Lessons learnt:
Screening durum wheat cultivars for agroforestry

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Contents

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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 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 one of the systems being studied within 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 Agroforestry for Mediterranean arable systems

The Mediterranean silvoarable systems stakeholder group forms a part of a wider Participative Research and Development Network (PRDN) within work-package 4 focused on agroforestry for arable farmers. 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. The stakeholder group in Southern France, as part of the wider PRDN, has addressed the following objectives:

1. to identify examples of the best practices, key challenges and innovations to address. Gosme (2014) reported the results of the initial stakeholder meeting which identified the principal positive aspects of agroforestry as income diversity, crop production, enhancement of biodiversity and wildlife habitats, and soil conservation; the key negative aspects were identified as potential cash flow problems, the lack of business opportunity when selling tree products and losses by predation, particularly bird predation. The innovation that was selected for further study was the creation of new varieties adapted to agroforestry, and the challenge that needed to be addressed concerned the management of the herbaceous vegetation on the tree line to avoid weed problems in the crop. Therefore, the following objectives were broken down into two subjects: plant breeding and weed control. This report concerns only plant breeding, for the results of the weed study, please refer to Mézière et al. (2017).
2. to agree and implement within the PRDN an experimental protocol to screen existing varieties of durum wheat in three sites (one experimental, two managed by farmers), in order to select interesting parents in a future plant breeding program (Gosme and Desclaux 2015). Indeed, cultivated varieties of all major arable crops have been selected under conditions of full light so there might be room for improvement for shade tolerance and/or other traits that would make varieties more adapted to cultivation in agroforestry systems.
3. to describe and explain the key inputs, outputs and ecosystem services (in particular the microclimate regulation service) for a case study site. This was initiated for the Restinclières site by Gosme and Mézière (2016) in a system report on durum wheat production in agroforestry systems in France.

4. The remaining objective, which is partly addressed by this report, is to provide and promote guidelines for farmers on how to establish economically viable agroforestry practices for arable farmers.

3 Objectives

The objective of this experiment was to determine if there is genetic variability in durum wheat that relates to its suitability in agroforestry systems and to perform a first screening of accessions from INRA collections in order to use them in a selection program of varieties adapted to agroforestry. During three years of experimentation, 45 accessions were compared by growing them in different shading conditions (obtained by using deciduous or evergreen trees, with different tree densities, tree heights or tree pruning strategies). The measurements comprised 1) the growth and development of durum wheat: germination, winter survival, phenology, growth in height and ground cover, and 2) the yield components. The decrease in light intensity under the trees was also measured. The comparison of these variables between the different shading conditions was used to classify the varieties regarding their shade tolerance.

4 Methodology

The trial was set up across nine situations:

1. at a farmer's farm, near Nimes, in a plot with almond trees.
    a. One alley between two rows of almond trees
    b. One alley with no trees on the South side (=> full sunlight)
2. at Restinclières estate, north of Montpellier, in plot B17 (in 2014-2015) and plot A6 (in 2015-2016):
    a. Plot B17: one alley between mature poplar trees (distance between trees: 6 m along tree row, 13 m across). Poplars are 15 years old and measure approximately 30 m in height
    b. Plot B17: one alley between stunted sorb (*Sorbus domestica*) trees (distance between trees: variable along tree row because of missing trees, 13 m across). Sorb trees are 20 years old but grew poorly and measure approx. 2 m in height, providing virtually no shade.
    c. Plot A6: three alleys between ash trees (distance between trees: 4 m along tree row, 13 m across). Ash trees are 20 years old and measure approximately 15 m in height.
    d. Plot A6: three alleys between stunted sorb (*Sorbus domestica*) trees (distance between trees: variable along tree row because of missing trees, 13 m across). Sorb trees are 20 years old but grew poorly and measure approx. 2 m in height, providing virtually no shade.
3. at INRA experimental station, South-East of Montpellier:
    a. Plot 13B: Agroforestry+ (AF+): high density olive trees (distance between trees: 1.5 m along tree row, 5 m across), unpruned trees.
    b. Plot 15A: Agroforestry (AF): standard olive grove (distance between trees: 5 m along tree row, 6 m across), trees pruned regularly
    c. In an agricultural plot (15B in 2015, 12C in 2016 and 13 in 2017)

Tables 1, 2 and 3 summarize the characteristics of the three sites.

