DIVERSify: Designing InnoVative plant teams for Ecosystem Resilience and agricultural Sustainability

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Summary report on performance of stakeholder-driven plant teams (Report, Public)

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Work Package 2: Ecological Approach to identify mechanisms and traits for optimised plant teams

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Executive Summary

In the EU-Horizon 2020 project "DIVERSify", a series of crop mixture trials were set up at eight different sites across Europe. The aim of these trials was to find pairwise combinations of crops (termed "plant teams") that show desirable agronomic properties (yield, nutritional value). Here, we report on the first two years of trials, using "stakeholder-driven" plant teams – that is, combinations of crop species and/or cultivars that are currently already grown by farmers in different European regions. We show that yield and nutritive value in cereal-legume and grassland mixtures can be optimized by combining suitable cultivars. In addition, management intensity (high vs. low agronomic input) can modify which cultivar combinations show optimal performance. Our results highlight the importance of multi-site experiments with multiple treatment combinations (mixture and management intensity) to study cropping systems useful for crop diversification across Europe.

1. Introduction

In the DIVERSify project, crop diversification experiments have been carried out across several European pedoclimatic zones and across several years (2017, 2018). The aim of these co-ordinated field trials was to assess the performance of crop species and crop cultivars in monocultures vs. two- or multi-species-mixtures (termed 'Plant Teams'). In addition, the aim was to study effects of management intensity on crop performance.

Based on pre-existing knowledge of scientific and breeder project partners, and being informed by the focus of national stakeholders and relevance to existing supply chains, pea-barley and faba bean-wheat combinations were used as recurrent plant teams across partner sites. Choice of management, crop genotypes and cereal-legume intercropped plant teams was coordinated among partners and included common cultivars between sites. To ensure that the tested material was relevant from breeder and stakeholder perspectives, selection of plant cultivars was done in close collaboration with breeders within and outside the project, as well as farmers and agronomists in our organisational stakeholder networks. The focus was on modern elite material, making use of available information (e.g. variety National Lists and Recommended Lists) on varietal differences in stature, development time and pest and disease susceptibility.

Here, we report on the performance of crop species and cultivars in monocultures and mixtures under high- vs. low-intensity management from these two years of trials. Data was collected according to standardised protocols (Kiær et al. 2017). Plant team performance was assessed using a range of agronomic performance measurements (absolute yield, over-yielding, product quality, weed/pest/disease incidence) tailored to stakeholder interest in each region. The data provided in this report should be helpful for decisions on which crop(s) and cultivars to grow where, if the aim is to grow two-species crop mixtures or multi-species annual forage mixtures.

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2. Performance of stakeholder-driven plant teams

2.1. Trials run by Consejo Superior de Investigaciones Científicas (CSIC), Spain

Trials run by CSIC (Consejo Superior de Investigaciones Científicas) were established to study barley-pea and wheat-faba bean combinations. In the 2017-18 growing season, two different experiments were carried out in Almodovar, in the Guadalquivir Valley in Andalucia (Spain). In one of them wheat was combined with faba bean; two cultivars of each crop were tested for all possible combinations (Table 1). In a second experiment, barley was combined with pea, again two cultivars for each crop (Table 2). Proportion of crops in both cases was 50/50. Plot size was 1.2 x 10 m. A randomized block design with four replications was the chosen design (Figure 1, Figure 2). Two different management systems were also tested in each experiment: conventional and low-input.

First analyses point to an increase of up to 20% in faba bean yield when combined with wheat (Figure 3). No differences in plant emergence was detected for any of the crops for any treatment (intercropping or management system). No differences either were found for plant biomass for any crop. *Septoria* spp. disease was evaluated on wheat, and no significant differences between intercropped plots and monocrop was found.

Yield of barley increased by 55% when combined with pea, but the yield of the legume fell by 57% in the mixture (Figure 4). No differences in plant emergence was detected for any of the crops for any treatment (intercropping or management system). Biomass of pea plants was significantly reduced when combined with barley (Figure 5). The combination with pea had no significant effect on the severity of *Helminthosporium* spp. disease on barley.

Table 1

Cultivars of crops and their combinations tested in the experiment for wheat/faba bean intercropping (green: wheat; blue: faba bean).

Wheat/faba bean
Exotic
Artur Nick
Prothabat
Jaspe
Exotic/Prothabat
Arthur Nick/Prothabat
Exotic/Jaspe
Arthur Nick/Jaspe

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Table 2

Cultivars of crops and their combinations tested in the experiment for barley/pea intercropping (red: barley; blue: pea).

Barley/pea
Shakira
Pewter
Audit
Livia
Shakira/Audit
Pewter/Audit
Shakira/Livia
Pewter/Livia

Figure 1

Plots of the barley/pea intercropping experiment showing monocrops and intercrops.

Figure 2

Plots of the barley/pea intercropping experiment showing monocrops and intercrops.

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Figure 3

Yield of wheat and faba bean in mixtures and as monocrops. Different letters on the same crop mean significant differences (Tukey test, p<0,05).

