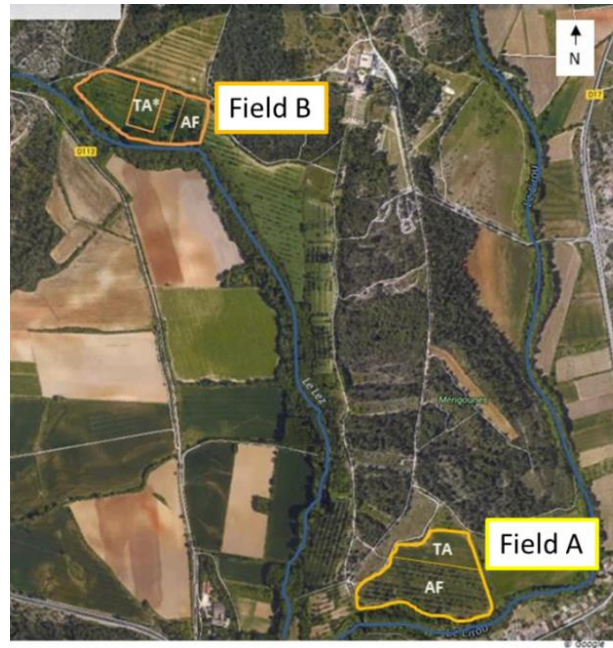


Figure 2. Location of Field A and Field B on the Restinclières estate. Field A: TA = pure crop system, AF = Walnut/arable crop agroforestry system; Field B: TA* = Sorb/arable crop agroforestry system (poor shade), AF = Poplar/arable crop agroforestry system (dense shade). The crop was barley in 2015 and pea in 2016 in Field A, pea in 2015 and durum wheat in 2016 in Field B (Map: Google)

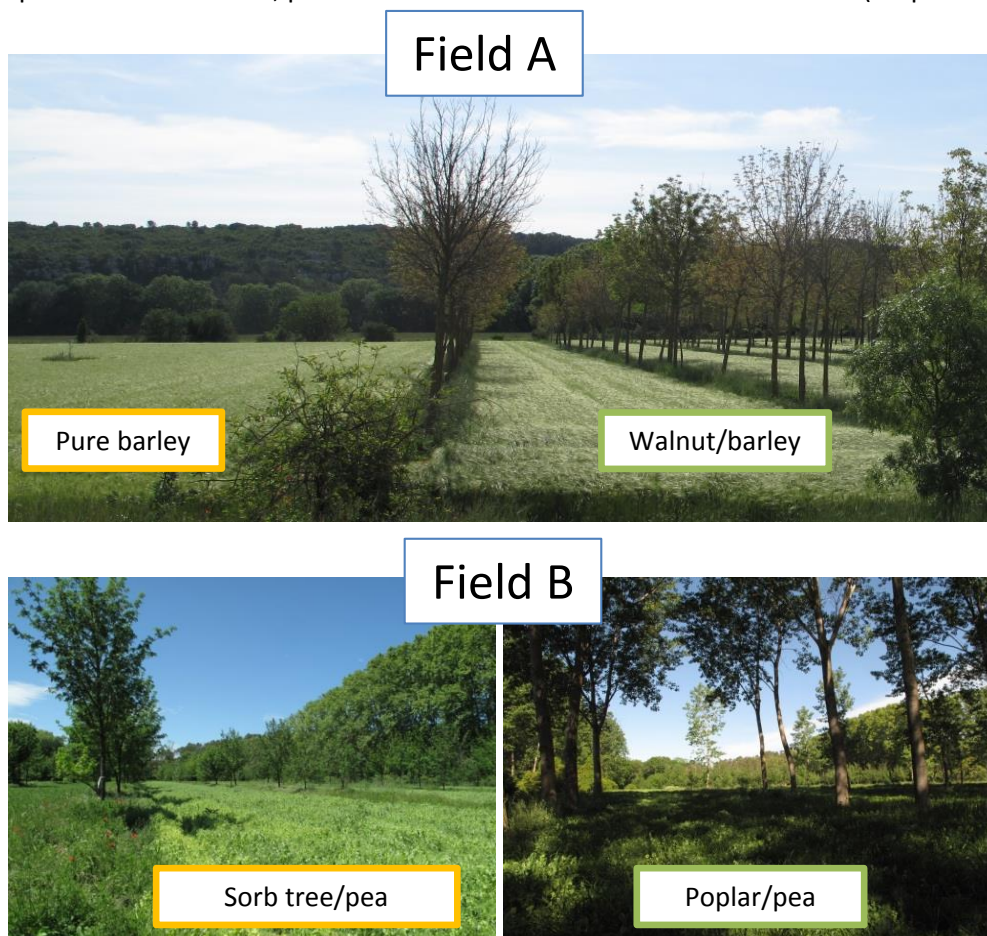
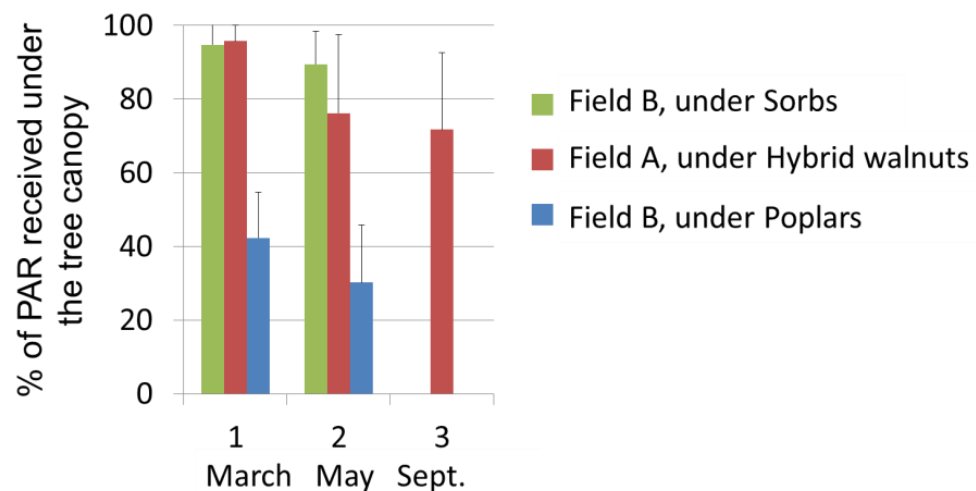