Table 1. Description of the farmer's field near Nimes

Specific description of site	
Area	0.07 ha
Co-ordinates	43°53'08.2"N 4°31'24.6"E
Site contact	François Caizergue
Site contact	fcaizergues@yahoo.fr
Example photograph	 Figure 1. Cultivated area between almond trees (19 January 2015)
Map of system	 Figure 2. Aerial photograph of the almond tree orchard.
Climate characteristics	
Mean monthly temperature	13.8°C
Mean annual precipitation	726 mm
Details of weather station	Data from Station Nimes-Courbesac (30189001) Meteo France
Soil type	
Soil type	Mediterranean soil characterized by a deficiency in humus, numerous stones and high rate of clay.
Soil depth	70 cm
Soil texture	50% sand, 30% silt and 20% clay
Additional soil characteristics	The main river (Gard) has a typical intermittent hydrological regime: low water levels during the summer (approx. 3 m under the ground-level), floods occurring mainly in the fall.
Aspect	Flat
Tree characteristics	
Species and variety	Almond tree (cultivar Ferraduel and Ferragnés)
Date of planting	1980
Intra-row spacing	4 m

Inter-row spacing	6 m
Tree row orientation	East-West
Tree protection	None
Crop understory characteristics	
Species	Durum wheat (*Triticum turgidum* L. subsp. durum (Desf.) Husn.)
Management	Organic farming with horse-powered tools
Typical crop yield	1.5 t/ha (wheat grain yield)
Fertiliser, pesticide, machinery and labour management	
Fertiliser	None
Pesticides	None
Machinery	Horse-powered tools for sowing and harvest. The narrow cultivated strip make it easier for the horse to start working because it seems more manageable.
Manure handling	Yes
Labour	1 person
Fencing	None

Table 2. Description of site at Restinclières Estate, north of Montpellier

Specific description of site	
Area	2 (shade vs sun) x 3 reps x 12 varieties x (1.55mx6m in 2015 or 1.55m x 7m in 2016)
Co-ordinates	43°42'54.4"N 3°51'12.9"E (B17 plot) 43°42'43.0"N 3°51'28.3"E (A6 plot)
Site contact	Lydie Dufour
Site contact	lydie.dufour@inra.fr
Example photograph	 Figure 3. Left: Plot B17: Wheat under poplars in the foreground with wheat in full sun in the background (17 June 2015). Right: Plot A6: soil preparation before sowing, the tractor is below the ash trees, where the agroforestry plots will be located, the two trees in the foreground (right- hand side) are wild cherry trees, and the "full sun" plots will be located in the gap between the last wild cherry and the first ash tree (23 October 2015)

Map of system	 Figure 4. Left: Aerial photograph of the B17 plot, the black squares indicate the location of the experimental plots (under poplars/in full sun). Right: Aerial photograph of the A6 plot, the black squares indicate the location of the experimental plots (under ash trees/full sun).
Climate characteristics	
Mean monthly temperature	14.2 °C
Mean annual precipitation	851 mm
Details of weather station	Data from 2011-2013 (Campbell station on site)
Soil type	
Soil type	Silty deep alluvial fluvisol
Soil depth	Deep
Soil texture	Silty clay limestone
Additional soil characteristics	Carbonated soil
Aspect	Flat
Tree characteristics	
Species and variety	Poplar, clone I214 (B17) and Ash (A6)
Date of planting	1999 (B17) and 1995 (A6)
Intra-row spacing	6m (B17) and 4 m (A6)
Inter-row spacing	13 m
Tree row orientation	East-West (B17) and North-South (A6)
Tree protection	None
Crop understory characteristics	
Species	Durum wheat (*Triticum turgidum* L. subsp. durum (Desf.) Husn.)
Management	Conventional arable crop management with ploughing
Typical crop yield	Farmer's yield: 4.5 t/ha. The yield with the selected durum varieties was lower because of the use of old varieties.
Fertiliser, pesticide, machinery and labour management	
Fertiliser	No fertiliser in 2015, ammonium nitrate + sulphur in 2016
Pesticides	No pesticide in 2015 harvest year, herbicide (Athlet, 3.6 L/ha) on 13 November 2015 for the 2016 harvest year
Machinery	Need for tractor access in crop alleys to allow soil preparation, sowing , phytosanitary treatments and harvesting
Manure handling	None
Labour	Normal practices
Fencing	None

Table 3. Description of the site at the INRA Experimental station, South-East of Montpellier

Specific description of site	
Area	0.45 ha (12C), 0.25 ha (15B), 0.8 ha (13B), 0.45 ha (15A)
Co-ordinates	43°36'35.2"N 3°58'49.5"E
Site contact	bruno.bernazeau@inra.fr ; dominique.desclaux@inra.fr
Example photographs	 Figure 5. Top left: Plot 15A: two varieties of wheat under pruned olive trees, Top right: Plot 13B: one variety of wheat under unpruned olive trees; Bottom: Plot 15B: agricultural control in Mauguio (16 June 2015)
Map of system	 Figure 6: Aerial photograph showing the location of the agroforestry (15A), agroforestry+ (13B) and agricultural controls of 2015 (15B) and 2016 (12C) in Mauguio experimental station.