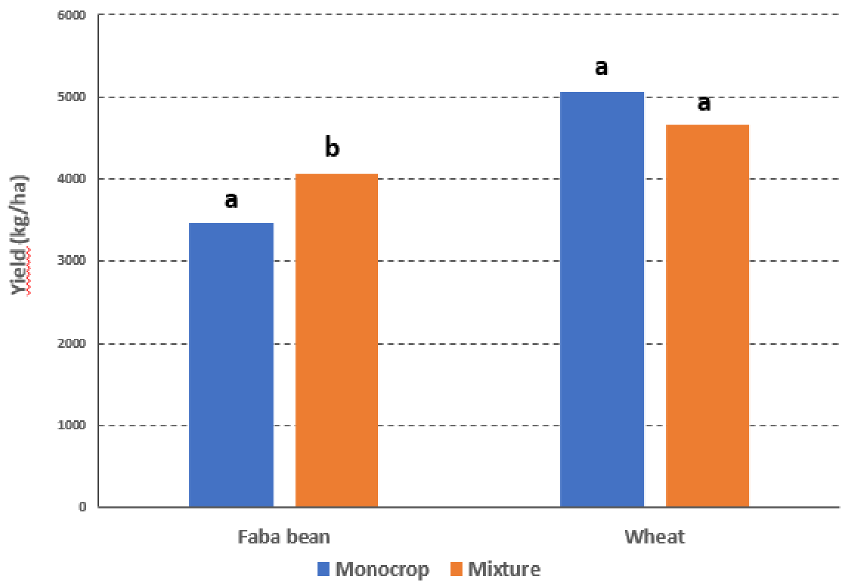

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Figure 4

Yield of barley and pea in mixtures and in monocrops. Different letters on the same crop mean significant differences (Tukey test, p<0.05).

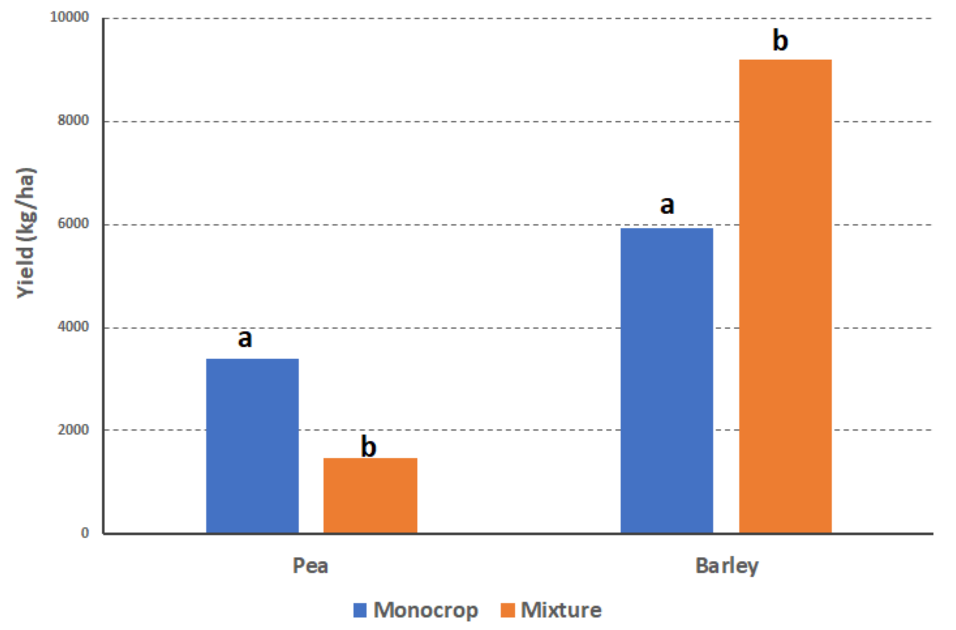
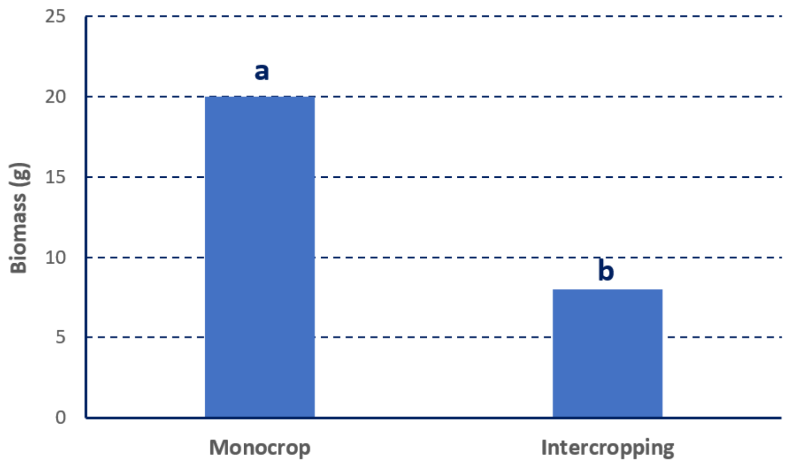


Figure 5

Biomass of pea (g/plant) as monocrop and intercropped with barley. Different letters on the same crop mean significant differences (Tukey test, p<0.05).