Figure 3. View of Field A and Field B in May 2015 (Pictures: D. Mézière).

Table 1. Description of the site, with soil, tree, understory, and climate characteristics

Site characteristics		
Area:	6 ha + 1 ha	
Co-ordinates:	43°43' N, 4°1' E	
Site contact/e-mail	Lydie Dufour; dufourl@supagro.inra.fr	
Soil characteristics		
Soil depth and texture	Deep silty clay limestone	
Tree characteristics		
Field A	Agroforestry system (AF walnuts)	Crop reference system
Tree species	Hybrid walnut (<i>Juglans x intermedia</i>)	None
Tree density (spacing)	100 trees ha ⁻¹ (13 m across lines, about 4 to 8 m along tree line)	None
Tree protection	None	None
Additional details	Uncultivated 1.5 m strip at tree base with spontaneous vegetation	
Field B	Shady agroforestry system (AF poplars)	Sunny agroforestry system (AF sorbs)
Tree species	Poplar (<i>Populus spp.</i>)	Sorb (<i>Sorbus domestica</i>)
Variety/rootstock	-	-
Tree density (spacing)	100 trees ha ⁻¹ (13 m between rows, about 4 to 8 m within row)	50 trees ha ⁻¹ (13 m between rows, about 4 to 12 m within tree row because of a lot of mortality)
Tree protection	None	None
Additional details	Uncultivated 1.5 m strip at tree base with spontaneous vegetation	Uncultivated 1.5 m strip at tree base with spontaneous vegetation
Crop characteristics in 2015		
Field A	Agroforestry system (AF walnuts)	Crop reference system
Species	Winter barley (<i>Hordeum vulgare</i>)	
Coverage	Complete	
Previous cropping	Durum wheat (<i>Triticum durum</i>)	
Field B	Shady agroforestry system (AF poplars)	Sunny agroforestry system (AF sorbs)
Species	Pea (<i>Pisum sativum</i>)	Pea (<i>Pisum sativum</i>)
Coverage	Complete	Complete
Previous cropping	Previous years: Durum wheat (<i>Triticum durum</i>) / durum wheat/pea (<i>Pisum sativum</i>)/durum wheat	Previous years: Durum wheat (<i>Triticum durum</i>) / durum wheat/pea (<i>Pisum sativum</i>)/durum wheat
Crop characteristics in 2016		
Field A	Agroforestry system (AF walnuts)	Crop reference system
Species	Pea (<i>Pisum sativum</i>)	
Coverage	Complete	
Previous cropping	Winter barley (<i>Hordeum vulgare</i>)	
Field B	Shady agroforestry system (AF poplars)	Sunny agroforestry system (AF sorbs)
Species	Pea (<i>Pisum sativum</i>)	Pea (<i>Pisum sativum</i>)
Coverage	Complete	Complete
Previous cropping	Previous years: Durum wheat (<i>Triticum durum</i>) / durum wheat/pea (<i>Pisum sativum</i>)/durum wheat	Previous years: Durum wheat (<i>Triticum durum</i>) / durum wheat/pea (<i>Pisum sativum</i>)/durum wheat

