DIVERSIFOOD

Embedding crop diversity and networking for local high-quality food systems

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Report on intercropping trials with underutilised genetic resources

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- **X PU:** Public (must be available on the website)
- ☐ **CO:** Confidential, only for members of the consortium (including the Commission Services)
- ☐ **CI:** Classified, as referred to in Commission Decision 2001/844/EC

Abstract

Species mixtures constitute one of the major strategies for crop diversification. However, despite high research interest and a large body of literature, their implementation in farming system is extremely limited. In DIVERSIFOOD several combinations of grains and legumes have been tested, according to the hypothesis that the phenotypic diversity of underutilised genetic resources could facilitate the constitution of successful associations.

Intercropping trials in DIVERSIFOOD have dealt with systems of concurrent sowing and harvest of both companion crops. Varietal adaptation to the mixed cropping emerges from the trials, and narrow genetic diversity for traits as growth cycle length and growth habits is one of the main constraints to successful mixed crops.

The participatory exploration of underutilised genetic resources can be essential in facilitating the constitution of successful crop mixtures: distributing a large panel of phenotypic diversity in farmers' fields can trigger decentralised breeding and selection programmes for adaptation to local conditions, which during DIVERSIFOOD have been started.

Contents

Introduction

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Species mixtures constitute one of the major strategies for crop diversification. However, despite high research interest and a large body of literature, their implementation in farming system is extremely limited. In DIVERSIFOOD several combinations of grains and legumes have been tested, according to the hypothesis that the phenotypic diversity of underutilised genetic resources could facilitate the constitution of successful associations.

Examples of underutilised genetic resources involved.

Lupins in Switzerland and the Netherlands. Both the Louis Bolk Institute in the Netherlands and the FiBL in Switzerland have focused on the inclusion of Lupins in intercropping with Cereals. In Switzerland, Lupins do not have a tradition of production, neither have they been introduced to the country from the northern neighbour Germany, the western neighbour France nor from the southern neighbour Italy, where since Roman times lupins have been cultivated for human consumption. Similarly, it is highly underutilised in the Netherlands. In both countries, there is however opportunity to integrate this crop for human consumption, animal consumption and as a green manure.

Field beans in North Western Europe. Traditionally, field beans (*Vicia faba*) were cultivated in Northern Europe, including the UK and The Netherlands for human food and especially animal feed purposes. However, this crop, as many other pulses, has been largely marginalised in the Netherlands as protein sourcing for animal feed has been largely dominated by soybean imports. In the UK, field bean production is important for feed and for export but is however very limited in organic farming and does not cover for local requirements. Increased production of home-grown proteins is an increasingly recognised priority for ensuring sustainability in food and cropping systems, and field beans may have an important role to play in this trend.

Wheat, as a major crop species, includes a huge diversity of underutilised germplasms. Landraces, old, historic varieties that do not fit modern industrialised cropping systems, as well as modern heterogeneous populations have been focused in the UK, Italy, the Netherlands, Spain and France. Main motivation for inclusion of these underutilised genetic resources is the seek for more stable and resilient yield and quality in low-input and organic systems, which modern varieties, often bred for response to high inputs, cannot reliably ensure.

Motivations for intercropping with underutilised genetic resources.

Beyond all the obvious but theoretical benefits of species diversity for improved resource use and stability etc., an intercropping based on concrete expectations. Examples are:

- Improving the Land Equivalent Ratio: basically, every intercrop is aimed at this, meaning that the yield of 1ha of ‘crop A’ mixed with ‘crop B’ is higher than the yield of ½ha of ‘crop A’ and ½ha of ‘crop B’
- Improving the use of nutrients, e.g. mixing cereals and legumes to exploit N-fixation, although, to optimise this, management must be adapted: e.g. if concurrently sown legumes are ploughed in-between wheat rows, wheat yield and/or quality are improved depending on when the legume is ‘killed’
- Improving competition against weeds
- Improving resistance/avoidance of pests and diseases and/or relationship with ‘associated functional biodiversity’
- securing a harvest in unpredictable years (if one crop fails, the other will yield)

Expectations from the DIVERSIFOOD intercropping trials are varied and seem to cover most of the above (tab. 1).

Tab. 1. Examples of expectations from specific crop mixtures tested in DIVERSIFOOD

Location	Species mixed	Key benefits expected
Southern Spain (CSIC)	Wheat/Spelt with Field Bean populations	– Improving faba bean resilience and yield stability through the use and support of bee pollinators. – Enhancing the management of bee pollinators as an agricultural input.
United Kingdom (ORC)	Wheat population with field beans	Improve wheat quality, support field bean production and protection from pest and diseases, improve competitiveness against weeds. (In addition, intercropping cereals with other pulses is in general also aimed to reduce legumes lodging or other similar mechanical functions)
France (ITAB)	Wheat with field beans and forage peas	Decrease of the diseases of legume, improving cereal nutrition, decrease lodging of cereal, testing the LER
Switzerland (FiBL)	Oats and triticale with white and blue lupins	– Weed suppression especially with blue lupin – risk insurance (if one crop fails totally, farmer has still something to harvest and no weed problem in the proceeding crop – reduce lodging of the lupins esp. if they have undetermined growth habit – reduce disease pressure due to mixed cropping
Italy (UNIBO)	Wheat (bread and durum) with Chickpeas	Improving the Land Equivalent Ratio Improving the nutritional properties of the species involved in the intercropping system

Main threads of results and outcomes

The intercrops tested in DIVERSIFOOD were based on concurrent sowing, and aimed at simultaneous harvest, of both crops in combinable, arable systems. This creates very unstable systems, as growth cycles of component crops overlap in full, including the most stress-exposed stages, with suboptimal complementarity in resource use. As the reader will appreciate in the factsheets presented in this document, the DIVERSIFOOD experiences with intercropping include a significant series of failures and/or disappointing results, difficulties with harvest, intercrops destroyed by diseases or climatic stresses. This has to be taken as an outcome in itself, because these 'failures' highlight the main challenges for future innovation with intercropping.

In fact, the most consistent outcome emerged from the DIVERSIFOOD intercropping trials is the impact of component crops phenotypes on the performance of intercrops. This confirms and strengthens the scientific argument of 'varietal adaptation to intercropping' and the need to select phenotypes adapted to crop mixtures. Despite widespread scientific awareness, few efforts have been made so far in the direction of breeding for intercropping. **Diversification of growth habits and growth cycles** in component crops are two main directions for mixed cropping adaptation that can be highlighted from our trials and should be taken into account in existing breeding programmes as well as in mixed cropping system planning, as summarised in Tab. 2.

Tab. 2. Main directions for breeding and system design in cereal/pulses intercropping

	Breeding goals	**Intercrop design**
Growth habits	Reconsider growth habits (branching and indeterminate growth for legumes, straw height for cereals) to enhance complementarity and benefits of mixed cereal-legume intercrops	Consider alternatives to combine harvest, such as whole crop harvest for cereals with late indeterminate lupins, to maximise weed suppression and other benefits
Growth cycles	Seek simultaneous ripening to facilitate combine-harvest	Consider alternatives to concurrent sowing to minimise crop-crop competition and synchronise ripening times.

It is essential to recognise that every intercropping system can be so specific to local conditions and needs, that the needed "intercropping-adapted varieties" would be such a high number that no conventional breeding programme could sustainably deliver. This is where the participatory exploration of underutilised genetic resources can be essential in facilitating the constitution of successful crop mixtures: distributing a large panel of phenotypic diversity in farmers' fields can trigger decentralised breeding and selection programmes for adaptation to local conditions, including mixed crops and their management. The intercrop itself be the breeding ground, where selection within populations of mixed species can take place time- and cost-effectively.

Oats, Triticale and Wheat with Lupins

Oats and triticale with lupins in Switzerland

FiBL – Switzerland

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Abstract

Lupins can have a role in legume production in Switzerland, including in mixed cropping with cereals. In three subsequent years, four trials, two with blue lupin (*L. angustifolius*) and two for white lupin (*L. albus*) were performed in Rümikon (CH). Blue lupin trials showed that triticale is financially the best partner. However, oats resulted in better weed competition. Cultivars Boregine and Rumba yielded most, but Boruta showed best lodging resistance and homogeneous maturity. For white lupins, the best partner so far is winter triticale. No complete anthracnose resistant has been detected so far. Performance of cultivars is levelled over the years, but Feodora has best combination of early maturation and lodging resistance.

Location(s)

Rümikon, High Rhine Valley, Kanton Aargau, Switzerland, 2015, 2016, 2017, 2018

List of accessions

See attachment

List of traits assessed

Crop development and agro-ecological performance (phenology, weeds, diseases, …)		
Trait	**How it has been assessed**	**Type of data available**
Field emergence (2016, 2017, 2018)	Counting of two representative meters of row in each plot, then calculated for plants/m^2	Continuous quantitative
Competition against weeds	Scoring 1-9 on the field in May (2015); estimating percentage of crop plant ground coverage in May (2016,2017, 2018)	quantitative - scoring
Lodging score	Scoring 1-9 on the field	quantitative - scoring
Phenology of crop and partner	Scoring according to BBCH	Quantitative - scoring
Disease symptoms of anthracnose in lupins	Scoring 1-9 on the field	quantitative - scoring

Trial background and evolution

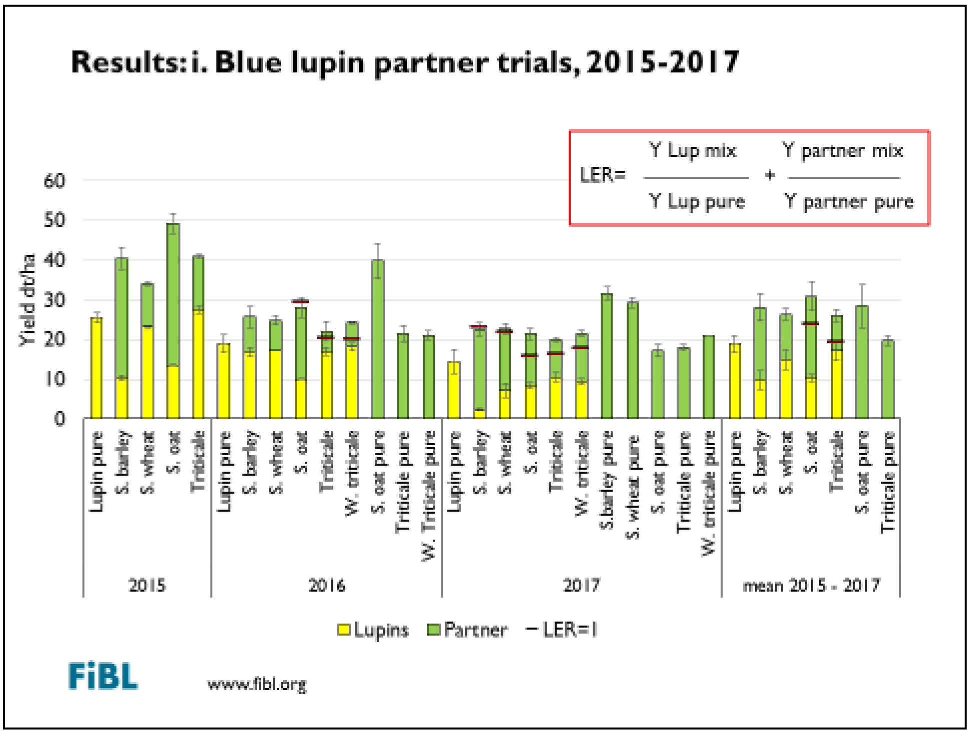
FiBL took the initiative to enhance grain legume diversity in Switzerland. Mixed cropping had proven well in the FiBL extension department on farm trials with peas and barley. Mixed cropping was adopted as an opportunity to reduce weed problems. Cultivars and cropping partners had therefore to be tested. Blue and White lupins had to be treated in separate trials due to different harvest dates. For each of these, one cultivar trial with only one oats partner and one partner trial with one or two lupin cultivars were designed. In 2018, a combined cultivar-partner trial with triticale was established on two sites for White Lupin. For Blue Lupin, five farmers were encouraged to perform mixed cropping trials with blue lupins and (mostly) oats on their fields.