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2.2. Trials run by the James Hutton Institute (UK)

Two field trials were established between 29–30 March 2017 at the Balruddery Farm site of the James Hutton Institute, Dundee, UK (Figure 6). Commercial cultivars of cereal crops (spring wheat and spring barley) and legume crops (spring faba bean and spring pea) were selected from national recommended lists to represent a range of morphological, developmental, agronomic, yield and quality characteristics. Trial design is described in Karley et al. (2017). Seeds were sown at monoculture densities of 360 seed m^{-2} for barley, 440 seed m^{-2} for wheat, 80 seed m^{-2} for peas and 50 seed m^{-2} for beans, into a stale seed bed treated with a pre-emergence herbicide. Sowing densities of each crop in the species mixtures treatments were half those of monoculture plots. Fertiliser was applied just after sowing, with nitrogen (N) added to high input treatment plots at 25% standard-N rate, but no N was added to low input plots. No other chemicals were applied during the trial period except for desiccant applied to the barley-pea trial approximately 10 days prior to harvest. The wheat-faba bean trial was cut and baled on 2 August 2017 and the pea-barley trial was combined-harvested on 28–30 August 2017.

Post-harvest analysis of crop yield and quality was conducted following standard protocols developed in the project (Kiær *et al*., 2017). Over-yielding was estimated as the percentage deviation of average yields of mixture plots from the expected yield calculated from average yields of monoculture plots of each component using the formula:

$$E_i = p_i M_i$$

where p_i is the proportion of species *i* in the mixture (i.e. 0.5, as sowing density was 50% that of monocultures), M_i is the yield of species *i* in monoculture and E_i is its expected yield based on the yield in monoculture (Loreau, 1998).

Wheat-bean: Fresh mass of plot bales of spring wheat-faba bean mixtures was highest for faba bean monocultures and lowest for wheat monocultures. Overyielding was detected (3-23% higher yield than expected) for some cultivar combinations, particularly for mixtures including wheat cultivar Tybalt, which performed better than Alderon in monocultures and in mixtures (Table 3). The best-performing wheat-faba bean combinations maintained high silage protein concentration compared with faba bean monocultures. The effects of N input level were limited (not shown).

Pea-barley: Total seed mass per plot was, on average, highest for barley monocultures and lowest for pea monocultures, although some pea-barley mixtures gave high total grain yields (e.g. pea cultivars paired with spring barley cultivar RGT Planet: see Table 4). Over-yielding was detected in most barley-pea mixtures (5-29% higher yield than expected), except for three combinations (Table 4). Higher than expected productivity in barley-pea mixtures was generally due to improved performance of pea – but not barley - relative to monoculture. Best-performing mixtures included pea cultivars Ingrid and Daytona mixed with barley cultivars RGT Planet or KWS Sassy (Table 4). Worst-performing mixtures included pea cultivars Clara and Sakura mixed with barley cultivars Tamtam or Laureate (Table 4). The

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performance of individual pea cultivars in mixtures varied with management: Clara and Daytona showed greatest over-yielding under high inputs while Ingrid and Sakura showed greatest over-yielding under low inputs. There was no effect of the barley cultivar identity on pea performance, but pea cultivar identity affected barley performance as higher yields than expected were obtained when barley was paired with Daytona and Ingrid, but not with Clara and Sakura. Compared with monocultures, nitrogen concentrations of barley grain and pea seed were enhanced in mixtures; the barley cultivars KWS Sassy, Laureate and Tamtam, and the pea cultivar Clara were most responsive.

Table 3

Rank order of yield performance of wheat-faba bean mixtures based on percentage deviation of average yields of mixture plots from the expected yield calculated from average yields of monoculture plots of each component (highest first). Results are averaged across input levels.

Faba bean–wheat mixture
1. Boxer & Tybalt
2. Fuego & Tybalt
3. Boxer & Alderon
4. Fuego & Alderon

Table 4

Rank order of yield performance of pea-barley mixtures based on percentage deviation of average yields of mixture plots from the expected yield calculated from average yields of monoculture plots of each component (highest first). Results are averaged across input levels.

Pea-barley mixture
1. Ingrid & RGT Planet
2. Daytona & RGT Planet
3. Daytona & KWS Sassy
4. Ingrid & KWS Sassy
5. Ingrid & Laureate
6. Ingrid & Tamtam
7. Clara & RGT Planet
8. Daytona & Laureate
9. Daytona & Tamtam
10. Sakura & RGT Planet
11. Sakura & KWS Sassy
12. Clara & KWS Sassy
13. Clara & Laureate
14. Sakura & Laureate*
15. Sakura & Tamtam*
16. Clara & Tamtam*

*No overyielding

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Plot-scale field trials were conducted in 2018 to test the effect of different crop cultivars on the performance of spring-sown cereal-legume intercrops, including barley-pea, barley-lentil, wheat-faba bean and oat-faba bean. The trials experienced difficult growing conditions in 2018, including cold wet conditions after sowing and unusually hot dry conditions during the main growing period. Barley-pea mixtures performed poorly under these conditions, as peas matured much faster than barley leading to yield loss through pod shatter. The growing conditions were tolerated better by faba bean intercrops (with wheat or oat), and although lentil establishment was patchy, mature grain was harvested from this crop.