Climate data																	
Climate type	Mediterranean																
Mean monthly temperature	14.2 °C																
Mean annual precipitation	851 mm																
Details of weather station	Data from 2011-2013 (Campbell station on site)																
Light radiation in fields																	
Method	<p>Hemispherical pictures were taken at the centre of each quadrat of the weed sampling of 2015 (see below) by using Winscanopy software, the photosynthetically active radiation (PAR) was calculated from the pictures.</p> <p>Pictures were taken on the same first two dates as weed sampling in 2015 (i.e. before tree budbreak at the end of March and some weeks after budbreak when tree leaves are quite well developed and winter crops are flowering, at the end of May).</p>																
Results	<div><table><caption>Approximate data from Figure 1</caption><thead><tr><th>Session</th><th>Field B, under Sorbs (%)</th><th>Field A, under Hybrid walnuts (%)</th><th>Field B, under Poplars (%)</th></tr></thead><tbody><tr><td>1 March</td><td>~95</td><td>~95</td><td>~42</td></tr><tr><td>2 May</td><td>~90</td><td>~75</td><td>~30</td></tr><tr><td>3 Sept.</td><td>-</td><td>~72</td><td>-</td></tr></tbody></table></div> <p>Figure 1. Percentage of Photosynthetically Active Radiation (PAR) received under the tree canopy compared to the pure crop control from Field A (100%) for the three weed survey sessions.</p>	Session	Field B, under Sorbs (%)	Field A, under Hybrid walnuts (%)	Field B, under Poplars (%)	1 March	~95	~95	~42	2 May	~90	~75	~30	3 Sept.	-	~72	-
Session	Field B, under Sorbs (%)	Field A, under Hybrid walnuts (%)	Field B, under Poplars (%)														
1 March	~95	~95	~42														
2 May	~90	~75	~30														
3 Sept.	-	~72	-														

4.2 Measurements in 2015

The number of measurements taken in each of the four surveyed systems are described in Table 2. In each system, weed measurements were recorded within 1 m x 1 m quadrat plots placed regularly (each 1.17 m) along three transects in each treatment (Figure 3). In both fields, the transects were placed perpendicular to the tree lines. In the pure crop reference of Field A, the transect extended beyond the agroforestry transect (Figure 3). The distances from trees are not exactly the same at the cross between transect and tree lines as some trees were cut to reduce tree density in 2003.

Table 2. Measurements and the number of sampled quadrats in 2015

Measurements	Field A		Field B	
	Pure barley	Walnut/barley	Pea/Sorb	Pea/Poplar
Weed sampling in alley crop	90 quadrats x 3 dates	90 x 3 dates	75 x 3 dates	75 x 3 dates
Weed sampling in understory	-	21 x 3 dates	21 x 3 dates	18 x 3 dates

In the table, 90 quadrats is derived from 5 quadrats/alley x 6 alleys x 3 transects.

75 quadrats = 5 quadrats/alley x 5 alleys x 3 transects;

21 quadrats = 1 quadrat x 7 understories x 3 transects;

18 quadrats = 1 quadrat x 6 understories x 3 transects;

111 quadrats = 90 plots in alley crop + 21 in understories;

93 quadrats = 75 plots in alley crop + 18 in understories. Only 20 quadrats for PAR in the pure barley as in the middle of the field, it is full light (and we do not need take photos alongside all the transects).

Five quadrats were sampled for each crop alley in the agroforestry field, which enabled i) the measurement of the light radiation variability in alley cropping induced by trees and ii) weed samples at different distances from grass strips of the tree understories. Given the absence of trees in the reference crop, each group of five plots are separated by an empty zone (corresponding to the tree line in the agroforestry field). Otherwise the protocol was the same.

Because of other trials on the same fields (pollarded tree trial in Field A, participatory durum wheat breeding in Field B), some crop alleys are not sampled in the agroforestry field. Hence six crop alleys were surveyed in Field A, and 5 crop alleys were surveyed in Field B.