Trial design and management

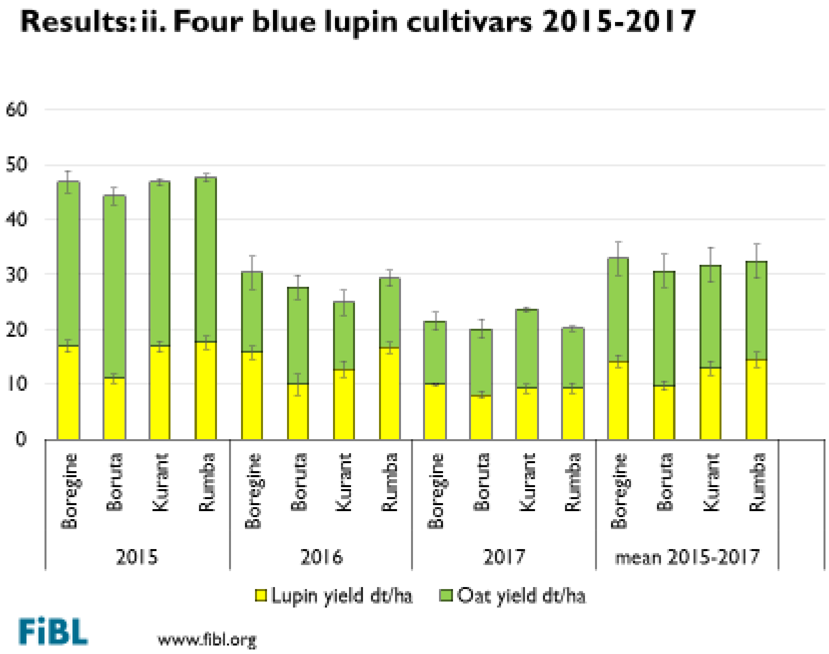
Randomised block design with mostly 3 replicates. No weed control was carried out in 2015 and 2016 except hand weeding of single tall weed plants. In 2017 and 2018, a combination of hoe and currycomb was used for mechanical weed control once in May . Statistical analysis is ongoing using mixed model of the randomized complete block design for each environment and across environments with the programme jmp.

Main results

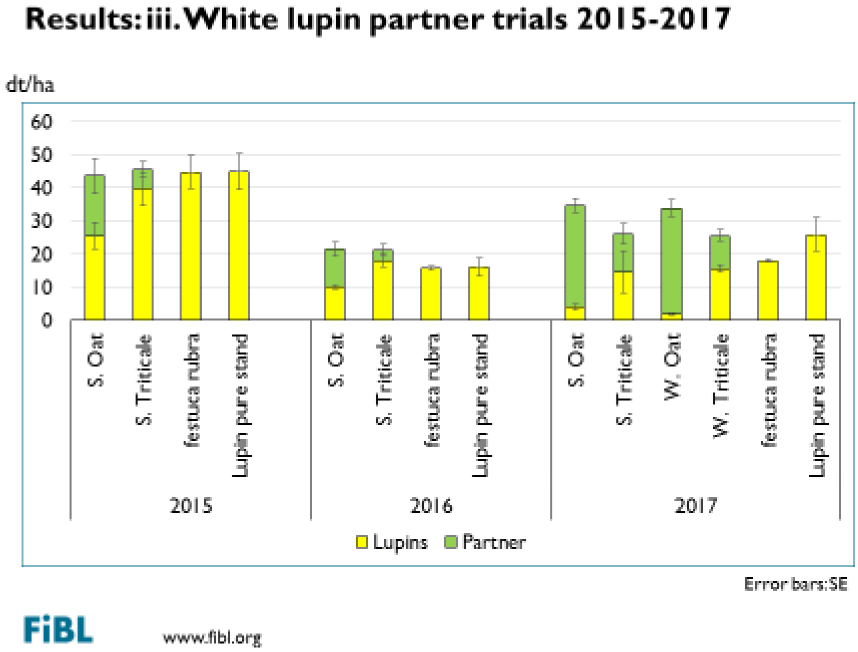
Blue lupin partner trials: in 2015, total yield in mixtures was 35-50 dt/ha with 10-30 dt/ha of lupins. In the other two years, yields were much lower due to unfavourable weather conditions (2016) and late sowing, pod shedding and weed competition (2017). On average, mixtures with oats have the highest total yield and LER, but the lupin share is sometimes < 30% (threshold for Swiss federal direct payments).



Blue lupin cultivars: The three best lupin cultivars rendered 10-20 dt/ha with additional 10-30 dt/ha of oats, depending on the year. The determined cultivar Boruta yielded less but showed a far more uniform maturation and had the best lodging resistance. The low yield level was also due to a strong thunder storm just before harvest in 2017 resulting in severe scattering of lupin seeds.

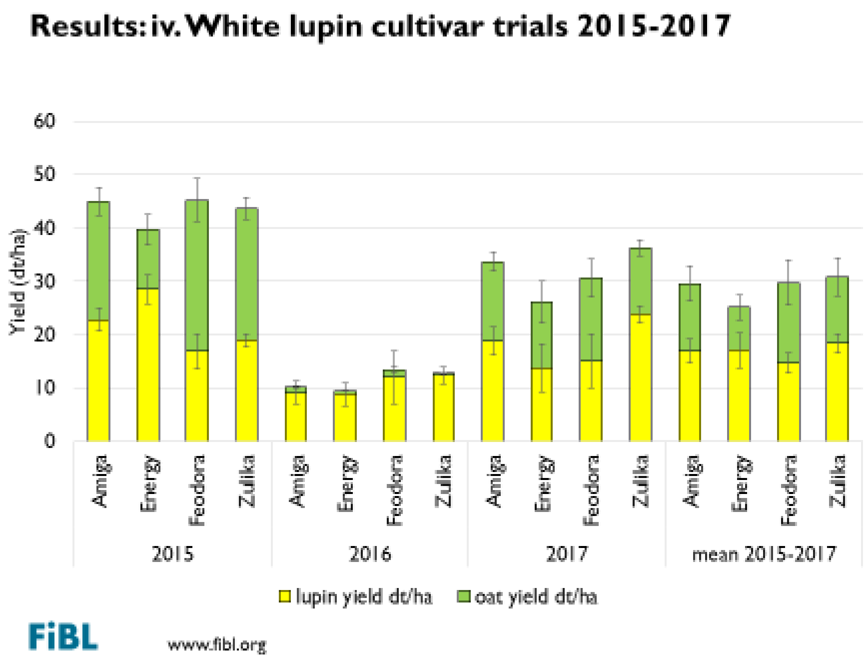


White lupin partner trials: The hot and dry summer of 2015 resulted in yields of ca. 45 dt/ha lupins in pure stand. Over the three years, the best but still not ideal partner was triticale, especially winter triticale which had best maturation synchronization with white lupins. Early sowing is important to stimulate vegetative development of lupins and winter triticale. The oats cultivars used in the partner trial were more competitive than cv. Buggy which was used in the cultivar trial. White lupins grown in pure stand still produce highest total yield but are prone to late weed invasion.



White lupin cultivars: The late, vigorous cultivar Energy yielded most in the dry summer of 2015 but least in 2016. Cultivar differences are levelled over the years. Zulika had the best average yield of about

18dt/ha with additional 10 dt/ha of oats. In spite its lower yield, cv. Feodora showed a far more uniform maturation and had the best lodging resistance.



Discussion

Mixed cropping helped ensure yields in less favourable years to lupins, especially in blue lupins. Sowing date was earlier in 2015, one week later in 2016 and two weeks later in 2017 (see attachment). The data suggest that **early sowing dates are crucial for a good blue lupin yield**. Oats and barley show considerable variation over years and competed lupins. Triticale produced reliable yields and a lupin share > 30% of the harvest mixture. Wheat was also an interesting partner but is generally not recommended as a companion crop for lupin because of high prevalence in the crop rotations in Switzerland.

For white lupin, it is more difficult to find a good mixed cropping partner due to its late maturation. We will continue to test undersowing of lupins with grasses or biennial plants that form a rosette in the first year (eg., *Isatis tinctoria*). In both blue and white lupin, we prefer the determined, early maturing cultivars - in spite of their lower yields - because of more reliable maturation and lodging resistance.

Conclusion and next steps

The financially best combination of blue lupin is cv. Boregine or Rumba mixed with triticale. Hovewer, oats had a better LER, better weed competition and lodging resistance, and cv. Boruta had more levelled maturation and better lodging resistance. Blue lupin mixed cropping can be recommended in spite of low yields in our trials due to good multiple year results of the FiBL extension department. Early seeding is crucial for a good yield. The best partner for white lupin so far is winter triticale, sown as early as possible. For white lupine, no cultivar could be identified with sufficient anthracnose resistant. Though rather low yielding, cv. Feodora has reliable early maturation, thus less prone to anthracnose, and lodging resistance. We aim to create early, anthracnose resistant pre-breeding lines.

SUPPLEMENTARY MATERIAL

Accessions list

		LUPIN	OAT
2015	White lupin cultivar trial	Amiga	Buggy
		Baer BLU 18 (22)	Buggy
		Baer BLU 17 (281)	Buggy
		Zulika	Buggy
		Feodora	Buggy
		Baer 2011-5-BL 411	Buggy
		Energy	Buggy
		Baer 2011-5-BL 431	Buggy
2016	White lupin cultivar trial	Feodora	Buggy
		BLU 27-16	Buggy
		Energy	Buggy
		Figaro	Buggy
		Amiga	Buggy
		BL 431	Buggy
		BLU 26-15 B	Buggy
		Zulika	Buggy
2017	White lupin cultivar trial	BLU 25	Buggy
		Figaro	Buggy
		Victor	Buggy
		Energy	Buggy
		Dieta	Buggy
		Alba	Buggy
		Butan	Buggy
		Feodora	Buggy
		Amiga	Buggy
		Zulika	Buggy

Year	Trial subject	Accessions of lupin tested	Partners tested
2015	Blue lupin partner trial	Boruta	Cameline
		Boruta	flowering weed mix
		Boruta	Festuca rubra
		Boruta	S. barley Eunova
		Boruta	S.oat Buggy
		Boruta	Triticale Trado
		Boruta	S. wheat Fiorina
		Boruta	no partner
		Tango	Cameline
		Tango	flowering weed mix
		Tango	Festuca rubra
		Tango	S. barley Eunova
		Tango	S.oat Buggy
		Tango	Triticale Trado
		Tango	S. wheat Fiorina
		Tango	no partner

		no lupin	Triticale Trado pure stand
		no lupin	S. oat Buggy pure stand
2016	Blue lupin partner trial	Boruta	Festuca rubra
		Boruta	S. barley Eunova
		Boruta	S.oat Buggy
		Boruta	S. oat 395-12
		Boruta	Triticale Trado
		Boruta	W. Triticale ARTI 8
		Boruta	S. wheat Fiorina
		Boruta	no partner
		no lupin	Triticale Trado pure stand
		no lupin	W. Triticale ARTI 8 pure stand
		no lupin	S.oat Buggy pure stand
		no lupin	S. oat 395-12 pure stand
2017	Blue lupin partner trial	Boruta	Festuca rubra
		Boruta	S. barley Eunova
		Boruta	S.oat Buggy
		Boruta	S.oat Buggy
		Boruta	Triticale Trado
		Boruta	W. Triticale ARTI 8
		Boruta	S. wheat Fiorina
		Boruta	no partner
		no lupin	Triticale Trado pure stand
		no lupin	W. Triticale ARTI 8 pure stand
		no lupin	S.oat Buggy pure stand
		no lupin	S. barley Eunova pure stand
		no lupin	S. wheat Fiorina pure stand

Wheat and lupins in the Netherlands

Louis Bolk Institute

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Abstract

Mixed cultivation of lupin with cereals is limited in the Netherlands because of lack of simultaneous ripening. The aim of the trial was to better understand how to breed for mixed cropping of lupin with cereals. For that reason, populations of lupins were sown mixed with wheat (the most suitable cereal crop in the Netherlands for mixture with lupin) to understand whether and how selection under such conditions can result in a lupin population that is better suited for mixture with wheat. If successful, such procedure could mean a simple and cheap method for breeding lupin for mixed cropping. First experiences described.