Figure 6

Wheat-Faba Bean trial (top) and pea-barley trial (bottom) at the James Hutton Institute in 2017

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2.3. Trials run by the Swedish University of Agricultural Sciences (SLU)

Trials were set up in 2017 and 2018 by the Swedish University of Agricultural Sciences to study differences in the performance of pea/barley and wheat/fava bean plant teams. Grain yield results of these trials are shown in Table 5.

Table 5

Mean ± 1 SD of grain yield (t ha-1) for different cultivars of cereals and legumes grown in pure and mixed culture under low and high nutrient input in the 2017 and 2018 growing seasons in Uppsala, Sweden.

	2017				2018			
	Low nutrient input		High nutrient input		Low nutrient input		High nutrient input	
Plant teams	*cereal*	*legume*	*cereal*	*legume*	*cereal*	*legume*	*cereal*	*legume*
Pea+barley								
Barley RGT Planet pure	2.44±0.72		2.91±0.88		0.60±0.41		0.84±0.12	
Barley Tamtam pure	2.66±0.60		2.96±0.33		0.83±0.08		0.97±0.07	
Barley Vilgott pure	2.91±0.57		2.36±0.85		1.41±0.15		1.44±0.24	
Pea Ingrid pure		0.87±0.22		1.00±0.38		1.58±0.17		1.62±0.12
Pea Clara pure		0.79±0.22		1.09±0.36		1.12±0.10		1.18±0.09
RGT Planet+Ingrid	4.37±0.92	0.71±0.31	3.10±1.01	0.69±0.34	0.95±0.27	1.47±0.43	1.06±0.16	1.40±0.26
Tamtam+Ingrid	3.67±1.85	0.78±0.53	4.14±1.12	0.76±0.16	0.95±0.10	1.39±0.26	1.35±0.15	1.30±0.20
Vilgott+Ingrid	3.69±0.96	0.62±0.31	3.88±1.17	0.79±0.34	1.60±0.22	1.15±0.51	1.96±0.21	1.20±0.26

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RGT Planet+ Clara	4.30±1.25	0.45±0.14	5.08±0.76	0.38±0.14	0.90±0.15	0.76±0.18	1.15±0.26	0.57±0.12
Tamtam+ Clara	4.35±1.23	0.49±0.42	3.80±1.75	0.32±0.11	1.16±0.21	0.54±0.13	1.26±0.39	0.75±0.14
Vilgott+ Clara	3.81±1.73	0.40±0.20	4.73±1.31	0.29±0.12	1.88±0.13	0.63±0.20	2.25±0.52	0.60±0.19
Faba bean+wheat								
Wheat Diskett pure	1.78±0.61		1.88±0.88		1.41±0.23		1.73±0.26	
Wheat KWS Alderon pure	2.75±0.82		2.87±0.75		1.97±0.20		2.16±0.21	
Wheat Cornetto pure	2.14±0.67		2.63±0.88		1.78±0.44		2.42±1.00	
Faba bean Fuego pure		1.72±0.39		1.76±0.32		1.50±0.18		1.41±0.29
Faba bean Boxer pure		2.07±0.35		1.74±0.63		1.46±0.45		1.59±0.36
Diskett + Fuego	2.54±1.03	0.80±0.29	3.24±0.97	1.04±0.23	1.29±0.70	1.19±0.18	2.42±0.97	1.14±0.64
KWS Alderon+ Fuego	4.27±0.79	0.95±0.15	4.51±1.73	0.99±0.21	2.96±0.26	0.87±0.07	2.98±1.15	0.96±0.02
Cornetto+ Fuego	3.74±0.69	0.97±0.16	3.23±0.48	0.89±0.07	2.45±0.41	1.07±0.25	1.98±0.70	1.61±0.49
Diskett+ Boxer	2.58±0.68	1.22±0.43	3.44±1.18	0.84±0.30	1.71±0.35	1.17±0.50	2.16±0.48	1.16±0.57
KWS Alderon+ Boxer	4.15±1.09	0.75±0.21	4.42±1.52	0.84±0.39	2.88±0.46	0.80±0.19	3.59±0.70	0.95±0.21
Cornetto+ Boxer	3.30±0.99	0.98±0.22	4.22±1.28	0.90±0.23	2.22±0.21	1.02±0.20	2.73±0.13	1.23±0.01

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2.4. Trials run by the Università Politecnica delle Marche (UNIVPM), Italy

In 2018, two field trials were established at the UNIVPM Experimental Station in Italy, including the cereal-legume combinations durum wheat-faba bean and barley-pea, respectively. Durum wheat, mainly dedicated to pasta production, and barley, used for animal feed, are the most important cereal crops in our region, whereas faba bean and pea are legume crops suitable for protein concentrate production for animal feed. All cereal and legume crops included in the trials are suitable for non-irrigated agricultural systems characterizing most of the cultivated areas of central Italy. Both trials were sown after winter to reduce the risk of broomrape parasitic attacks to the legume crops. This has been an important problem in the last few years that has restricted the cultivation of faba bean and pea cultivation in many areas due to the use of narrow rotations and early sowing of the legume crop (usually in November).