Climate characteristics	
Mean monthly temperature	15.5°C (mean 2012-2014)
Mean annual precipitation	598 mm (mean 2012-2014)
Details of weather station	
Soil type	
Soil type	Fluvisol FL
Soil depth	Deep
Soil texture	Loam (23% clay, 30 to 40% sand)
Aspect	Flat
Tree characteristics	
Species and variety	Olive tree, clones Picholine and hybrids Verdale x Picholine (15A) - Hybrid Olivière x Arbequine (13B)
Date of planting	2002-2003 (15A) and 2005 (13B)
Intra-row spacing	5 m (15A) and 2 m (13B)
Inter-row spacing	6 m
Tree row orientation	North West – South East
Tree protection	None
Crop understory characteristics	
Species	Durum wheat (*Triticum turgidum* L. subsp. durum (Desf.) Husn.)
Management	Organic arable crop management with ploughing
Typical crop yield	2t/ha wheat
Fertiliser, pesticide, machinery and labour management	
Fertiliser	None
Pesticides	None
Machinery	Experimental sowing and harvesting machines
Manure handling	None
Labour	done by INRA personnel
Fencing	None

A total of 45 varieties were tested over the three years (Table 4). They were chosen to include pure line elite varieties, old varieties and wild populations, in order to test if (i) there might be adaptation to agroforestry in old varieties, as agroforestry used to be a traditional system before mechanization and land reparcelling that came with it; and (ii) if population-based varieties included more genetic variability, allowing them to better adapt to agroforestry conditions.

Each genotype that was tested in a given site-year was replicated two or three times in agroforestry conditions and two or three times in full sun conditions. Depending on the geometry of the agroforestry field, there was one (farmer's field, field 13B at INRA experimental station), two (field 15A at INRA experimental station) or six (Restinclières estate) micro-plots transversally laid out between two rows of trees. The micro-plots were 1.55 m wide and between 7 and 10 m in length, yield components were measured on a subset of the micro-plot that was harvested manually (0.5 m x 0.5 m, 0.75 m x 1 m or 1 m x 1 m depending on the site and year), and the rest of the micro-plot was harvested with a combine harvester. Measured variables included measurements of plant growth, development, and yield, of tree phenology and microclimate (Table 5).

Table 4. Genotypes tested in each of the three sites in each of the three years. A cross indicates that the genotype was tested in the site-year both in agroforestry and full sun conditions, with 2 to 3 replicates. (mpl = modern pure line, pop = population, apl = ancient pure line)

Code	Genotype	Type	2015			2016			2017
			Farmer	INRA	Restin-clières	Farmer	INRA	Restin-clières	INRA
1	LA1823	mpl	x	x	x	x	x		x
2	Clovis	mpl	x	x	x		x	x	x
3	2007D001.37	mpl		x					x
4	2007D023.655	mpl		x			x	x	x
5	2007D020.602	mpl		x					x
6	2007D003.109	mpl		x		x	x		x
7	2004D367.667	mpl		x					x
8	2004D326.262	mpl		x	x				
9	2007D010.255	mpl		x		x	x	x	x
10	Pop F2	pop	x	x	x			x	x
11	Pop Algérie 1	pop	x	x	x	x	x		x
12	Pop Algérie 2	pop	x	x		x	x		x
13	Pop Algérie 3	pop	x	x	x		x		x
14	Pop F2 + lég Salernes	pop			x	x	x		
16	PopF2 + leg AMPUS	pop					x		
20	Pop F3	pop	x	x					
22	Pop F3 + lég Mauguio	pop	x			x	x		
23	Pop F3 + lég Salernes	pop			x				
38	Perfcom28	mpl		x	x				
40	Perfcom7	mpl		x					
43	RG425	apl		x			x		x
45	RG137	apl					x		x
47	Perfcom4	mpl		x					
50	Perfcom32	mpl		x					
52	Perfcom3	mpl		x					
53	Perfcom34	mpl		x	x				
54	L3534	mpl		x	x				
55	Lign1à18_Pop_PMG	pop	x	x			x		
56	Lign37à54_Pop_PROT	pop	x	x		x	x		
57	Lign55à72_Pop_Sécheresse	pop		x			x		
58	Lign19à36_Pop_HR	pop	x	x		x	x		
59	Pop NIRS 73	pop					x		
77	EL KHROUB 06	apl					x		
79	EL KHROUB 10	apl					x		
88	Oued Zenati	apl			x				
100	Claudio	mpl				X	x		
101	Dakter	mpl				x	x		
102	SURMESURE	mpl					x		
266	RG 266	apl					x		
534	RG534	apl							
535	Amel 1	pop					x		
537	KARIM	pop					x		
538	La MERCI	pop					x		
539	Mourhad	pop					x		
540	Pop Caizergues	pop					x		