Location(s)

2016: Olst

2017: Kraggenburg

2018: Ens

List of accessions

2016: spring wheat population Convento C with 2 breeding populations (one branching and one non-branching) of white lupin

2017: spring wheat variety Lavett with 3 breeding populations (2 branching, one non-branching) of white lupin

2018: spring wheat variety Lavett with selections conducted in 2017 of 3 breeding populations (2 branching, one non-branching) of white lupin

List of traits assessed

Crop development and agro-ecological performance (phenology, weeds, diseases, …)		
Trait	**How it has been assessed**	**Type of data available**
Earliness in ripening	Counting and harvesting ripe plants	Numerical
Weed cover development	Visual	Score 1-9
Disease development	Visual	Score 1-9

TRIAL BACKGROUND AND EVOLUTION

Initiative: FIBL

Key decision: instead of working with oat (done in Switzerland), it was decided to work with wheat as partner crop in the Netherlands as this is a more common partner crop in the Netherlands.

TRIAL DESIGN AND MANAGEMENT

Sowing: by machine, adjacent to trials with wheat population. Each population was sown in a single plot because of limited seed availability. In 2017 harvesting was done by hand (only the early ripening lupin plants). In 2018 no difference in ripening was observed due to prolonged hot and dry weather, and all plots were harvested mechanically.

MAIN RESULTS

Major outcomes: Right choice of partner crop.

In 2016, it appeared that the wheat population grew too tall (approx. 1.1m) and shaded the lupin too much. The lupin flowered but did not set seed. In 2017, a somewhat shorter wheat variety was chosen as partner crop (approx. 1m tall). All thee lupin populations set seed.

In 2018, the aim was to observe whether there a selection effect could be observed as the result of selection in 2017. No differences were observed in time of ripening within the selections of the populations. This might be a selection effect, but also a result of the prolonged hot and dry weather for three months (including the ripening phase).

Advantages and disadvantages of branching a non-branching lupin

In 2017, the non-branching population had pod set on a taller position in the plant compared to the branching populations, which may be an advantage with harvesting. Also, the tendency to set a further stage with flowers and pods was minimal.

The two branching populations did develop a second flowering stage but did not produce many pods in the second stage. An advantage of the branching populations is that they have a more closed canopy compared to the non-branching population, in that way contributing to weed suppression.

Earliness of ripening seems unrelated to the architecture of the plants (branching or non-branching).

DISCUSSION

Mixed cultivation of lupin with cereals is limited in the Netherlands because lack of simultaneous ripening. The aim of the trial was to better understand how to breed for mixed cropping of Lupin with cereals. For that reason, populations of lupins where sown mixed with wheat (the most suitable cereal crop in the Netherlands for mixture with lupin) to understand whether and how selection under such conditions can result in a lupin population that is better suited for mixture with wheat. If successful, such procedure could mean a simple and cheap method for breeding lupin for mixed cropping. First experiences are that the selection procedure for populations of lupin is different from that for populations of wheat. To improve simultaneous ripening, the earliest ripening lupin plants need to be selected by hand (unlike machine harvesting for wheat). Non-branching and branching types have both advantages and disadvantages, which need to be further investigated in the near future.

CONCLUSION AND NEXT STEPS

This approach of breeding lupin for mixed cropping may have potential. More research is needed on the advantages and disadvantages of branching and non-branching types.

Wheat and Field Beans (*Vicia faba*)

Field bean and spelt in Southern Spain

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Abstract

A bi-crop system, faba bean-spelt, was tested to compare two cropping management systems (alternate strips intercropping vs. monoculture). In this bi-crop pollination environment, we explored different faba bean genepools derived from two breeding approaches, selfing *vs.* open-pollination, and with contrasting levels of heterogeneity and heterozygosity. Our results showed that combining competitive gene-pools with intercropping and open-pollination approach allowed for higher yield components. Thus, open pollination is a method of crossing well adapted to farmer management as well as to site-particularities to make the beneficial effects of heterozygosity and heterogeneity available to farmers in a time-effective way.

Rationale

Faba bean is an enthomogamous partially allogamous crop with a mixed mating system. Two basic philosophies have been developed by faba bean breeders to deal with the partial allogamy of *V. faba*: (a) open-pollinated populations and (b) inbred line cultivars. Open-pollinated cultivars make the most of heterosis effects to enhance yield, yield stability and resistance to biotic and abiotic stresses. Faba bean plays an important role in the diversification of cropping systems by enhancing diversity of wild fauna, such as bee-pollinators. Populations with high level of heterozygosity and heterogeneity should be developed by using the services of pollen vectors, local wild bees. Intercropping management may reduce the visits of pollinators and consequently the insect-mediated outcrossing and increased selfing and, consequently, to increase or decrease yield stability and resistance to stresses mediated by heterosis.

From all mentioned above it is relevant to explore what are the overall effects on yield and yield determinants, when faba bean cultivars are grown under intercropping, as compared when faba bean cultivars are grown under monoculture, and to examine whether the promising genetic resources grown under intercropping system are different from those grown in monoculture.

List of accessions

Farmer spelt local cultivar + faba bean gene-pools from SOLIBAM. Faba bean genepools selection was based on: 1) Genetic structure: a) highly homozygous and b) highly heterozygous and 2) Potential response associated with the inter-play plant pollinator, a) independent (self-fertile), b) dependent (attractive for the pollinator) and c) better performance with pollinators excluded.

Faba bean: 28 (3 genepools x 2 genetic structures + local control (nationally popular cultivar) x 2 cropping systems (faba bean- sole +faba bean/spelt -1:1) x 2 replications in one location. The initial

synthesis of each gene pools involved different components selected from the world germplasm collection of the IAS (Cordoba, Spain) consisting of:

1) adapted Spanish local landraces;

2) synthetic and elite populations (based on agronomics performance and heterotic patterns as deduced from historical information from the IAS breeding program in order to increase heterosis mediated yield and resilience and

3) lines with specific traits as deduce from evaluation and characterization of the inbred line germplasm collection. The seed criterion was no importance of seed size and striking phenotypic diversity

4) Additionally, minor (tall and not tillering, potentially useful for avoiding lodging), equina and major entries (shorter and more tillering and greater seed size) northern European and Mediterranean region were also incorporate. Bulking of genetic resources has been carried out both under cages without pollinators (selfing conditions) and under natural open pollination environment allowing the visit of pollinators for three seasons

LOCATION(S)

On a farmer field in Córdoba (Culturhaza: 37°50'17.7"N 4°54'05.5"W), Spain. Soil with medium texture, water retention capacity and almost neutral or slightly alkaline pH.

CLIMATE

Table.1 Environmental seasonal climate variables for the tree growing seasons

Season	Growing season	Climate data			
		Average temperature ºC	Maximum temperature ºC	Minimum temperature ºC	Precipitation mm
Winter	15-16	10.57	16.75	5.17	3.20
Spring		16.61	23.14	10.68	7.58
Average		*13.59*	*19.95*	*7.93*	*5.39*
Winter	16-17	10.26	17.38	4.80	2.92
Spring		18.14	26.03	10.82	7.56
Average		*14.20*	*21.71*	*7.81*	*5.24*
Winter	17-18	9.34	15.60	4.28	6.85
Spring		16.02	22.99	9.68	3.53
Average		*12.68*	*19.30*	*6.98*	*5.19*

TRIAL DESIGN AND MANAGEMENT

The initiative of the trials was taken by the researcher according to the goals of the project. Traits to evaluate were chosen by the researcher based on the previous methodological approach derived from the project SOLIBAM and accepted by the farmer. In the farm, evaluation was done by the researchers helped by the farmer depending on the trait. Additionally, the farmer and other stakeholders, that have been involved occasionally, make their own observations while farming (health and vigour,

general disease incidence). The farmer and the other stakeholders shared their views and observations in meetings.

Field preparation and cultivation practices were conducted by the farmer applying local farmers' agronomic techniques. The gene-pools were hand planted in a randomized block experiment design, with two replications. Ten plants of each replication were analysed. Harvesting was done manually. Data were grouped into four groups according to the following criteria: (a) cropping system (intercropping *vs*. monoculture) and (b) breeding approach (open-pollination *vs*. self-pollination). Descriptors of central tendency, dispersion and variability were used. Two-factor ANOVA comparing cropping management x breeding approaches and gene-pool was performed each season. Data were subjected to multivariate Principal Component Analysis and Discriminant Function Analysis.

MAIN VARIABLES ASSESSED

Phenotypic variability in two super-categories was considered: agro-ecological traits potentially involved in the cropping management system adaptation and seed production patterns. Information on the agro-ecological and yield performance traits was given in D2.2 .

Crop development and agro-ecological performance (phenology, weeds, diseases, …)		
Trait	**How it has been assessed**	**Type of data available**
Branching from basal nodes	number of stems per plant	*quantitative*
Plant height (cm)	measured at near maturity from ground to the tip of the plant	*quantitative*
Leaf form size and shape	cm	*quantitative*
No specific incidence of any disease and pest was detected		

Crop productive performance (yield, yield components)		
Trait	**How it has been assessed**	**Type of data available**
Pods per plant	Number	quantitative
Seeds per plant	Number	quantitative
seed dimensions	cm	quantitative
seed weight	g	quantitative
seed yield	g	quantitative

MAIN RESULTS

ANOVA results (Table 2 in supplementary materials) illustrate the influence of gene-pool, cropping system x breeding approach on all yield components except seed length. Intercropping management and open-pollination breeding approach interactively increase the number of seeds per plant and per pod in the first and third growing season suggesting that intercropping intensifies the positive effect of outcrossing breeding scheme (breeding in presence of pollinators) in these determinants of yield. However, in the second growing season, plants grown in monoculture from the open pollination strategy produced the higher number of seeds per plant and per pod .

The effect of the cropping system x breeding approach interaction is however modified by the gene-pool on seeds per plant in the first season and on seeds per pod in the first and third seasons. The cropping system x breeding approach interaction did not impact seed size, although there was a significant gene-pool x cropping system x breeding approach interaction in the third season.

Discussion and Conclusion

Overall, our results suggest that intercropping and open-pollination approach may be the best strategy, although in stress environments, such as those of the second growing season, monoculture and open-pollination approach could be a better strategy.

Regarding faba bean cultivar development, open-pollination instead of selfing conditions should be used. Thus, it is important to conserve the quality of open natural pollination, by encouraging effective pollinators, particularly those insects which facilitate crosspollination. Moreover, our outcome prompted the development of cultivars that incorporate traits providing suitable floral resources. In addition, this strategy indirectly will benefit farmers by their contribution to the mitigation of pollinator decline.

Final benefits on yield components of crop system x open-pollination approach, however, may be influenced by the gene-pool. Our results highlight the importance of assessing cultivar-specific responses to the cropping system and breeding approach. Combining competitive gene-pools with intercropping and open-pollination approach allowed for consistently higher yield components. However, this study has only been performed during three growing seasons and other studies have to be undertaken to evaluate the long-term impact of intercropping compared to that resulting from monoculture.