4.2.1 Weed sampling 2015

For the crop alleys, all weed species and their specific abundance (number of individuals for each species) was recorded within each 1 m² quadrat. For the quadrats of the tree understory, specific abundance was related to an abundance class following the scale of Barralis: 0, 1 if 1 individual, 2 if 2-3 individuals, 3 if 4 to 20 individuals, 4 if 21 to 50 individuals, 5 if more than 50 individuals. If there were problems with species identification (due to juvenile stage), individuals were recorded and identified later (e.g. when flowering).

4.2.2 Weed competition

Crop competition caused by the weeds was expressed by the relative weed biomass ratio = DM weeds / (DM weeds + DM crop), where DM is dry matter as used by Lutman et al. (1996). Thus, in each system, nine 1 m² quadrats (three in the middle of the alley, three in the north part of the alley, and three in the south part of the alley) were completely harvested. The total harvested biomass was separated between crop biomass and total weed biomass. The harvests was carried out some days before crop harvest (10 June 2015 for barley and pea), dried at 50°C for 72 hours and weighed.

4.2.3 Sampling date

Composition, abundances and total PAR under canopy was measured three times in the same quadrats during the campaign:

- Before tree budbreak (end of March-Beginning of April), which corresponds to the situation with minimum shade.
- Some weeks after budbreak when tree leaves were quite well developed and provided shade, as well as when crops are flowering (22-26 May). Crop flowering is a critical period for yield build-up of wheat.
- Two weeks after 1st post-harvest tillage (September), meaning when post-harvested weeds were largely developed and tree-LAI max was reached.

Because the site received an application of herbicide after the weeds started to appear at the end of winter, the sampled weeds are the residual flora remaining after treatment. Weed management was strictly the same in the control and in the agroforestry plots.

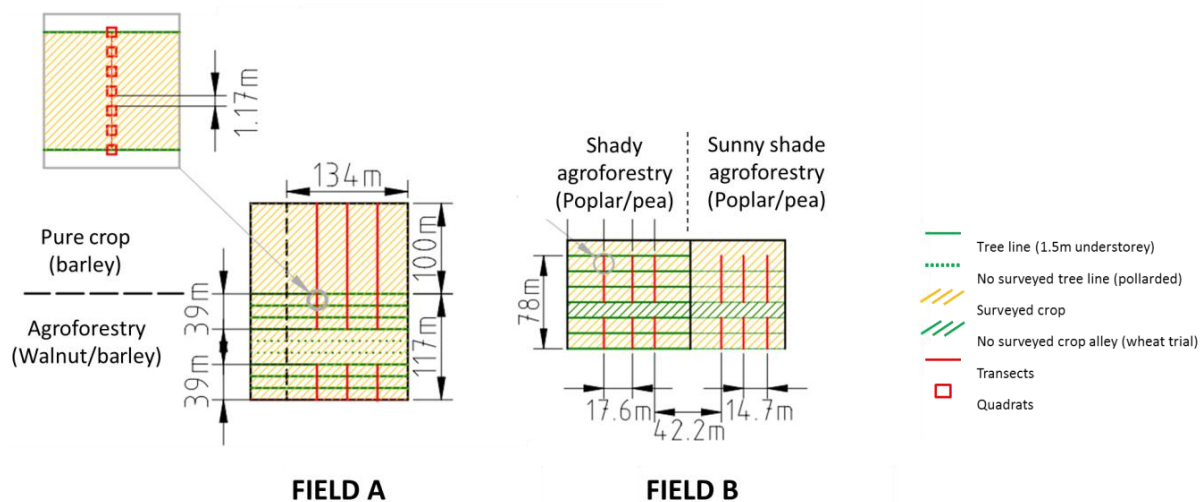


Figure 4. Location of the transects and the quadrats in each field (protocol 2015).

4.3 Measurements in 2016

In 2016, only the weed sampling was carried out. For this, the protocol was adapted depending on the results obtained in 2015 and on some methodological trials to define the optimal number of quadrats and disposition to obtain the same quality of data with the least sampling effort (results not shown here). Thus, weed sampling in 2016 used the Barralis scale abundance (see Measurements 2015) for both the understorey vegetation and for the alley cropping. Compared to 2015, the transects were modified and only 6 mini-transects, randomly placed in the crop alleys in each field, were sampled (Figure 5). To better study the effect of the strip, two additional quadrats were added in the crop alley, resulting in seven quadrats in the crop (Figure 6). In 2016, there was only one sampling date in May, after budbreak.