Table 5: Description of the measurements taken

Component	Description of measurements
Plants	• Components of yield: number of plants/m^2, number of tillers/plant, number of spikes/tiller, number of grains/spike, 1000 kernels weight, and grain yield • Growth and development : plant height and phenology
Trees	• Bud break dates
Microclimate	• Hemispherical photographs and/or radiation measurements (PAR sensors at INRA experimental station, pyranometers at Restinclières estate) to quantify light interception by trees • Soil and air temperature and humidity.

5 Results

Due to severe problems of predation by ants in 2015 and horses (escaped from a nearby meadow) in 2016, no measurements could be made in the farmer's field. Therefore, the following results concern only the experiments carried out at Restinclières and the INRA experimental station.

5.1 Light available for the crops

Crops under agroforestry conditions received between 40 and 75% of the light available in full sun conditions, with a high variability between sites (different tree species and different tree row orientations). There were also differences between periods of the year due to tree phenology (e.g. date of budbreak for deciduous trees or period of leaf flush for evergreen trees). The proportional light observed during each period at Restinclières and INRA experimental station is given in Table 6.

Table 6: Proportion of light (sum over the period) available to the crops in agroforestry in comparison with the full sun condition at different periods and different sites. M: measured with light sensors, C: calculated through analysis of hemispherical photography.

Site	Period	2015		2016		2017	
		Dates	Proport-ion light (%)	Dates	Proport-ion light (%)	Dates	Proport-ion light (%)
Restinclières	Before budbreak	12 Jan 15-9 Apr 16	M: n.a. C: 55%	2 Nov 15-1 Mar 16	M: 55% C: 70%		
	After budbreak	9 Apr 16-30 Jun 16	M: 41% C: 40%	1 Mar 16-6 Jul 16	M: 50% C: 42%		
INRA station (low density trees : AF)	Winter	19 Dec 14 30 Mar 15	M: 65%	18 Nov 15-30 Mar 16	M: 62%	3 Dec 16-30 Mar 17	M: 62%
	Spring	1 Apr 15-26 Jun 15	M: 70%	1 Apr 16-25 Jun 16	M: 75%	1 Apr 16-26 Jun 17	M: 70%
INRA station (high density trees: AF+)	Winter	19 Dec 14 30 Mar 15	M: 45%	18 Nov 15-30 Mar 16	M: 44%	3 Dec 16-30 Mar 17	M: 47%
	Spring	1 Apr 15-26 Jun 15	M: 45%	1 Apr 16-25 Jun 16	M: 44%	1 Apr 16-26 Jun 17	M: 44%

5.2 Crop phenology

Generally, the crops developed more slowly in agroforestry conditions than in full sun conditions. The following observations were made for each site-year:

In Restinclières:

- In 2015, the wheat under the poplar reached the BBCH GS30 (1 cm head) quicker than the wheat in the full sun. However after 28 May 2015, the development of wheat under full sun was more advanced, and maturity was reached 10 days earlier in full sun than under the poplars.
- In 2016, development was always quicker in full sun than under the ash trees, and maturity (GS89) was reached 7 days earlier in full sun than under the ash trees.

At INRA experimental station:

- In 2016, before booting stage (GS40), the development of plants was not significantly different between the full sun and agroforestry treatments. However, after the booting stage, plants in full sun developed faster than in the agroforestry plots, and no difference was found between the "AF" and "AF+" plots.
- In 2017, durum wheat grown under agroforestry condition showed a slower phenology compared to full sun conditions: from 2 to 9 days according to the stage considered and the cultivar observed. This lag increased with increasing shade level: with the "AGF+" (- 55% PAR) treatment taking an average 8 days more than the control to reach each maturity while AGF (-33% PAR) took about 3 days more than the full sun control. However, the magnitude of this slowing down of phenological development within agroforestry was highly variable among genotypes (from 0 to 14 days of difference).

5.3 Crop yield and yield components

Crop yields ranged from 0 (variety L3534 did not germinate at all) to 5.14 tonnes of dry matter per hectare (Figure 7). Crop yields in Restinclières were lower than typical commercial yields due, in part, to the use of old varieties although these varieties can perform quite well at INRA experimental station under organic agriculture. At the two sites, the mean yield in 2015 (1.21 t/ha) was very low due to unfavourable conditions for sowing (floods delayed sowing until December at INRA experimental station and January at Restinclières). In 2016, the yields were average (1.94 t/ha) while in 2017, yields were higher than average (2.68 t/ha).