Supplementary material

Table 2 - Mean per group (standard error) for yield determinants for the three growing seasons

Yield determinant	Growing Season	Intercropping		Monoculture	
		IO	**IC**	**SO**	**SC**
Seed length	15-16	1.66 (0.25)	1.66 (0.20)	1.66 (0.18)	1.65 (0.17)
	16-17	1.58 (0.02)	1.60 (0.02)	1.62 (0.02)	1.63 (0.02)
	17-18	1.75 (0.02)	1.75 (0.02)	1.75 (0.02)	1.76 (0.03)
Seeds per plant	15-16	31.76(1.69)	26.03(1.46)	26.04(1.43)	27.24(1.63)
	16-17	14.47 (0.91)	16.77(0.89)	18.79(1.16)	17.05(1.02)
	17-18	33.16 (2.24)	32.48(2.26)	27.19(2.31)	34.63(2.27)
Seeds per pod	15-16	2.96 (0.59)	2.70 (0.71)	2.94 (0.65)	2.85 (0.64)
	16-17	2.73 (0.09)	2.72 (0.08)	2.76 (0.09)	2.57 (0.08)
	17-18	3.07 (0.08)	2.76 (0.09)	2.90 (0.08)	2.95 (0.08)

Groups: IO-intercropping x open-pollination; IC-intercropping x selfing; SO-monoculture x open-pollination; SC-monoculture x selfing

Wheat with field beans and lupins in the United Kingdom

Ambrogio Costanzo – Ambrogio.c@orgnanicresearchcentre.com

With Dominic Amos, Tegan Gilmore, Anne-Lise Villard

Abstract

Intercropping wheat and field beans is a useful tool to support the production of home-grown protein. In fact, field beans are a challenging crop in UK organic farming because of the risk of diseases and susceptibility to weed competition. Here, we tested the most common field bean cultivar in UK organic farming with either a commercial spring wheat or a Composite Cross spring wheat. No significant results were found in 2017 and some trends emerged in 2018, when also white and blue lupin were included. Overall, the challenges of organically growing field beans were confirmed by these trials even in intercropping with wheat.

Location(s)

– ***Sonning experimental farm,*** Reading (Berkshire) UK

List of accessions

Field bean var. Fuego was tested in intercropping with spring wheat cv. Mulika and with a spring wheat Composite Cross Population. In 2018, a white lupin and a blue lupin variety were also included in the trial and intercropped with the two wheats.

List of traits assessed

Crop development and agro-ecological performance (phenology, weeds, diseases, …)		
Trait	**How it has been assessed**	**Type of data available**
Establishment	Plants count on 0.5m^2	Plants/m^2
Cover	Visual estimate	%
Weed cover	Visual estimate	%
Biomass	Biomass sample at wheat BBCH GS 65 on 0.5m^2	g/m^2
Crop productive performance (yield, yield components)		
Trait	**How it has been assessed**	**Type of data available**
Grain yield	Combine harvest and grains separation	T ha^{-1}

Trial background and evolution

An attempt to test winter wheat-field bean intercrops had been done in 2015/16 in Doves farm, with either a commercial or population wheat mixed with either a commercial or population field bean.

However, the trial failed due to scarce establishment and compete destruction of all bean plants by rust and chocolate spot. Then, in 2017 we tested a spring intercrop focusing on a commercial field bean. The trial is integrated in ongoing intense discussions on the opportunity and options to intercrop wheat and beans, and on the better combination of traits. However, we are still limited in access to diverse, yet adapted to the British Isles, accessions of field beans which seems to be the most constrained crop.

Trial design and management

The trial was arranged as a RCB with four replicates. Wheat and field beans were sown in mixed rows (to represent the most feasible on-farm practice), both at 75% the recommended sowing rate as monocrops (350 and 60 seeds m^{-2}, respectively). High weed infestation was not controlled due to the presence of beans and has possibly reduced the relevance and power of the trial. In 2018, the trial was designed including two additional factors: position in rotation, following either a grass-clover ley ("High-fertility") or a spring oats crop ("Low-fertility"), and tillage system, with soil preparation done either by ploughing or by shallow non-inversion tillage. Statistical analyses were carried out through linear mixed model (including rotational position and tillage as random error terms in 2018, with intercrops and varieties nested into tillage) using R package 'lme4'.

Main results

In 2017, no differences in wheat yield were detected. In beans, although non-significant, a 50% reduction in grain yield was observed in the intercrops. However, the excessive weed pressure (mainly *Chenopodium album*) has clearly reduced the reliability of the trial. *Chenopodium album* was by far the most abundant weed. Beans were well established and growing, but were severely affected by aphids and diseases from the onset of flowering (fig. 2). Varietal difference where found in wheat head density (p = 0.01):

- monocrop Mulika had the highest heads density, higher than monocrop CCP
- both varieties had reduced heads density when in intercrop, but for the CCP this reduction was not significant
- intercropped Mulika had the lowest head density

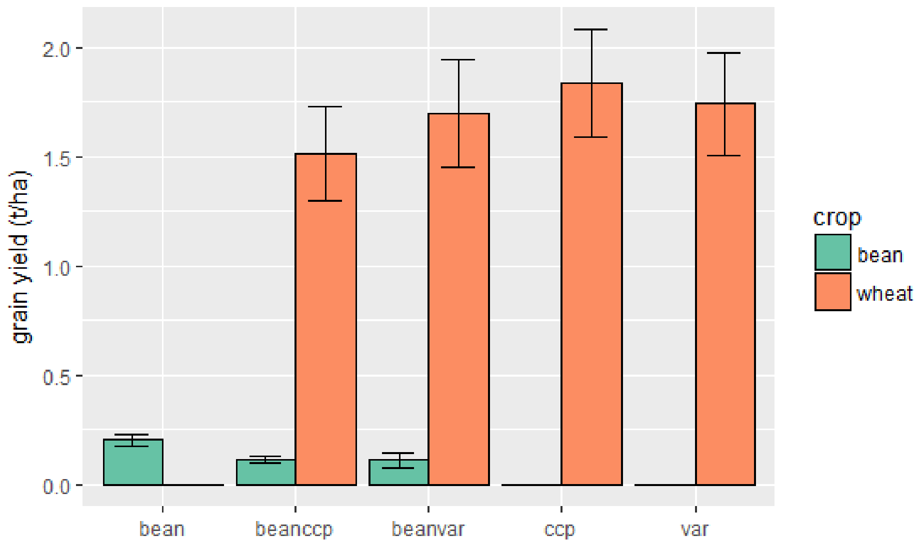


Fig. 1. Yield of (left to right) field bean monocrop, intercropped field bean and wheat CCP, intercropped field bean and wheat commercial variety, wheat CCP monocrop and wheat commercial variety monocrop in 2017.

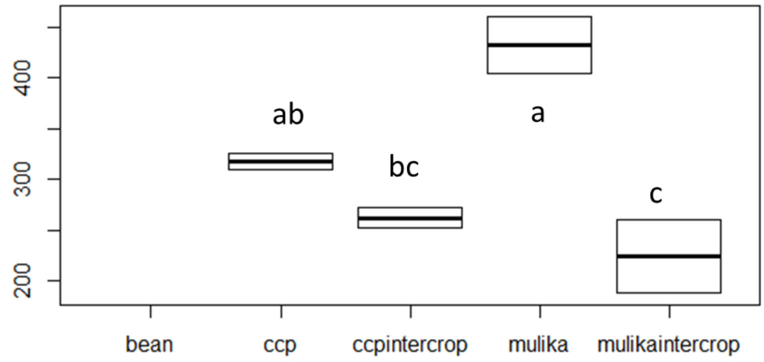


Fig. 2. Head density (ears/m2) of wheat in 2017; Mulika had higher head density than the CCP when grown as monocrop, but the trend is inverted when grown as an intercrop with field bean. Letters indicate pairwise differences (LSD test)

Fig. 3. Chocolate spot (Botrytis fabae) affecting pods and flowering stems in 2018, probably the most important yield-limiting factor.

In 2018, field bean was again underperforming, also due to an unusually warm and dry summer. Interesting insights could be derived from observations of crops and weed cover in correspondence of wheat anthesis in the four different environments represented by the trial:

1. Overall, intercropping tended to increase crop cover compared to all monocrops. The shallow-non-inversion tillage drastically reduced crop cover compared to the ploughed system in both rotational positions.
2. Looking at wheat, its canopy cover was significantly reduced in the shallow non-inversion tillage compared to the ploughed, and by presence of all companion crops compared to wheat monocrops
3. Weeds cover was higher in the shallow non-inversion tillage than in the ploughed system in both rotational position but was especially high in the non-inversion field following the spring oats crop, where weeds were drastically overwhelming the crop.

4. Despite such high variation, we could identify a significant effect of both wheat variety and the legume species on weed cover:
    a. unlike the variety Mulika, the presence of the wheat CCP significantly reduced weed cover compared to each legume monocrop, which is possibly due to a taller canopy and a slightly earlier development
    b. weeds cover was significantly lower in presence of field beans than in presence of blue lupins, probably due to a fast and vigorous early growth. However, this advantage is counterbalanced by the pressure of diseases on beans later in development.

Yield data are still under processing. An unexpected result was the good performance of the two lupin types: the early ripening blue lupin, with good pod setting and production even without a suboptimal establishment and early vigour, and the vigorous growth of the white lupin (Fig. 8).

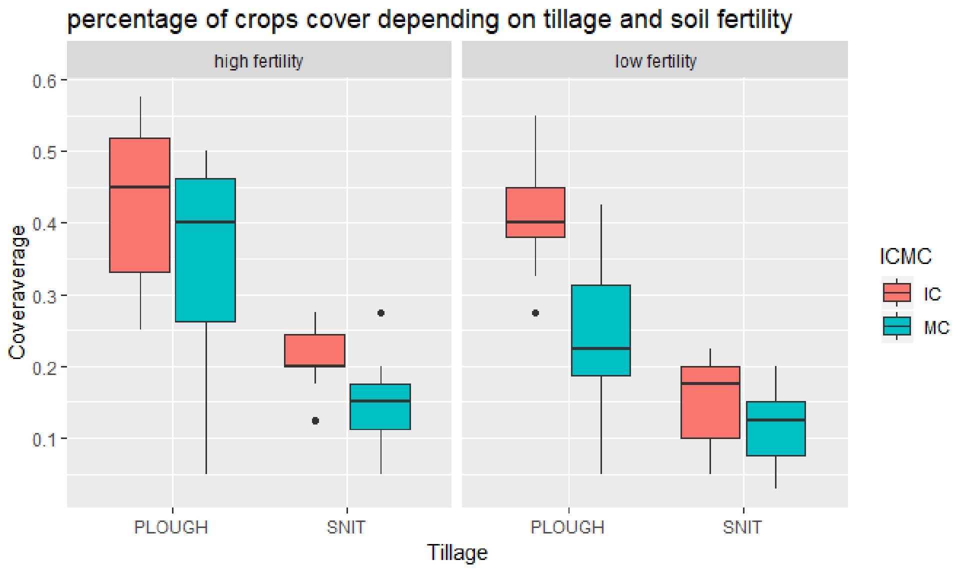


Fig. 4. average cover of crop as affected by rotational position (High fertility = following a grass-clover ley; low-fertility = flowing spring oats) and by tillage (SNIT= shallow non-inversion tillage)

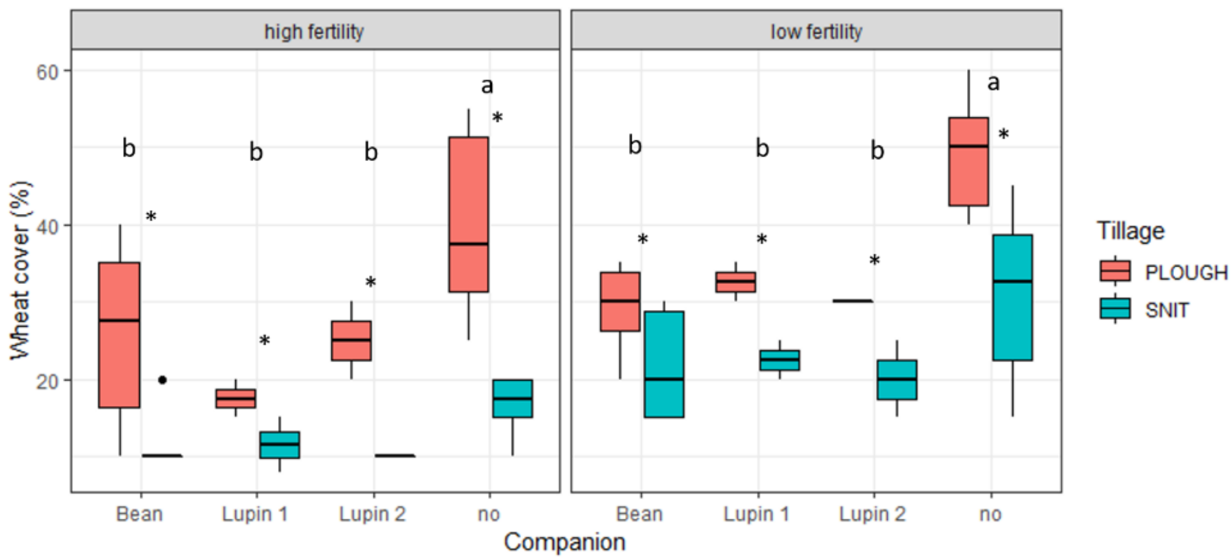


Fig. 5. Average cover of wheat as affected by rotational position (High fertility = following a grass-clover ley; low-fertility = flowing spring oats), by tillage (SNIT= shallow non-inversion tillage) and by companion crop (Lupin 1 = blue lupin, Lupin 2 = white lupin)