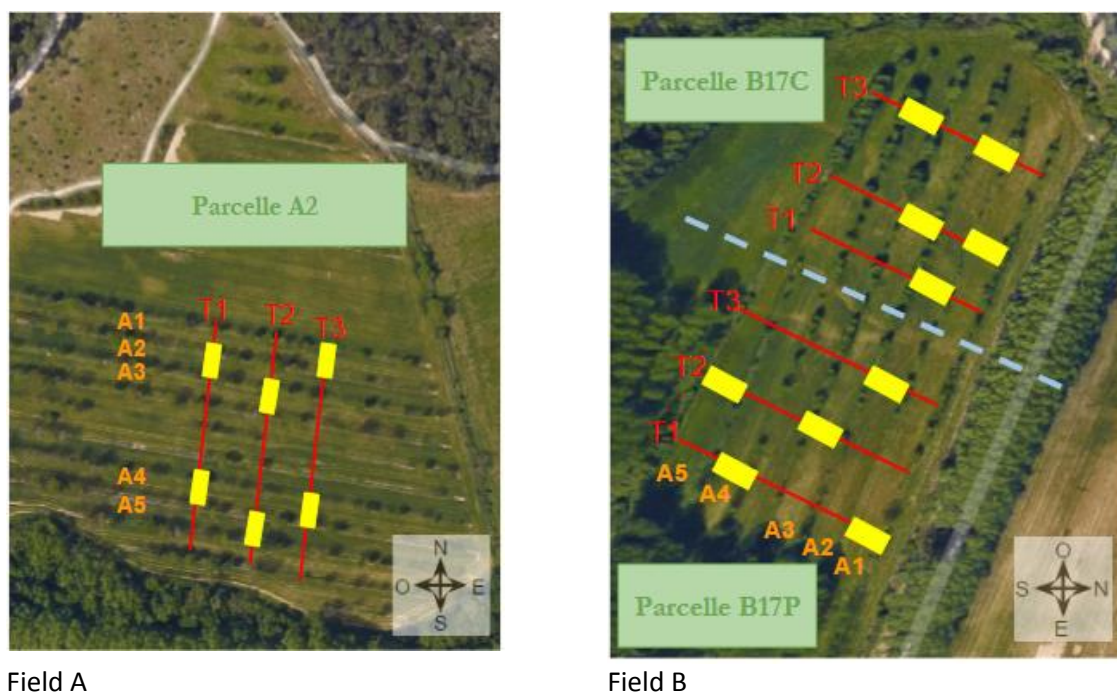


Figure 5. Location of the mini-transects (in yellow) in the two surveyed fields (protocol 2016)

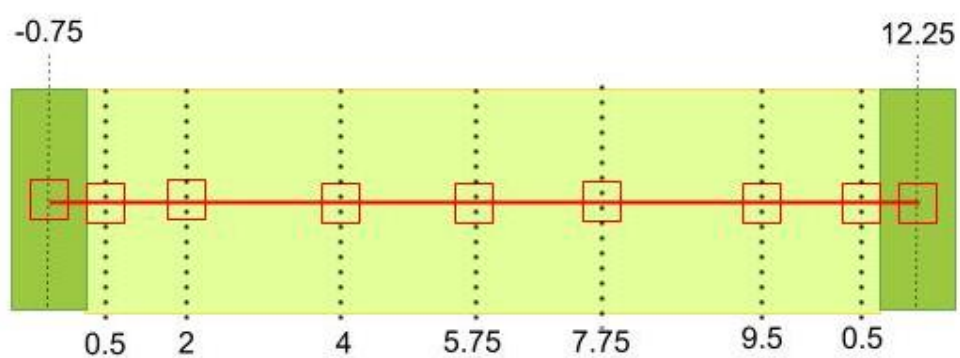


Figure 6. Disposition of the quadrat along the mini-transect (protocol 2016)

5 Results

5.1 Does the weed community of arable crops in silvoarable systems differ from those in conventional arable systems?

5.1.1 Number of weed species and abundance

It seems there were more weed species in the agroforestry arable crop than in the pure crop control; this difference was only statistically significant in 2015 (Figure 7a). Conversely, there were fewer individuals in the crop in agroforestry than in pure crop control and again this difference was significant only for 2015 (Figure 7b).