Crop yields was significantly reduced in agroforestry conditions, and even more so under AF+ (unpruned dense olive grove). However, particularly in 2015, some cultivars performed better in the agroforestry than the control areas, suggesting that the agroforestry mitigated the negative impact of the delayed sowing (Figure 8).

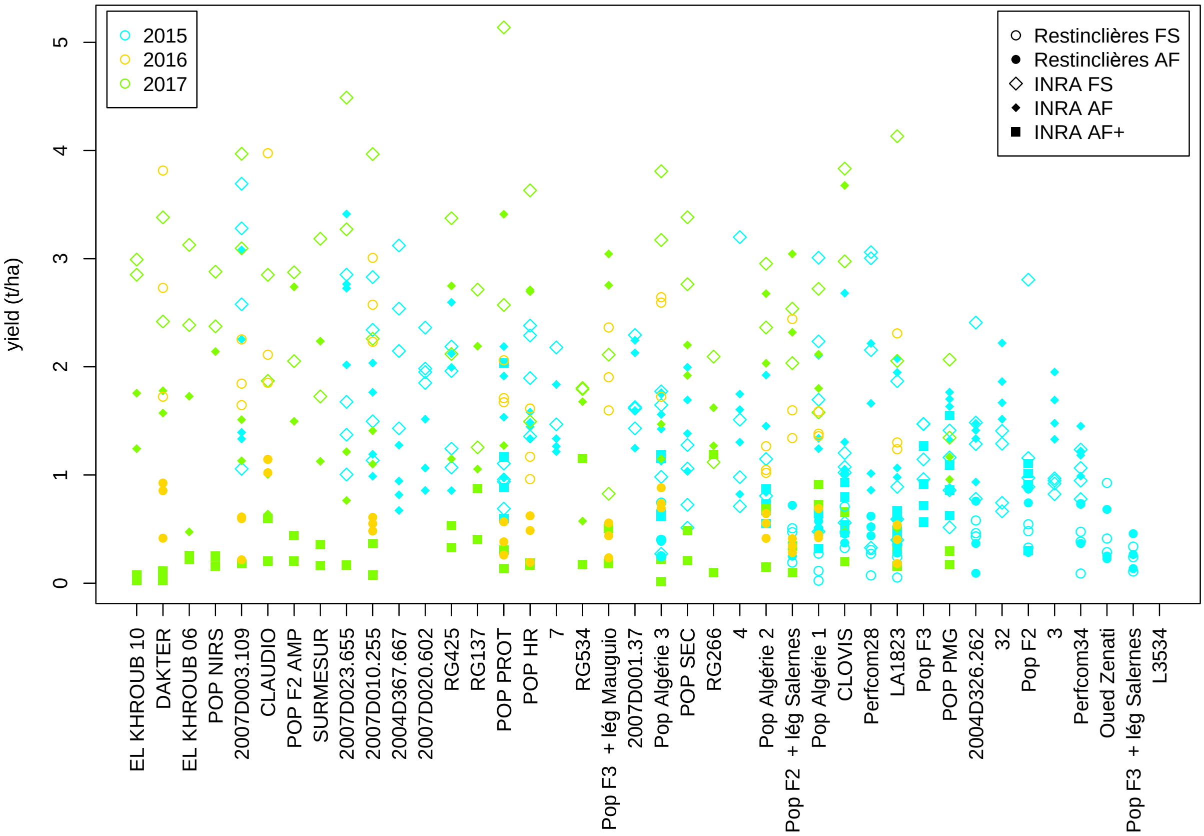

Figure 7. Yield observed for each cultivar in different conditions (site, year, agroforestry conditions). Cultivars are ordered according to their mean yield in full sun conditions. Data from INRA 2016 is not presented in the graph.