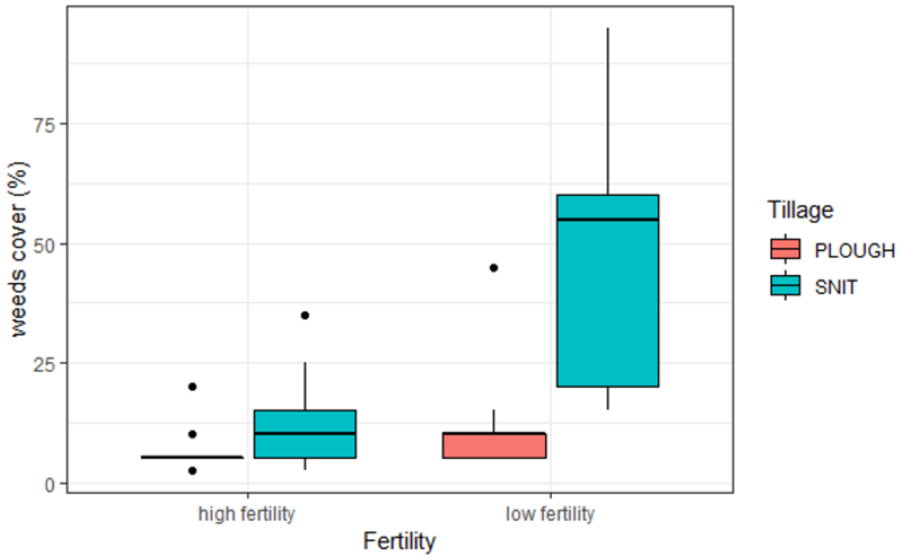


Fig. 6. Average cover of weeds as affected by rotational position (High fertility = following a grass-clover ley; low-fertility = flowing spring oats) and by tillage (SNIT= shallow non-inversion tillage)

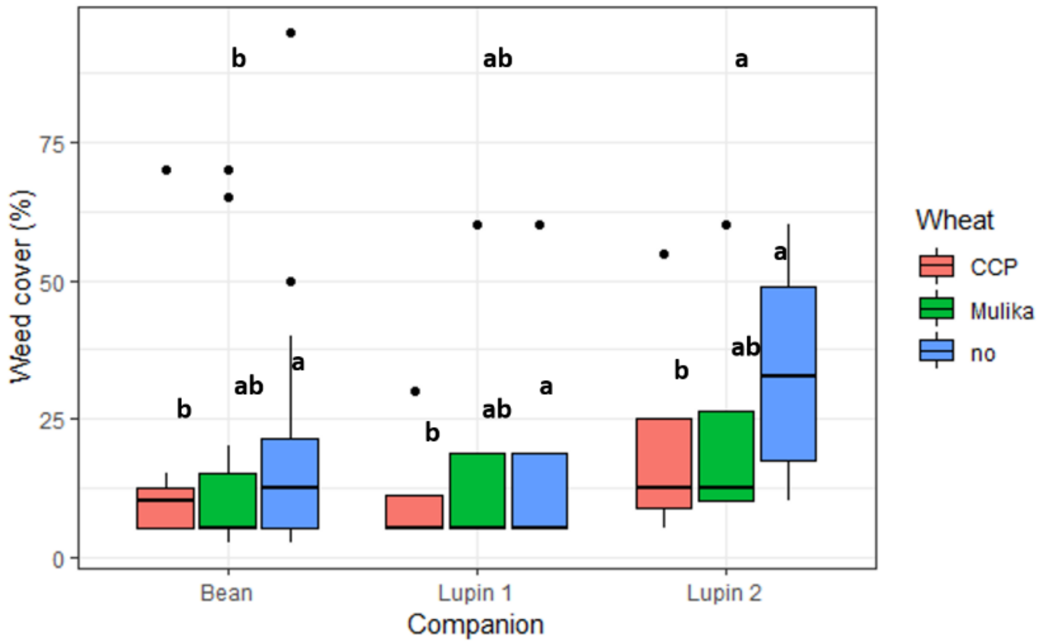


Fig. 7. Average cover of weeds as affected by by companion crop (Lupin 1 = blue lupin, Lupin 2 = white lupin) and by wheat presence (no = legume monocrop) and cultivar.

DISCUSSION, CONCLUSIONS AND NEXT STEPS

The main disease constraints of field bean production seem to be unaffected by intercropping and keep field bean a challenging species to be grown organically. Despite this failure, we were able to identify insights regarding competitive ability against weeds and between companion crops, which is particularly relevant since weed pressure were very high in both years. No intercrop effect on head density in 2017 suggest that the CCP may be better suited to intercropping than Mulika, where the head density difference was very high. Similarly, the presence of the CCP, either on its own or

intercropped, significantly reduced weed abundance in 2018, whereas this did not seem to happen for Mulika.

The factorial 2018 trial highlight the instability and challenges of spring cropping, and shows that serious problems can arise, both in wheat or legumes monocrops and in intercrops, when moving away from 'high-fertility' rotational positions and for ploughing, in presence of significant weed pressure. Whilst this research suggests that the absolute priority for field bean is to explore the widest possible panel of genetic resources, we were surprised to find the relatively good performance of both white and blue lupins. Further research and inquiries will be done to confirm this performance in further growing season, perhaps with less unusual climatic pattern than the dry 2018 summer, and to understand the best options for use in intercropping with wheat, considering the (too) early ripening of blue lupin that may lead to pods opening and grain loss, and the indefinite growth of white lupin, which may prove good for whole-crop harvest or even for weed-reduction.

Fig. 8. (1) early ripening and good pod setting in blue lupin intercropped with wheat; (2) visual differences in wheat cover between the CCP (left) and the variety Mulika (right) in the weedy "low-fertility" rotational position; (3) vigorous vegetative growth of white lupin intercropped with wheat.

Wheat with field bean populations in the Netherlands

LBI – Netherlands

Edwin Nuijten – e.nuijten@louisbolk.nl

Abstract

The aim of the trial was to understand whether growing a population of faba bean with wheat is a simple and cost-effective approach for breeding for mixed cropping. Two populations from Spain where tested as winter and spring crop. First results suggest that the approach is sound, but that the starting resources needs to be better adapted to the target conditions.

Location(s)

2016: Bemmel

2017: Kraggenburg

2018: Kraggenburg

List of accessions

- Faba bean / spring wheat:
- Population C15-16 masiva 4 / Lavett
- Population C15-16 masiva 2 / Lavett
- 2017: Variety Imposa/ Lavett (reference)
- 2018: ….

List of traits assessed

Crop development and agro-ecological performance (phenology, weeds, diseases, …)		
Trait	**How it has been assessed**	**Type of data available**
Emergence	Visual	Score 1-9
Weeds	Visual	
Diseases	Visual	
Time of maturity	Visual	
Lodging	Visual	

TRIAL BACKGROUND AND EVOLUTION

The initiative was taken by partner CSIC. Key decisions: choice of resources, and time of sowing (in spring instead of in winter, because of lack of adaptation to the Netherlands). The trial is of limited scale and only CSIC, ORC and LBI and only direct involved farmers (where the trials are situated) are involved.

TRIAL DESIGN AND MANAGEMENT

Sowing: by machine, adjacent to trials with wheat population. Each population was sown in a single plot because of limited seed availability. Harvesting was done by machine

MAIN RESULTS

The results in the season 2015/16 showed that the winter populations of faba bean developed in Spain where not adapted to winter conditions in the Netherlands: only very few plants survived the winter, and eventually these plants where overgrown by the wheat. The winter populations also did not survive the winter in the UK.

In 2017 the populations were sown in spring. Vegetative development and flowering were ok. The two populations also seemed slightly less susceptible to brown leaf spot disease (*Didymella fabae*). However, lodging was far more severe compared to the reference variety of faba bean. Because of problems with the mechanical harvesting, no yield estimates can be given.

In 2018 the populations were sown in spring, in single stand. The reason for this was to select for early maturing plants with good lodging tolerance, with a selection intensity of approximately 10%. In 2019 the selections can be evaluated to observe whether there is improvement in earliness of ripening and lodging tolerance.

DISCUSSION

The aim of the trial was to better understand how to breed for mixed cropping of faba bean with cereals. For that reason, populations of faba bean where sown mixed with wheat (the most suitable cereal crop in the Netherlands for mixture with faba bean) to understand whether and how selection under such conditions can result in a faba bean population that is better suited for mixture with wheat. If successful, such procedure could mean a simple and cheap method for breeding faba bean for mixed cropping.

CONCLUSION AND NEXT STEPS

This approach of breeding faba bean for mixed cropping may have potential. It seems the breeding approach needs to be conducted differently from that of population breeding for cereals. Instead of harvesting by machine, which is the common practice with wheat populations, suitable plants of faba bean should be harvested by hand to optimise the selection process. Next steps may also include simple selection methods to analysis levels of convicin and vicin, in order to develop faba bean populations suitable for human consumption.

Cereals and Legumes

Bread and durum wheat with chickpeas in Italy

UNIBO

Giovanni Dinelli, Sara Bosi. sara.bosi@unibo.it

ABSTRACT

Intercropping is defined as the growth of more than one crop species or cultivar simultaneously in the same field during a growing season. It is the practical application of ecological principles such as diversity, crop interaction and other natural regulation mechanisms. Intercropping has many advantages, such as increased and more stable yields, better nutrient recycling in the soil, better control of weeds, pests and diseases and an increased biodiversity. The main objective of the trial is to evaluate the potential of this technique and define intercropping strategies for sustainable plant production management in organic farming systems.

LOCATION(S)

Az. Agr. Cenacchi Andrea – Argelato (BO)

LIST OF ACCESSIONS

Senatore Cappelli (durum wheat) and Inallettabile (soft wheat) and a chickpea variety.