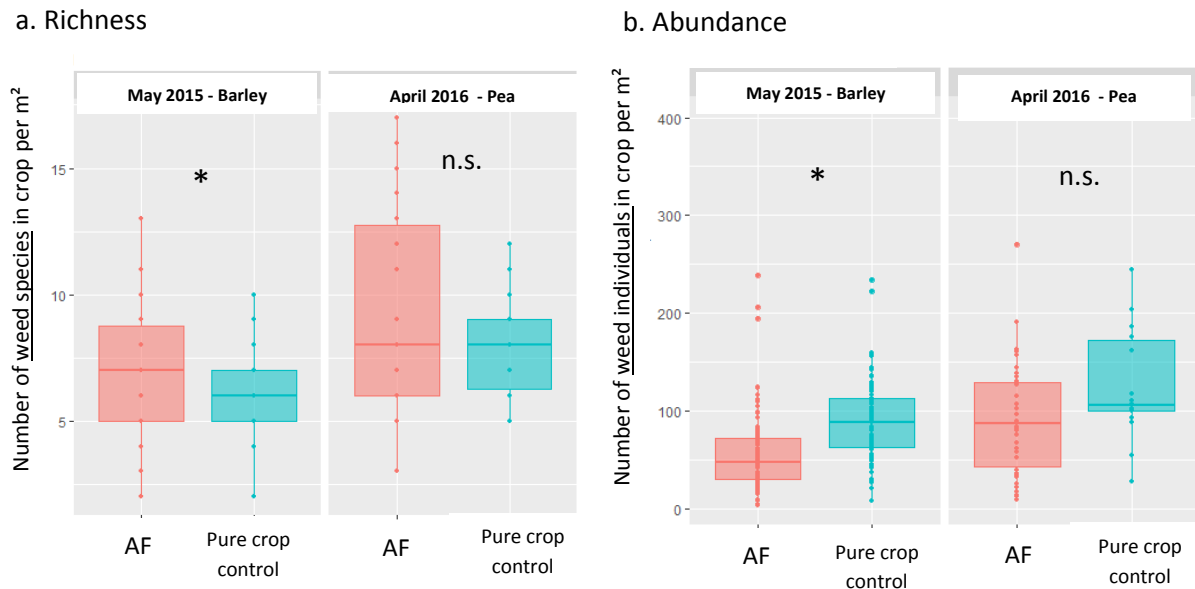


Figure 7. Richness (a) and Abundance (b) of weeds in crop alleys (AF) or in pure crop control in Field A. The significance of the differences between AF and Pure crop control was analysed by an analysis of variance on the general linear mixed model with Poisson family ($\alpha = 0.05$). Fixed effect: system (AF vs. pure crop), Random effect= mini-transect). *: significant difference. n.s. : non-significant difference.

5.1.2 Composition

The Principal Coordinates Analysis (PCoA) (Figure 8) shows the similarity between the quadrats in terms of specific composition and relative abundances (Bray-Curtis index). The weeds found in agroforestry in field A were more similar to the weed community of the pure crop from the same field (same crop: barley, pink group on Figure 8) than from the other agroforestry plots (crop: pea, blue group on Figure 8). Hence the effect of the crop species on the weed species was thus stronger than the system (AF vs. pure crop).

The vegetation found in the strips under the trees across the two sites were similar (green group; Figure 8), and distinctive from the weed vegetation in the crops (pink and blue group). Figure 9 supports this result, showing that weed communities in the agroforestry crop was broadly similar to that in the open crop. Even if the weed community in the agroforestry was richer and smaller than the one in pure crop (e.g. Figure 7), the dominant species were the same (e.g. *Papaver rhoeas*, *Fallopia convolvulus*) in each case.