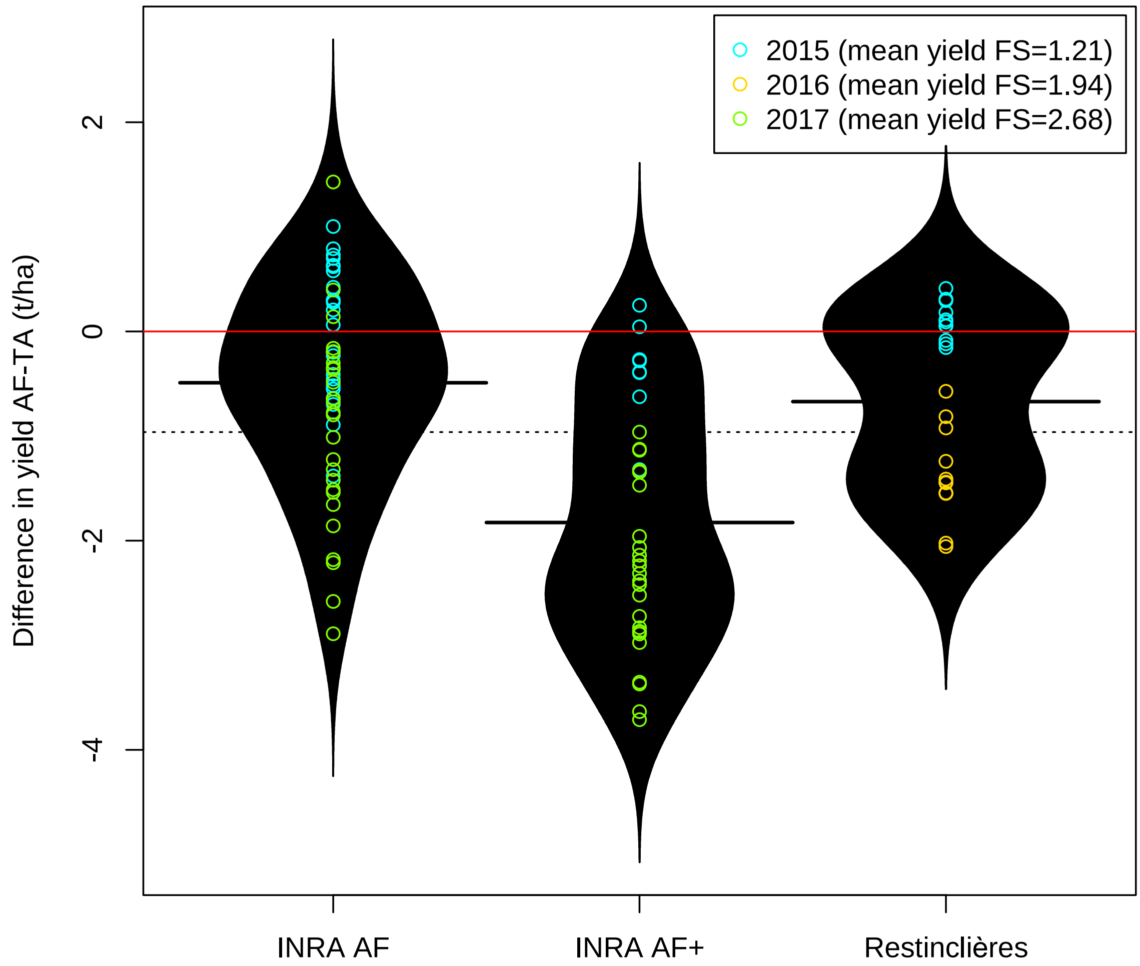

Figure 8. Beanplots of the difference in yield between agroforestry and full sun control for each of the three sites: above the red line, yield is higher in agroforestry than in full sun while below the line, yield is reduced in agroforestry compared to full sun conditions. The width of the bean indicates the density distribution, the dots indicate the individual values (one dot = one cultivar in one year in one site), the short horizontal segments indicate the mean for each site, and the dotted line indicates the overall mean. Data from INRA 2016 is not represented in the graph.

After taking into account the site and year effect, and computing the percentage of extra loss (or gain) due to cultivation in agroforestry conditions, it appears that some cultivars perform better in agroforestry than in full sun conditions: cultivars 2007D001.37, RG425, 2007D023.655, Pop Algérie 2, and Pop F2 (codes 3, 43, 4, 12, and 10).

Yield decomposition showed that the yield components that the number of plants/m^2 was significantly increased in agroforestry. The number of spikes per tiller and the weight of one grain were increased in the AF treatment compared to full sun conditions, but decreased in AF+ (unpruned dense olive orchard) and the number of tillers per plant and the number of grains per spike were significantly decreased in agroforestry (AF and AF+). The mean for all cultivars of the different steps of yield formation in each site, year and condition are represented in Figure 9.