LIST OF TRAITS ASSESSED

Crop productive performance (yield, yield components)		
Crop production	Field evaluation	Wheat and chickpea yield
Plant habitus	Field evaluation	Height of the plant
Plant habitus	Field evaluation	Height of the ear

Crop quality performance (organoleptic, processing, nutritional, nutraceutical, immaterial)		
Nutraceutical	Spectrophotometric analyses	Dietary fibre (wheat)
Nutraceutical	Spectrophotometric analyses	Content of free, bound and total polyphenols (mg of polyphenols/g of flour of wheat)
Nutraceutical	Spectrophotometric analyses	Content of free, bound and total flavonoids (mg of flavonoids/g of flour of wheat)

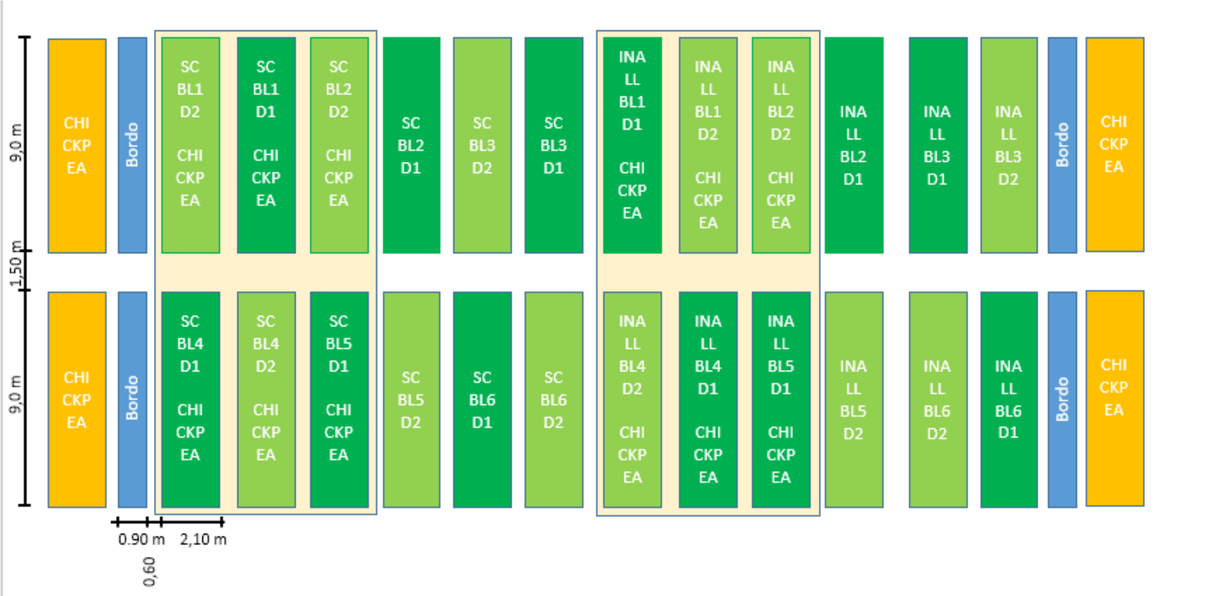
Nutraceutical	Spectrophotometric analyses	Antioxidant activity (DPPH test)on wheat flour

TRIAL BACKGROUND AND EVOLUTION

The main objective of the trial is to evaluate the potential of this technique, in order to determine the agronomic performance of cereal-grain legume intercrops in terms of yield advantage and environmental benefits. During the second growing season, the meteorological conditions did not allow to carry out the spring sowing of the chickpea, so the second year of the trial failed. In order to verify the possibility of avoid these difficulties in trial management, two different dates of chickpea sowing were realized during the third growing season (autumn and spring sowing).

TRIAL DESIGN AND MANAGEMENT

During the agronomic seasons 2015/16 and 2016/17, a split-plot experimental design has been adopted with the factor wheat genotypes (Senatore Cappelli and Inallettabile) as main plot and sowing density (D1=180 kg/ha; D2= 120 kg/ha) as sub-plots with three replications. Period of sowing were between 1-15 November for wheat and between 5-15 April for chickpea.



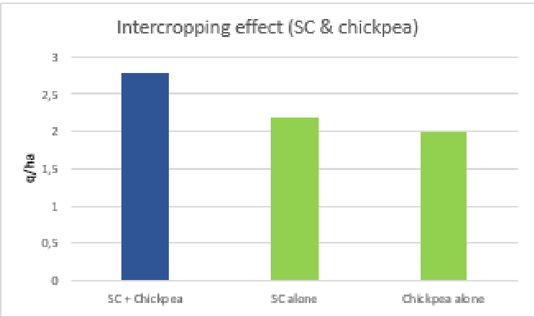
During the growing season 2017/18, only one sowing density (D1) and two different chickpea sowing periods (autumn and spring sowing) were realized. Also in the third trial, winter and spring sowing of chickpea failed.

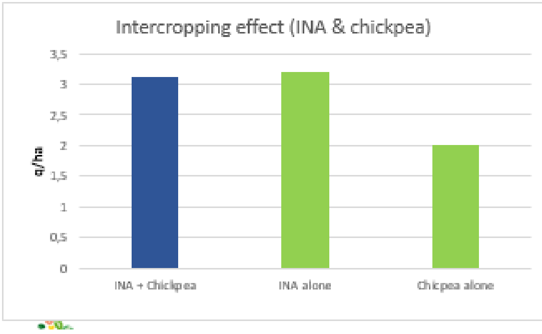
MAIN RESULTS

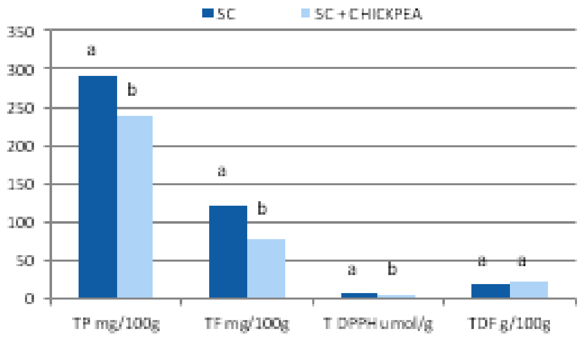
For the Senatore Cappelli, the total biomass harvested in 2015/16 in the intercropping area is higher in respect to those harvested for wheat and chickpea when cultivated alone. This effect is not observable in the Inallettabile trial, where the total biomass harvested in the intercropping system is lower than the biomass produced by wheat cultivated alone.

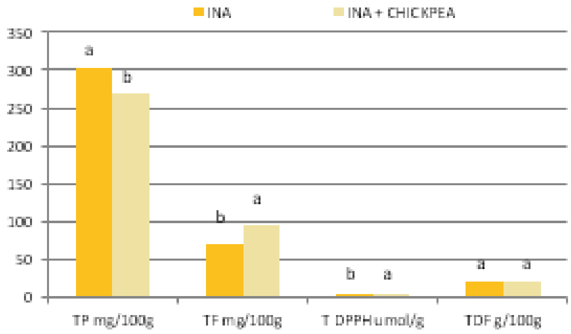
For nutritional and nutraceutical compounds, different results were bserved between the durum (Senatore Cappelli) and the soft wheat (Inallettabile). In the Senatore Cappelli trial, a greater amount of polyphenol compounds (polyphenols and flavonoids) and antioxidant activities was observed when the wheat are sown

alone. In the Inallettabile trial, higher amount of polyphenol compounds is produced in the plot whithout chickpea, while the intercropping plots exhibits higher levels of total flavonoids and antioxidant activities.









Discussion

Chickpea did not reduce yield of durum and soft wheat in comparison to the control, while the extra total biomass of legume increased the productivity.

Only in the Inallettabile trial, thousand seed weight and the height of the plants were incremented by the presence of chickpea. In addition, some differences in the nutraceutical profile were recorded in both wheat trial.

During the first year, positive results were correlated to the intercropping technique. However, the use of chickpea as legume does not guarantee stable performance.

Wheat with *Trifolium repens, Vicia ervilia* and *Hedysarum coronarium* in Southern Spain

RAS – SPAIN

María Carrascosa, maria_carrascosa@riseup.net

ABSTRACT

The trials have been carried out in two organic farms in the winter of 2015-2016 and 2016-2017. One farm (L1) has assessed a durum wheat (Trigo Recio de Ronda) with white clover and *Vicia ervilia* in 2015-2016 and *Hedysarum coronarium* and *Vicia ervilia* in 2016-2017. The other farm (L2) has assessed soft wheat (Trigo Chamorro) with the same leguminous in the same periods.

The first objective of the trial is to evaluate an intercropping system that nourish soil and crops in locations with poor soil and drought conditions, with good results of the wheat. The second objective is to help in the weed control.

LOCATION(S)

One farm is located in Yunquera (Málaga) (Location 1) and the other in Castilblanco de los Arroyos (Sevilla) (Location 2).

LIST OF ACCESSIONS

The wheat local varieties selected are the main wheat varieties produced in L1 and L2.

- Trigo Recio de Ronda is a local variety recovered in 2012 by the *Grupo de Acción Compartida* (a group of organic farmers in the Málaga province where Alonso Navarro, the farmer of L1, participates). This variety in nowadays used in 3 bakeries.
- Trigo Chamorro was recovered 20 years ago by the Eco village Los Portales (L2) that produces their own wheat and bread (which is distributed in the local market).

The type of leguminous to be used in the trials where proposed by Alonso Navarro (L1).

- White clover and *Hedysarum coronarium* have been purchased in Semillas Cantueso. For the white clover the variety is *Trifolium repens blanco enano grasslands huia* and in the case of *Hedysarum coronarium*, Semillas Cantueso says that the variety is unknown
- The variety of *Vicia ervilia* used is Yero de Algatocín and it has been grown by Alonso Navarro for several years and it´s a local variety from a farmer in Algatocín (Málaga).

LIST OF TRAITS ASSESSED

Crop development and agro-ecological performance (phenology, weeds, diseases, …)		
Trait	**How it has been assessed**	**Type of data available**

STAGES OF GROWTH. Wheat sowing date		DDMMYYYY
STAGES OF GROWTH. Leguminous sowing date		DDMMYYYY
STAGES OF GROWTH. Date of wheat emergence	Date on which 70% of the plants have emerged on the plot	Number of days
STAGES OF GROWTH. Date of leguminous emergence	Date on which 70% of the plants have emerged in the plot	Number of days
STAGES OF GROWTH. Date of the start of the wheat stem elongation	Date on which the first stem node appears at the base of the main stem in 50% of the plants of the plots	Number of days
STAGES OF GROWTH. Date of the wheat spike	Date in which half spike emerges from the pod in 50% of the plants of the plot	Number of days
STAGES OF GROWTH. Date of the maturation of the wheat	Date in which 50% of plants of the plot are mature (that coincides with the fact that the wheat grains are milky)	Number of days
STAGES OF GROWTH. Date of the physiological ripening of the wheat	Date in which the grain of the plot is ripe for harvesting in 50% of plants of the plot	Number of days
STAGES OF GROWTH. Date of wheat harvesting	Moment in which wheat is collected from the elementary plot	Number of days
STAGES OF GROWTH. Physiological status of the legume at the time of wheat harvesting	Farmers´observation	Flowering, fruiting initiation or physiological maturity
STAGES OF GROWTH. Date of the legume harvest (for grain)	Moment in which the legume of the elementary plot is harvested to obtain seed	Number of days
AGRONOMIC CHARACTERISTICS. Emerging power	Analyze how the seed sprouts in the soil in each elementary plot. Take the measurement in the nascence stage.	1. High 2. Low
AGRONOMIC CHARACTERISTICS. Lodging	Analyze the response of the variety as a whole in each elementary plot. Take the measurement in the stage of physiological maturity.	1. Absent 2. Present
AGRONOMIC CHARACTERISTICS. Resistance diseases	In case of presenting problems with a disease, indicate which one or which ones have been and the level of plants attacked. Take the measurement in the stage of physiological maturity.	1. High 2. Medium 3. Low

AGRONOMIC CHARACTERISTICS. Resistance to pests	In case of presenting problems with a pest, indicate which or what they have been and the level of plants attacked. Take the measurement in the stage of physiological maturity.	1. High 2. Medium 3. Low
AGRONOMIC CHARACTERISTICS. Competition with weeds	Analyze the response of variety as a whole with respect to the competition with adventitious herbs. Take the measurement in the stage of physiological maturity	1. High 2. Medium 3. Low
AGRONOMIC CHARACTERISTICS. Resistance to frost	In case of presenting problems indicate the level of affected plants.	1. High 2. Medium 3. Low
AGRONOMIC CHARACTERISTICS. Resistance to heat	In case of problems, indicate the level of affected plants. Take the measurement in the stage of physiological maturity.	1. High 2. Medium 3. Low
AGRONOMIC CHARACTERISTICS. Resistance to lack of water	In case of problems, indicate the percentage of plants attacked. Take the measurement in the stage of physiological maturity.	1. High 2. Medium 3. Low
GENERAL OBSERVATIONS OF THE TRIAL. Do you consider the trial with a sufficient number of plants and regularly distributed?	Farmer´s opinion	Yes/No
GENERAL OBSERVATIONS OF THE TRIAL. Do you think that the evolution of the vegetative cycle has been normal or has there been a delay or significant advance to the usual in the area of cultivation in which the trial has been carried out?	Farmer´s opinion	Normal, significantly delayed or advanced
GENERAL OBSERVATIONS OF THE TRIAL. Do you think that the legume has prevented the appearance of adventitious herbs? in what grade?	Farmer´s opinion	High, medium or low
GENERAL OBSERVATIONS OF THE TRIAL. Which climatological factors have most influenced the final production?	Farmer´s opinion	High temperatures, low temperatures, lack of water, excess water or others, in case of marking others, indicate which ones, specify

		the date of the most important events
GENERAL OBSERVATIONS OF THE TRIAL. Have there been pathologies that have influenced the result of the test: pests, diseases, etc.?	Farmer´s opinion. Explain if there have been problems of relevant pests and diseases, which have been specifically and the dates in which they have occurred.	Qualitative and a priori non structured data
GENERAL OBSERVATIONS OF THE TRIAL. Have fungicide or other treatments been carried out on the plot?	List the treatments performed in the elementary plot and the dates	A priori non structured data
GENERAL OBSERVATIONS OF THE TRIAL. Has fertilization been provided to the plot? What and how? Crop rotation is considered a fertilization tool.	Explain the fertilization carried out in the elementary plot, indicate the date of the imputs	A priori non structured data
GENERAL OBSERVATIONS OF THE TRIAL. Do you think that the association with the leguminous has influenced the fertilization of the cereal?	Explain your opinion in this regard	A priori non structured data
GENERAL OBSERVATIONS OF THE TRIAL. Do you think that the association with the leguminous has influenced the tendency to bed of the variety?	Explain your opinion in this regard	A priori non structured data
GENERAL OBSERVATIONS OF THE TRIAL. Has the cropland been of excellent, good, fair or poor quality?	Subjective opinion of the soil quality of the plots	Excellent, good, fair or poor