Durum wheat – faba bean trial. Due to the extremely rainy season in January and February, the sowing was delayed until March 14, 2018.

Durum wheat cultivars: Odisseo (high yield but lower protein content) and Aureo (lower yield potential but very high technological quality for pasta).

Faba bean cultivars: Chiaro di Torre Lama (traditional Italian cultivar for Central Italy with small seeds) and Prothabat69 (large seeds).

Monocrops and mixed crops (all combinations between the two durum wheat and the two faba bean cultivars) were included in the trial. In particular, three different mixed combinations were used, all including durum wheat at 50% seed density of the sole crop: MIX1 (50-50), MIX2 (50-65) and MIX3 (50-80); the numbers in parenthesis refers to the percentage of the sole crop seed density of the cereal and the legume, respectively.

The establishment of both crops was very good due to soil water availability to the crops (Figure 7), but it was particularly favourable to faba bean which developed very fast and vigorously. The cereal was overwhelmed by faba bean especially in the last part of the crop cycle and this influenced the quality parameters of durum wheat. To test the effectiveness of intercropping vs. monocrops the Total Land Equivalent Ratio (LERtot) was calculated as sum of the LER of durum wheat (LERw) and fababean (LERfb) included in each mixed crop combination:

$$LERtot = LERw + LERfb.$$

Values of LERtot higher than 1 shows greater yield when growing mixed crops compared with sole crops. The whole plot overall results on yield of sole crops and mixed crops, together with the LERw, LERfb and LERtot values, are summarized in Table 6. All mixed crop combinations had LERtot higher than 1, the highest values being observed for MIX2 and MIX3 combinations (Table 6).

Overall, the 2018 results, although being influenced by the late sowing and the rainfall, confirmed what was hypothesized by the results of the 2017 field trial that showed LERtot values close to 1 for

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the MIX1 (50:50). Better results were obtained by increasing the faba bean plant densities, as shown by the performance of MIX2 (50-65) and MIX3 (50-80).

Figure 7

Establishment of durum wheat-faba bean field trial (left: April 27, 2018; right: May 18, 2018).

Table 6

Durum wheat – faba bean field trial: Whole-Plot Results.
Multiple comparisons: Tukey's Honest Significant Difference test (HSD test). Mixed crops showing the highest LERtot values are highlighted in bold. Mix1 (50:50), Mix2 (50-65), Mix3 (50-80): values in parenthesis represent the percentage of sole crop seed density applied in the mix to durum wheat and faba bean, respectively.

WHOLE-PLOT RESULTS	WHEAT		FABA BEAN		MIX
Plant Teams	YIELD (t/ha)	LERw	YIELD (t/ha)	LERfb	LERtotal
Odisseo (sole crop)	2,54 A	-----	-----	-----	-----
Aureo (sole crop)	1,95 B	-----	-----	-----	-----
Prothabat (sole crop)	-----	-----	2,68 A	-----	-----
Chiaro di Torre Lama (sole crop)	-----	-----	2,47 A B	-----	-----
Chiaro-Aureo Mix1	0,86 C D	0,45 A	1,41 D	0,58 A B	1,03
Chiaro-Odisseo Mix1	1,08 C D	0,43 A	1,73 C D	0,71 A B	**1,13**
Proth-Aureo Mix1	0,85 C D	0,46 A	1,53 C D	0,57 A B	1,03
Proth-Odisseo Mix1	1,25 C	0,49 A	1,39 D	0,53 B	1,01
Chiaro-Aureo Mix2	0,86 C D	0,45 A	1,57 C D	0,65 A B	1,09
Chiaro-Odisseo Mix2	1,03 C D	0,40 A	1,91 B C D	0,78 A	**1,19**
Proth-Aureo Mix2	0,89 C D	0,48 A	1,78 C D	0,67 A B	**1,15**
Proth-Odisseo Mix2	1,02 C D	0,41 A	1,72 C D	0,64 A B	1,05
Chiaro-Aureo Mix3	0,75 D	0,39 A	1,78 C D	0,73 A B	**1,12**
Chiaro-Odisseo Mix3	1,11 C D	0,44 A	1,71 C D	0,70 A B	**1,13**
Proth-Aureo Mix3	0,70 D	0,38 A	2,06 B C	0,77 A	**1,15**
Proth-Odisseo Mix3	0,90 C D	0,36 A	1,94 B C D	0,72 A B	1,08

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Barley – Pea field trial. The field trial was established on February 1, 2018. A split-plot design including High and Low nitrogen fertilization levels as main plots was applied.