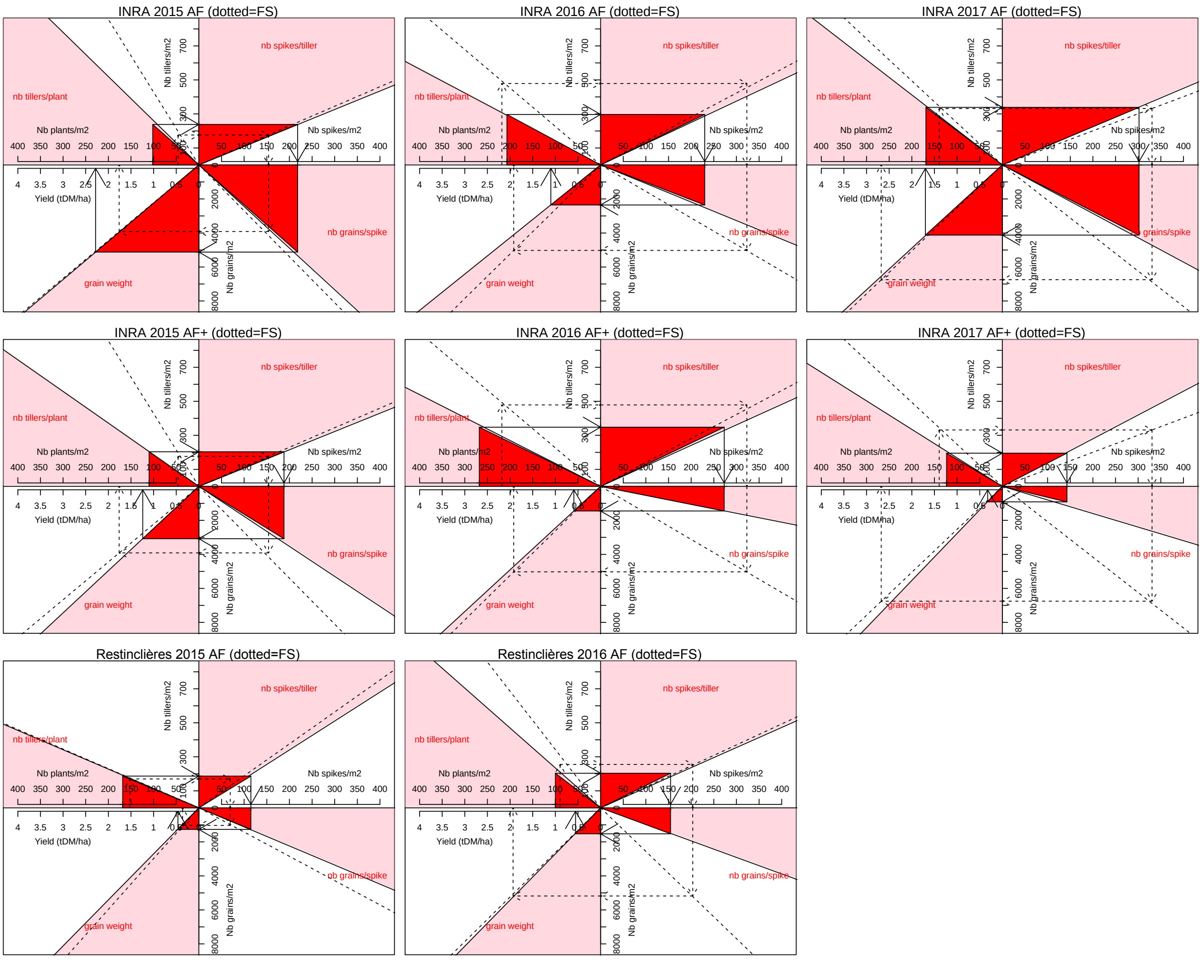

Figure 9. Yield formation in agroforestry (solid line) and full sun control (dotted line) in eight site-years, averaged across all cultivars. Each graph represents yield formation, turning clockwise from the number of plants per square meter (upper left abscissa) to the yield in tons of dry matter per ha (lower left abscissa) by multiplying the yield components (red angles) number of tillers/plant, number of spikes/tiller, number of grains/spike and grain weight.

5.4 Variance to mean relationship

In order to identify cultivars that have a good yield and that perform well across different growing conditions, the variance of yield for each cultivar was plotted against the mean yield of the cultivar (Figure 10). This allowed identifying three cultivars with a high yield and low variance of yield: 2007D001.37, 2007D020.602 and Perfcom7 (numbers 3, 5 and 40 in Figure 10). However, these cultivars were only tested in one site over one year. Other cultivars that could be interesting for their robustness are Lign1à18_Pop_PMG and RG425 (numbers 55 and 43).