Crop productive performance (yield, yield components)		
Trait	**How it has been assessed**	**Type of data available**
YIELD. Yield wheat ears	Number of ears harvested on the elementary plot	kg
YIELD. Yield wheat grain	Amount of grain harvested in the elementary plot	kg
YIELD. Wheat straw yield	Amount of straw in the elementary plot	kg
YIELD. Leguminous straw yield	Amount of leguminous straw in the elementary plot	kg

YIELD. Grain yield of legume	Amount of legume grain harvested on the elementary plot	kg
YIELD. Weight of 50 grains of wheat	Measure the weight in grams of 50 grains of the collected wheat in each elementary plot	gr
MORPHOLOGICAL CHARACTERIZATION. Tilling	Choose 5 random plants that are healthy, within type, that are not on the edges and far from each other. See if in the chosen plants exist or not tillers. Carry out the measurement in the tillering phase (when the main stem has 3 to 4 leaves, one month after the sprouting)	1. Absent 2. Present
MORPHOLOGICAL CHARACTERIZATION. Number of tillers per plant	Count the number of tillers in the chosen plants. Carry out the measurement in the tillering phase (when the main stem has 3 to 4 leaves, one month after hatching).	Number
MORPHOLOGICAL CHARACTERIZATION. Growth habit	Evaluated in the five choosen plants during the tillering phase, approximately 3 weeks after emergence.	1. Postrate 2. Intermediate 3. Erect
MORPHOLOGICAL CHARACTERIZATION. Vitality of the plant	Evaluate the vitality of the chosen plants. Make the measurement in the maturation stage	1. High 2. Medium 3. Low
MORPHOLOGICAL CHARACTERIZATION. Homogeneity of the plant	Choose in which aspect of the indicated is more homogeneous. Make the measurement in the maturation stage.	1. Color 2. Eared 3. Height
MORPHOLOGICAL CHARACTERIZATION. Ear emergence of the tillers	See in each plant chosen the percentage of ears in the tillers. Make the measurement at the stage of physiological maturity.	1. High > 70% 2. Medium 70-40% 3. Low <40% 4. Void 0
MORPHOLOGICAL CHARACTERIZATION. Height of the plant	Measure of the height of the 5 selected plants, from the ground to the final part of the last spike without including the edge. Make the measurement at the stage of physiological maturity.	cm
MORPHOLOGICAL CHARACTERIZATION. Length of the beards	Choose 5 main ears of the plants chosen above. Value of each spike measured in the central third of the spike. Make the measurement at the stage of physiological maturity.	1. Absence 2. Absence by deciduous 3. Semiaristadas 1-3 cm 4. Aristadas 3-8 cm 5. Long edges > 8 cm
MORPHOLOGICAL CHARACTERIZATION. Roughness of the beards	Make the measurement in the stage of physiological maturity.	1. Rough 2. Smooth

MORPHOLOGICAL CHARACTERIZATION. Color of the beards	Make the measurement in the stage of physiological maturity.	1. White 2. Black at the base 3. Black (gray / black for sp. Spelta) 4. Red to brown
MORPHOLOGICAL. CHARACTERIZATION Spike length	Continue with the 5 main spikes previously chosen. Value of the spikes measured from the base (not including sterile spikelets that have no grain, usually two or three at the base of the spike), to the end of the apical spikelet (not including edges). Make the measurement at the stage of physiological maturity.	mm
MORPHOLOGICAL CHARACTERIZATION. Number of spikelets per spike	Value of the 5 spikes. Total number of spikelets excluding sterile basal one. Make the measurement at the stage of physiological maturity.	Number
MORPHOLOGICAL CHARACTERIZATION. Number of grains per spike	Value of the 5 spikes. Total number of grains in each one. Make the measurement at the stage of physiological maturity.	Number
MORPHOLOGICAL CHARACTERIZATION. Weight of the grains of a spike	Value of the five spikes. Weight in grams of the grains of each spike. Make the measurement at the stage of physiological maturity.	gr
MORPHOLOGICAL CHARACTERIZATION. Hairiness of the glume	Continue with the 5 main spikes previously chosen. Data taken for each spike chosen, from the lower glume of the central third of the spike. Make the measurement at the stage of physiological maturity.	1. Hairless (without hairs) 2. Pubescent (fine and soft hairs) 3. Hairy (very long hairs)
MORPHOLOGICAL CHARACTERIZATION Color of the glume	Data taken for each spike chosen, from the lower glume of the central third of the spike. Make the measurement at the stage of physiological maturity.	1. White 2. Red / brown 3. Purple to gray / black
MORPHOLOGICAL CHARACTERIZATION Color of the grains:	Continue with the 5 main spikes previously chosen. See the dominant color of the grains of the 5 ears. Make the measurement at the stage of physiological maturity.	1. White 2. Red (red / brown for sp. Spelta) 3. Purple 4. Gray (only ssp. Spelta)

Crop quality performance (organoleptic, processing, nutritional, nutraceutical, immaterial)		
Trait	**How it has been assessed**	**Type of data available**
General data elaboration bread. Flour type	Bakers ‘opinion	wholemeal, semi (%), white flour
General data elaboration bread. Amount of flour used	Bakers ‘opinion	gr

General data elaboration bread. Type of mother sourdough	Bakers 'opinion	Variety of wheat, etc.
General data elaboration bread. Amount sourdough used	With the tools of the bakery	gr
General data elaboration bread. Amount of water used	With the tools of the bakery	ml
General data elaboration bread. Amount of salt used	With the tools of the bakery	gr
General data elaboration bread. Kneading	With the tools of the bakery	Manual / mechanic
General data elaboration bread. Other ingredients used	With the tools of the bakery	
General data elaboration bread. Kneading time	With the tools of the bakery	min
General data elaboration bread. Rest time	With the tools of the bakery	min
General data elaboration bread. Ball weight	With the tools of the bakery	gr
General data elaboration bread. Oven temperature	With the tools of the bakery	ºC
General data elaboration bread. Baked time	With the tools of the bakery	min
General data elaboration bread. Final weight bread	With the tools of the bakery	gr
Observations on bread formation. Tenacity	Bakers 'opinion	1: Very little; 2: little; 3: middle; 4: a lot; 5: Very good / optimal
Observations on bread formation. Elasticity	Bakers 'opinion	1: Very little; 2: little; 3: middle; 4: a lot; 5: Very good / optimal
Observations on bread formation. Tears	Bakers 'opinion	1: Very little; 2: little; 3: middle; 4: a lot; 5: Very good / optimal
Observations on bread formation. Gluten	Bakers 'opinion	1: Very little; 2: little; 3: middle; 4: a lot; 5: Very good / optimal
Observations on bread formation. Appearance of the dough	Bakers 'opinion	1: Very little; 2: little; 3: middle; 4: a lot; 5: Very good / optimal

Observations on bread formation. Gloss mass	Bakers 'opinion	1: Very little; 2: little; 3: middle; 4: a lot; 5: Very good / optimal
Observations on bread formation. Resting time	With the tools of the bakery	min
General evaluation fitness baker	Bakers 'opinion	1: Very little; 2: little; 3: middle; 4: a lot; 5: Very good / optimal

TRIAL BACKGROUND AND EVOLUTION

For RAS the description and evaluation of local varieties have been always a very important tool to promote their use (through the generation of information). The decision of involving farmers in the process (definition of the objectives, varieties, descriptors definition, collecting data) was taken in 2012. Another key decision was to include local varieties used by farmers participating in the trial. The intercropping for wheat grain production was not a good choice as the experiment in terms of the development of the leguminous has not been a success.

TRIAL DESIGN AND MANAGEMENT

How the trial has been sown, grown, harvested?

The plots have 10 m2, 2x5, (seed density 140 gr of wheat seed per plot).

The sowing of the wheat has been done in separate rows at a distance between 12 and 15 cm. The separation between plants has been between 3 and 5 cm and at a sowing depth of 3 cm. In the second year we have changed the sowing depth to 5-10 cm due to drought.

For the leguminous: broadcast sowing over wheat, seedling dose of Vicia ervilia 80 gr/10 m2, seedling dose White clover 20 gr/ 10 m2, seedling dose Hedysarum coronarium: 15 gr/ 10 m2, sowing date Vicia ervilia it is done a month and a half more or less from the sowing of the wheat (when it is about 20-25 cm high) (In the second year only one month later), sowing date white clover: it takes place a month and a half more or less from the sowing of the wheat (when it is about 20-25 cm high and sowing date Hedysarum coronarium: it is done 2 weeks after wheat sowing.

Trials 2015-2016: Randomised blocks, 3 repetitions.

Trials 2016-2017 : Combined p-rep (partially replicated designs) in row and columns. The plots have been merged with those from task 3.1.

Wheat landraces with field bean and forage peas in France

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Abstract

A group of farmers of Poitou-Charentes Region multiply and adapt soft wheat peasant populations for 7 years, and wanted to associate legumes with these farm varieties. During 5-6 years, they concentrated on breeding wheat varieties because of too many directions to follow to associate legumes, and no clear direction of the group. Now, some farmers have gained experience in sowing experiments corresponding to their questions in one hand, and some of the group are interested in breeding forage peas (not really available). So the initial objective of the farmers' group has split into 2 directions.

Location(s)

Poitou-Charentes Region (West of France)

List of accessions

- Wheat associated with legume (at one farmer):
  - Wheat varieties:
    - Cloche (old variety)
    - Angoulème (landrace multiplied on farm from INRA gene bank for 7 years)
    - Carré de Crète (landrace)
- Associated with faba bean (modern variety DIVA)
- Multiplication of forage peas (from ARS-GRIN)
- 38 accessions multiplied (see list at the end of the document)

List of traits assessed

Only the wheat associated was observed, the peas were just multiplied for the first year (about 10 seeds per variety). The farmer concerned by the association experiment realized the observations by himself.