Barley cultivar: Tea (early maturing).

Pea cultivars: Hardy and Astronaute.

Monocrops and mixed crops (all combinations between Tea and the two pea cultivars) were included in the trial. The 2017 results showed that barley, sown at 50% seed density in MIX1 (50-50), was a very strong competitor against pea. Therefore, in the 2018 trial mixed crops were chosen including a progressive decrease of barley density followed by a corresponding increase of pea density in the mixed crops. Therefore, four different mixed combinations were used: MIX1 (50-50), MIX2 (33-67), MIX3 (25:75) and MIX4 (20-80), the numbers in parenthesis refers to the percentage of sole crop seed density of barley and pea sole crop, respectively.

The establishment of both crops was very good, even though a late snow happened at the beginning of March (Figure 8). As previously explained for the durum wheat-faba bean trial, grain yield and LER were evaluated to test the effectiveness of the new mixed combinations tested. Results are summarized in Table 7.

Figure 8

Barley-Pea field trial: snow on March 4, 2018 (left) and crop establishment on April 27, 2018 (right).

Barley was very competitive in the mix, showing LERbarley values far higher than expected based on barley seed density in the mixed crops (Table 7). Conversely, pea had LERpea values much lower than expected. However, the LERtotal values were always higher than 1, even though the mixed crops including the higher density of barley (Mix1 and Mix2) showed the highest LERtotal values.

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Table 7

WP2 barley-pea field trial (HIGH and LOW INPUT): Whole-Plot Results. Multiple comparisons: Tukey's Honest Significant Difference test. Mix showing the highest LERtotal values are highlighted in bold. Mix1 (50:50), Mix2 (33-67), Mix3 (25-75), Mix4 (20-80): values in parenthesis represent the percentage of sole crop seed density applied in the mix to barley and pea, respectively.

WHOLE-PLOT RESULTS		BARLEY		PEA		MIX
Plant Team	INPUT	Yield (t/ha)	LERbarley	Yield (t/ha)	LERpea	LERtotal
Tea	HIGH	2,86 A	-----	-----	-----	-----
ASTRONAUTE	HIGH	-----	-----	3,18 A	-----	-----
HARDY	HIGH	-----	-----	3,04 A	-----	-----
Astronaute-Tea Mix1	HIGH	2,48 AB	0,87 A	0,82 E	0,26 D	**1,08**
Hardy-Tea Mix1	HIGH	2,32 ABC	0,80 ABCD	0,77 E	0,26 D	**1,16**
Astronaute-Tea Mix2	HIGH	2,04 BCDE	0,71 ABCDEF	1,15 BCDE	0,36 ABCD	**1,08**
Hardy-Tea Mix2	HIGH	1,79 CDEFG	0,64 ABCDEF	1,24 BCDE	0,41 ABCD	**1,12**
Astronaute-Tea Mix3	HIGH	1,60 DEFG	0,57 DEF	1,40 BCD	0,44 ABC	1,06
Hardy-Tea Mix3	HIGH	1,58 EFG	0,56 DEF	1,54 B	0,52 A	1,03
Astronaute-Tea Mix4	HIGH	1,53 EFG	0,54 EF	1,52 B	0,49 A	1,07
Hardy-Tea Mix4	HIGH	1,41 EFG	0,50 F	1,57 B	0,52 A	1,01
Tea	LOW	2,27 ABCD	-----	-----	-----	-----
ASTRONAUTE	LOW	-----	-----	3,18 A	-----	-----
HARDY	LOW	-----	-----	2,86 A	-----	-----
Astronaute-Tea Mix1	LOW	1,97 BCDEF	0,87 AB	0,96 CDE	0,30 CD	**1,13**
Hardy-Tea Mix1	LOW	1,90 BCDEFG	0,83 ABC	0,91 DE	0,32 BCD	**1,17**
Astronaute-Tea Mix2	LOW	1,68 CDEFG	0,74 ABCDE	1,16 BCDE	0,37 ABCD	1,01
Hardy-Tea Mix2	LOW	1,60 DEFG	0,71 ABCDEF	1,18 BCDE	0,41 ABCD	1,11
Astronaute-Tea Mix3	LOW	1,41 EFG	0,62 BCDEF	1,55 B	0,49 A	1,11
Hardy-Tea Mix3	LOW	1,40 EFG	0,61 CDEF	1,30 BCDE	0,45 ABC	1,06
Astronaute-Tea Mix4	LOW	1,34 FG	0,59 CDEF	1,55 B	0,48 AB	1,07
Hardy-Tea Mix4	LOW	1,24 G	0,55 EF	1,46 BC	0,51 A	1,05

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2.5. Trials run by the University of Münster (WWU), Germany

Field trials were established in 2017 and 2018 in Münster, North-West Germany (Atlantic climate). For the present report, we focus on the 2018 growing period. Sowing was carried out at end of April 2018. Plant teams comprising cereals and legumes were chosen in agreement with a local farmer. Species and plant teams chosen were spring wheat (*Triticum aestivum* L.) intercropped with faba bean (*Vicia faba* L.) (Figure 9) and barley (*Hordeum vulgare* L.) intercropped with pea (*Pisum sativum* L.). Seed yield obtained from such mixtures is commonly used as kettle feed. For each plant partner, two cultivars were selected, on the one hand cultivars that are locally relevant and on the other hand cultivars obtained from project partners from different climate regions, to test for performance and adaptation to the respective region's climate (for a list of cultivars see Table 8). Plant teams were tested both in monocultures and in intercrop for high and low input conditions, respectively.