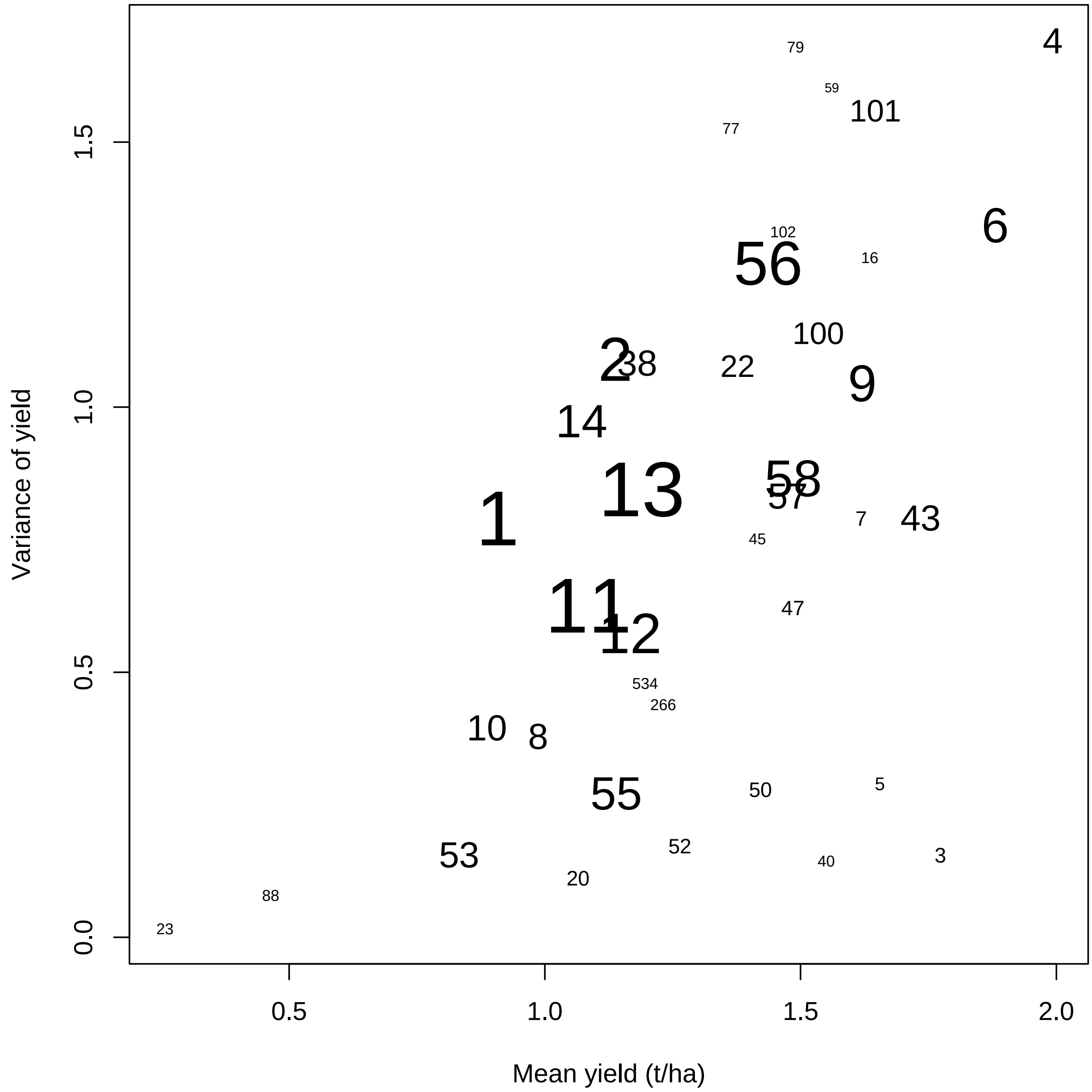

Figure 10. Mean and variance of yield of the tested cultivars (the numbers refer to the code in Table 4). The size of the number indicates the number of micro-plots in which the genotype was tested (from 6 to 30).

6 Conclusions

The principal lessons learnt from the measurements and observations of different cultivars in agroforestry and full sun conditions include:

- The detrimental effect of tree competition against crops was almost always larger than the potential beneficial effects of agroforestry on crop growth (e.g. facilitation for water, microclimate protection against extreme temperatures, increased biodiversity allowing greater biological control of pests, increased soil fertility). This can be seen from the comparison of yields in agroforestry vs full sun conditions. However, this does not mean that agroforestry is less productive than separate agriculture and forestry, as the productivity of agroforestry systems also includes the production of wood or fruits from the trees (olive production was monitored at INRA station, but the results have not been analysed yet).
- The yield components that were most affected by cultivation in an agroforestry system, relative to a control, were the number of grains per spike, and, to a lesser extent, tillers per plant.
- There was a large variability in the suitability of cultivars to cultivation in agroforestry conditions: yield differences in agroforestry compared to full sun conditions ranged from -62% to +77 %.
- Old varieties and populations were not systematically more adapted to agroforestry than newer or pure-line cultivars.

7 Acknowledgements

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