Crop development and agro-ecological performance (phenology, weeds, diseases, …)		
Trait	**How it has been assessed**	**Type of data available**
Emergence regularity	Note 1=regular 2=irregular	Semi-quantitative data
Speed of emergence	Note 1=slow 2=normal 3=rapid	Semi-quantitative data

Wheat/legume ratio at emergence	Note 1=really too much wheat 2=too much wheat 3=equilibrium 4=too much faba bean 5=really too much faba bean	Semi-quantitative data
Soil cover at 2 nodes	Note 1=weak 2=medium 3=important 4=very important	Semi-quantitative data
Weeds at 2 nodes	Note 1=no weeds 2=few weeds 3=medium 4=quite a lot of weeds 5=a lot of weeds	Semi-quantitative data
Tillering at 2 nodes	Note 1=very weak 2=weak 3=medium 4=important 5=very important	Semi-quantitative data
Colour at 2 nodes	Note 1=light green 2=green 3=dark green 4=other	Semi-quantitative data
Wheat/legume ratio at 2 nodes	Note 1=really too much wheat 2=too much wheat 3=equilibrium 4=too much faba bean 5=really too much faba bean	Semi-quantitative data
Spike density at maturity	Note 1=weak 2=medium 3=important 4=very important	Semi-quantitative data
Plant height at maturity	Mean in cm	Quantitative data
Diseases at maturity	Note 1=no diseases 2=very few diseases 3=presence of diseases 4=strong presence of diseases 5=diseases strongly endanger the yield	Semi-quantitative data
Lodging at maturity	Note 0=no lodging	Semi-quantitative data

	1=very few lodging 2=few lodging 3="half lodging" 4=very lodged 5=very very lodged	
Wheat/legume ratio at maturity	Note 1=really too much wheat 2=too much wheat 3=equilibrium 4=too much faba bean 5=really too much faba bean	Semi-quantitative data

Crop productive performance (yield, yield components)

Trait	How it has been assessed	Type of data available
Yield	Qx/ha	Quantitative data
Proteins	Evaluation with NIRS	Quantitative data

TRIAL BACKGROUND AND EVOLUTION

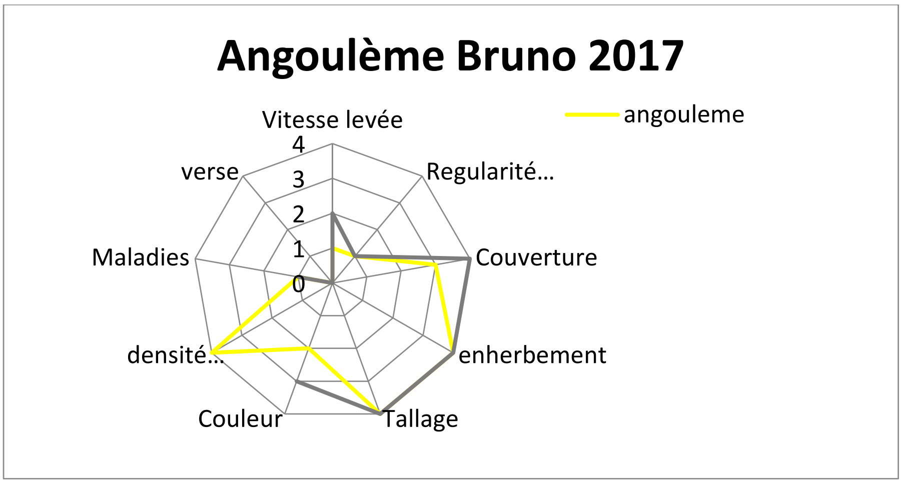
Those trials come from a demand of the group of farmers. They started to breed maize about 15 years ago and decided to continue with wheat in the 2010. The demand was very ambitious, but we tried to answer it (accompaniment by the engineer for several years) and the farmers learnt to experiment by themselves more than answering their initial answer. In 2017, one farmer managed a trial to experiment the differences of associations of different wheat varieties and faba bean.

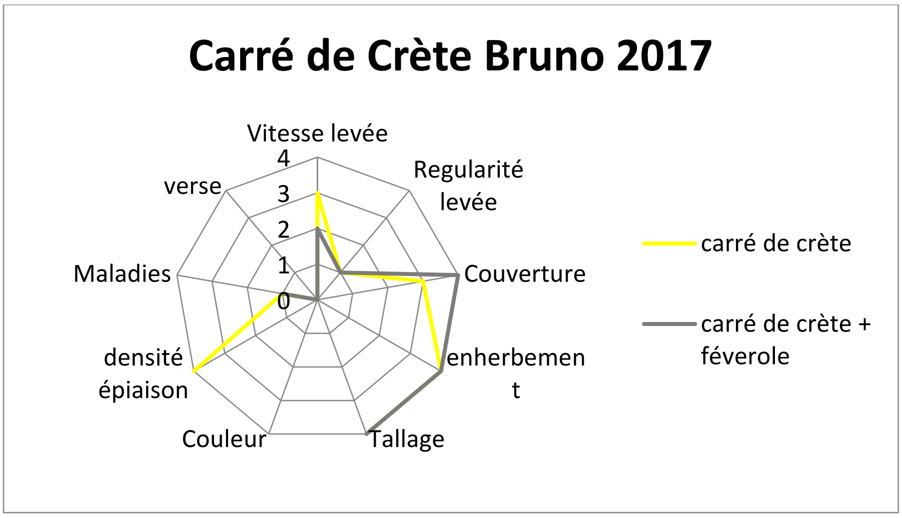
The data proposed here are simple and allow having a synthetic view of the culture (and easy to put in a database).

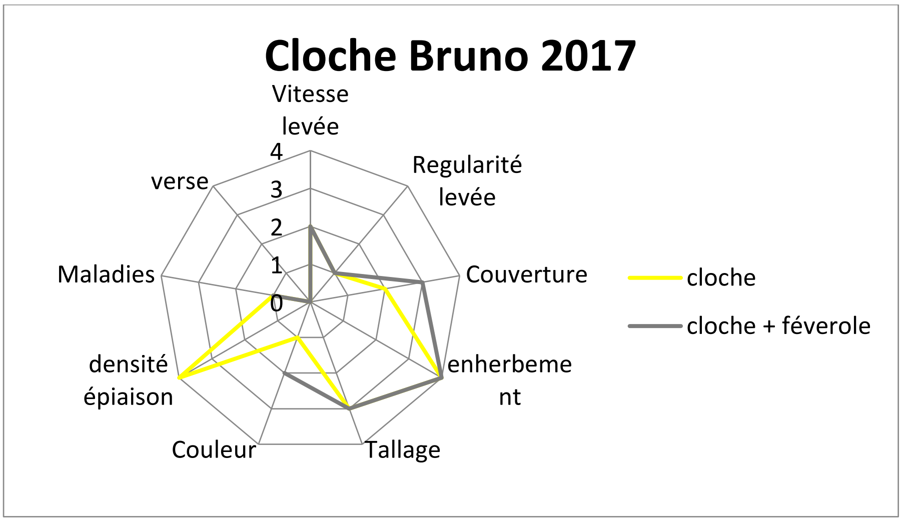
TRIAL DESIGN AND MANAGEMENT

The wheat-legume association was cultivated in 6m large plots and the field length. There was no replicate. Each wheat variety was cultivated single, and then associated. There was also a pure faba bean plot. We calculated the Land Equivalent Ratio of each association. We realized spider graphs in order to visual the different profiles of the varieties and also the differences between association or single crop.

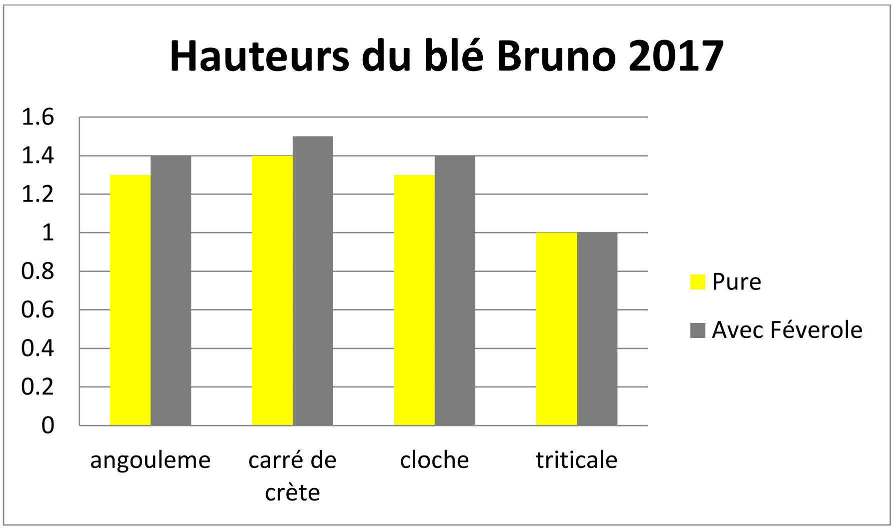
MAIN RESULTS







The differences between associated plots and single crop are very small. The only notable difference seems to be for covering (better soil cover with legume).



Wheat heights: the wheat is always slightly taller with faba bean than when cultivated single.

LER:

LER Carré de Crète	**1,32106667**
LER Angoulème	1,4898
LER Cloche	1,3232

The LER are different according to the variety. The most interesting variety for association is Angoulème at this farmer in 2017.

Proteins:

Single crop	Pur	Associated
Carré de Crète	10,8	**12,3**
Angoulème	10,6	**12,7**
Cloche	11,3	11,4

Carré de Crète and Angoulème produce more protein when associated with the legume, which is not the case for Cloche.

Forage peas multiplication:

Discussion

These results show that there is an interaction between the wheat variety and the legume species. The farmers may try different varieties to find the one more adapted to association in their conditions. We hope these results will encourage other farmers to realize such trials in order to verify the trends.

The farmers have difficulties to realize the observations by themselves. The observations proposed here are the result of 6 years of observation sheets (different sheets across years, built with farmers, to arrive to a good compromise). There was also a year of "common learning" to observe the wheat at the beginning of the project (meetings in the fields to observer wheat collectively). The farmers are technically good at observing plants, but they lack time once in their farm, with production to manage, the trials are "forgotten". So, the work of the animator is crucial: he/she can stimulate the farmers for the observations (mails, calls, visits…). This project put in light the role of the animator (different animators along the project and different way of working, with difficult phases when the animator didn't play his role enough).

Conclusion and next steps

More farmers will be engaged in association experimentation. Multiplication of forage pea will continue to be able to associate them with cereals and test the association.

SUPPLEMENTARY MATERIAL

Accession	Name	Country of origin	Type of variety	Year of aquisition
W6 3674	1-826a	Nepal	Wild material	
W6 3675	2052	Nepal	Wild material	
W6 12553	FENN	United States	cultivar	1993
W6 12713	MELROSE WINTER		cultivar	1992
W6 12719	KALOFER	Bulgaria	cultivar	1992
W6 12723	PLEVEN 2	Bulgaria	cultivar	1992
PI 639981	PLEVEN 10	Bulgaria	cultivar	1992
PI 639980	MIR	Bulgaria	cultivar	1992
PI 639979	YUBILEI	Bulgaria	cultivar	1992
PI 639978	KENEJA	Bulgaria	cultivar	1992
PI 639977	P-226	Bulgaria	cultivar	1992
PI 639976	P-77	Bulgaria	cultivar	1992
W6 12739	MARKOVO 1	Bulgaria	cultivar	1992
PI 601401	TREMONT SCOTCH	United States	cultivar	1988
PI 601551	IRBY SCOTCH	United States	cultivar	1988
PI 268480	Col. No. 317	Afghanistan	cultivated material	1960
PI 269760	G 16701	United Kingdom	cultivated material	1960
PI 269761	Aa135	Czech Republic	cultivated material	1960
PI 271936	L 805/5g.	Sweden	Uncertain improvement status	1961
PI 273279	G 10946	Peru	Uncertain improvement status	1961
PI 343991	22647	Turkey	wild material	1969
PI 343993	22652	Turkey	cultivated material	1969
PI 343998	22670	Turkey	cultivated material	1969
PI 560968	190785-02	Turkey	cultivated material	1992
PI 574505	COMMON AUSTRIAN WINTER	United States	cultivar	1993
PI 577142	2033b	Nepal	Wild material	1990
PI 639964	W6 17218	Bulgaria	Wild material	1995
W6 26154	G2501	Georgia	Wild material	2004
W6 26157	Ontofo	Georgia	Wild material	2004
W6 26159	Drka	Georgia	Wild material	2004
W6 26160	Levakhane	Georgia	Wild material	2004
W6 26161	Nokalskesni	Georgia	Wild material	2004
NSL 448203	Renn		cultivar	1973
NSL 448204	Renn		cultivar	1973
NSL 448205	NSL 448205		cultivated material	1973
W6 17293 PSP	PAK10198	United States	landrace	2009