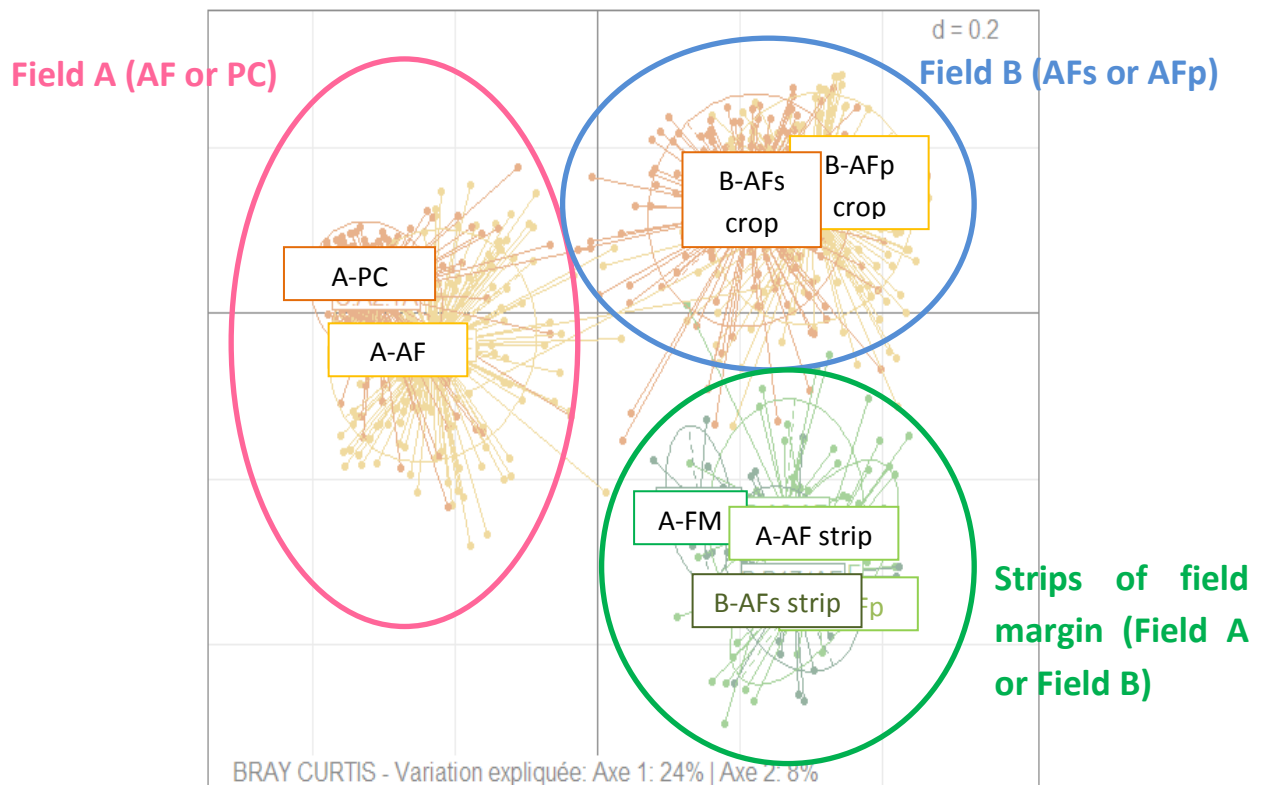


Figure 8. Principal Coordinates Analysis (PCoA) performed on the Bray-Curtis dissimilarity index (accounting for the dissimilarity in terms of species and relative abundance) (data 2015). Each point represents a 1 square-meter quadrat and is linked to the barycentre of the modality. Legend: A = field A, B: field B. PC=pure crop control, AF: agroforestry walnut, AFs: agroforestry sorbs, AFp: agroforestry poplars. Crop: crop alleys in agroforestry, strip: understory strip in agroforestry, FM: field margin of Field A.

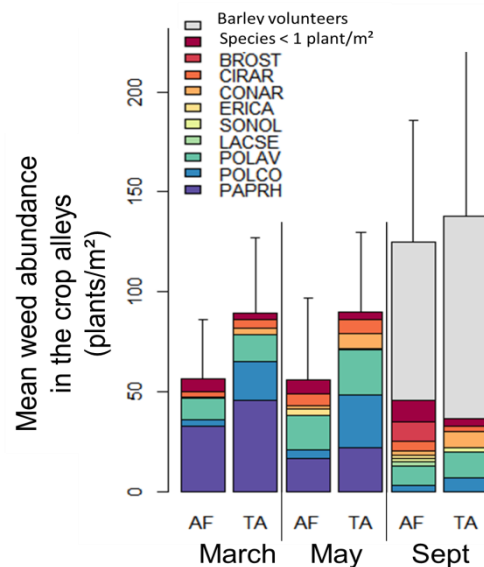


Figure 9. Specific and total abundances at quadrat scale in crop (pure crop) or crop alley (AF) in Field A for the three sessions of 2015 (March and May: barley, Sept.: bare soil). AF=agroforestry system, TA=pure crop control. BROST: *Bromus sterilis*, CIRAR: *Cirsium arvense*, CONAR: *Convolvulus arvensis*, ERICA: *Conyza canadiensis*, SONOL: *Sonchus oleraceus*, LACSE: *Lactuca serriola*, POLAV: *Polygonum aviculare*, POLCO: *Fallopia convolvulus*, PAPRH: *Papaver rhoeas*.

5.2 Are the shading conditions responsible for changes in weed composition and abundance?

Weed communities were affected by the crop species (barley or pea) and the habitat (crop vs. understory strip) (Figures 8). The analyses performed here do not allow us to determine the effect of shading on weed community. The greater number of weed species in the agroforestry, compared to the pure crop, could be a result of the presence of the understory strips. However we could also argue that the heterogeneous shade produced by the trees on the crop alleys creates a diversity of microhabitats in the alley, resulting in a more diverse plant community. This assumption has to be tested later.