Sowing of monocultures was carried out at a density of 320 seeds per m^2 for barley, 440 seeds per m^2 for wheat, 80 seeds per m^2 for peas and 40 seeds per m^2 for beans. In the species mixtures crop densities were reduced according to two ratios, 50:50 and 75:25 (legume:cereal). In high input plots, soil was treated with monocot herbicide prior to sowing and fertilised just after sowing with nitrogen (N, 25% standard-N addition). Low input plots received no soil treatment. To avoid spill-over of soil treatments from high- to low- input rows, the distance between treated and untreated blocks was at least 1 m.

Field layout followed a split-plot randomized complete block design, with plant team treatments randomized within a row and high- and low- input treatments assigned to full rows. Two high- and two low-input rows built up one block, each block being one replicate for a total of two replicates. Harvest was carried out in the beginning of August 2018.

Several plant traits and ecologically important data were recorded. For example, arthropod monitoring was carried out and flower visitors were monitored and analysed. Post-harvest analysis included crop yield and crop performance.

Table 8

List of cultivars used in 2018 at the University of Münster trial.

Plant Species	Cultivar	Country
Wheat	Tybalt	Germany
Wheat	Cornetto	Denmark
Barley	Sunshine	Italy
Barley	Salome	Germany
Faba bean	Julia	Austria
Faba bean	Fuego	Italy
Pea	Hardy	Italy
Pea	Astronaute	Italy

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Wheat-bean: There were differences regarding yield between high and low input. Yield was higher under high management input. All monocultures yielded higher than mixtures (Table 9). There were small differences between high and low management input, indicating that some cultivars like faba bean cv. Fuego can be used in both organic and conventional farming.

Figure 9

Wheat-bean trial, Münster 2018 (Jana Brandmeier ©)

Table 9

Rank of yield performance of wheat-faba bean monocultures and mixtures (based on average yields, unpublished data from 2018) for high and low input.

YIELD RANK POSITION	HIGH INPUT	LOW INPUT
1	Tybalt	Cornetto
2	Cornetto	Fuego
3	Fuego	Tybalt
4	Julia	Julia
5	Fuego & Tybalt	Fuego & Cornetto
6	Fuego & Cornetto	Fuego & Tybalt
7	Julia & Cornetto	Julia & Cornetto
8	Julia & Tybalt	Julia & Tybalt

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Barley-pea: Within the barley-pea field trial, both barley cultivars yielded highest (Table 10). Pea yield was significantly reduced due to severe bird damage in combination with water stress. Nevertheless, some barley-pea mixtures yielded higher than pea monocultures, indicating that growing plants in mixtures can moderate yield losses.

Table 10

Rank of crop performance for yield of barley-pea monocultures and mixtures (based on average yields, unpublished data from 2018) for high and low input.

YIELD RANK POSITION	HIGH INPUT	LOW INPUT
1	Salome	Sunshine
2	Sunshine	Salome
3	Hardy & Salome	Astronaute & Salome
4	Hardy & Sunshine	Astronaute & Sunshine
5	Astronaute	Hardy
6	Astronaute & Salome	Hardy & Sunshine
7	Astronaute & Sunshine	Hardy & Salome
8	Hardy	Astronaute

2.6. Trials run by Saatzucht Gleisdorf (SZG), Austria

The Austrian field trials of 2017 and 2018 were established in Gleisdorf, Austria (sub Mediterranean climate; Figure 10, Figure 11). Faba bean trials were performed in cooperation with the EIP project “Innobrotics - Lösung der Maiswurzelbohrerproblematik in dem Anbau- und Versuchsgebiet Österreich“, which was financed by the European Agricultural Fund for Rural Development LE14-20, supported by the federal government, the federal province and the European Union. The *Phaseolus* bean trials were performed for the DIVERSify project only.

Sowing was carried out in March/April (faba bean trials) and April/May (*Phaseolus* bean trials). Species, cultivars and plant teams, as well as sowing densities, are shown in Table 11 and Table 12.

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Seed obtained from faba bean mixtures is commonly used as feed, while seed obtained from *Phaseolus* bean mixtures is for human consumption (beans) and feed (corn, sorghum). For each plant partner, cultivars that are locally relevant were selected. In an additional trial, 16 cultivars obtained from project partner ICARDA from hot/dry climate regions were tested for their performance and adaptation to Austrian climate. All plant teams were tested both in monocultures and in intercrop. Faba bean intercrops were tested under low input conditions only, and *Phaseolus* bean intercrops were tested for high and low input, respectively. In high input plots, soil was fertilised just after sowing with Nitrophoska Perfekt 500 kg/ha (NPK: 15:5:20).