5.3 Is the understory vegetation responsible for increasing weed infestation in crops of the alleyways in a conventional alley cropping system?

In 2015, there was no significant effect of the distance to the closest understory on the weed abundance¹ in crop. In 2016, a significant effect of the distance was detected on weed abundance in the agroforestry sorbs, where the difference was only significant between the closest quadrat to the strip (50 cm from the crop edge) and the centre of the alley (Figure 10).

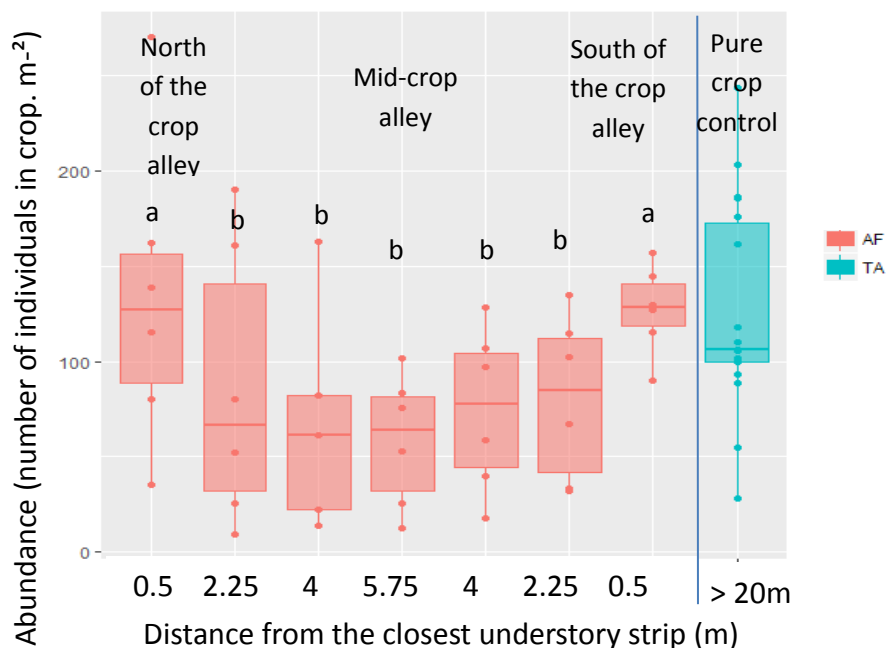


Figure 10. Weed abundance in the crop (pea) in 2016 in the Field A. Different letters indicates a significant difference of abundance between distances.

5.4 Does weed pressure for crops change in silvoarable systems compared to arable systems?

The results from the weed competition protocol are not shown here because of doubt about their significance (problem of scales and sampling date). The current PhD work of Sébastien Boinot (2016-2019, UMR SYSTEM, INRA) aims to answer this question.

¹ Anova was performed on the generalized linear mixed model with Poisson family for each of the agroforestry system (walnut, sorbs or poplars) and for each sampling date: abundance in crop ~ distance from the understory + 1|transect.

6 Conclusions

The principal lessons learnt from the measurements and observations in the alley cropping systems and the pure crop control include:

- The plant communities of the understory strip in 21 year old agroforestry plots in the South of France were different from the weed communities in the crop.
- Across the two sites, the weed community was more affected by the crop than whether the sample was an agroforestry or open arable crop.
- There were more weed species in the agroforestry plots, but the abundance of weed species was greater in the pure crop.
- Spontaneous understory vegetation has not resulted in an increased weed density in the crop in agroforestry, except on the first 50 cm of crop edge. This result should be taken with caution as it was obtained on a single site. Other sites should be investigated, including conventional and organic systems, with spontaneous as well as sown grass strip under the trees.
- Management of weeds from tree rows is still an area that has received little research. Indeed To our knowledge, this work was one of the first to consider the effect of understory strip on crop weeds (and not tree weeds). This initial work has raised some interesting questions and a PhD student has been engaged after these 2015 and 2016 results, and a follow-on research and development has been submitted. The project already made it possible to test protocols that have already been set up in 2017 in two French regions (Occitanie in the PhD work of Sébastien Boinot, UMR SYSTEM-INRA, and Poitou-Charentes in the training period of Clément Chevalier, CA Charente-Maritime).

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 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. The authors acknowledge Emilie Cadet, Guillaume Fried, Aude Ripoche and Oswaldo Forey for their valuable help for weed survey.

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