Table 11

List of cultivars used in SZG trials 2017 and 2018.

Plant Species	Cultivar	Year	Management
Faba bean mixtures			
Faba bean (*Vicia faba*)	Alexia	2017 (2x), 2018	Low input
Faba bean (*Vicia faba*)	Julia	2017 (2x), 2018	Low input
Faba bean (*Vicia faba*)	GL Sunrise	2017 (2x), 2018	Low input
Wheat (*Triticum aestivum*)	Cornetto	2017 (2x), 2018	Low input
Oat (*Avena sativa*)	Elison	2017 (2x)	Low input
Oat (*Avena sativa*)	Navigator	2018	Low input
Triticale (*Triticosecale*)	Somtri	2018	Low input
Grass pea (*Lathyrus sativa*)	RWA	2017 (2x), 2018	Low input
Additional faba bean trial with Lebanon/ICARDA material			
Faba bean (*Vicia faba*)	16 ICARDA cultivars + 2 local varieties	2018, 2019 (sown)	Low input
Wheat (*Triticum aestivum*)	Cornetto	2018	Low input
Triticale	Somtri	2018	Low input
Oat (*Avena sativa*)	Essex	2019 (sown)	Low input
***Phaseolus* bean mixtures**			
Bean (*Phaseolus vulgaris*)	Elsterbohne	2017	Low input/high input
Bean (*Phaseolus vulgaris*)	Schwarze	2018	Low input/high input
Bean (*Phaseolus vulgaris*)	Blau-Weiße	2017, 2018	Low input/high input
Bean (*Phaseolus coccineus*)	Bonela	2017, 2018	Low input/high input
Corn (*Zea mays*)	DKC4717	2017, 2018	Low input/high input
Corn (*Zea mays*)	DKC5007	2017, 2018	Low input/high input
Sorghum (*Sorghum bicolor*)	ES Harmattan	2017, 2018	Low input/high input

In 2017 the faba bean mixed culture trial was sown twice due to very dry conditions after sowing of the first trial. Unfortunately, the whole growing season of 2017 was very dry, so also the second trial suffered from drought. In contrast, spring 2018 was extremely wet, the soil was water soaked for long time periods and pressure of root diseases was very high, especially for faba beans.

After evaluation of the results of 2017, the sowing densities for 2018 were modified for faba bean-oat and faba bean-grass pea mixtures (Table 12).

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Table 12

Sowing densities of the faba bean mixed cultures in 2017 and 2018; ratio indicates relation to the sowing density of respective monoculture and seeds/square meter.

Plant Team	**2017**		**2018**	
	ratio	seeds/m²	ratio	seeds/m²
Faba bean - Wheat	50 : 50	20 : 220	50 : 50	20 : 220
Faba bean - Oat	50 : 50	20 : 165	67 : 33	26 : 123
Faba bean - Triticale	-	-	50 : 50	20 : 175
Faba bean - Grass pea	50 : 50	20 : 42	67 : 33	26 : 28

The *Phaseolus* bean monocultures were sown on rods as support (length of rods: 4 meters, 3 meters above ground) with one plant per rod. The mixed cultures were sown with corn or sorghum as supporting crop, where the distance between two rows was 72 cm and the distance within rows 40 cm for corn or sorghum and 40 cm for beans as well. This sowing density of corn equates to about 50% of the standard sowing density of corn monocultures in our region.

Faba bean trials field layout followed a complete randomized plot design with 4 replicates. *Phaseolus* bean trials field layout followed a split-plot randomized block design with 4 replicates, with plant teams randomized within a block for low input and within a block for high input management conditions. Harvest was carried out in August for faba bean trials and November for *Phaseolus* bean trials. Several plant traits and ecologically important data were recorded, for example, plants per square meter, plant and canopy height, start of flowering, growth stage, lodging, ripening and crop yield.

Ground cover of crops and of weeds in faba bean mixed cultures. Several times during the growing season, crop and weed ground cover was assessed. In 2017 and 2018, the percentage of weed ground cover at the end of vegetation period was highest in all faba bean monocultures and was suppressed significantly in oat monoculture and faba bean-oat mixed cultures. Also, faba bean-grass pea and faba bean-wheat mixed cultures led to a decrease of weed pressure.

Yield. Under the very dry conditions of 2017, faba bean-grass pea mixed cultures over-yielded compared with faba bean monocultures. The drought resistant grass peas compensated for the poor

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faba bean yield. Under the very wet conditions of 2018 grass pea yielded poorly and faba bean compensated in the mixed culture of faba bean-grass pea. This example shows that even legume-legume plant teams can moderate yield losses of legume monocultures under extreme weather conditions. Regarding total yield in tonnes per hectare, the faba bean-wheat and faba bean-oat mixed cultures over-yielded compared with the faba bean monoculture in the first sowing of 2017 as well as in 2018.

Figure 10

Innobrotics and DIVERSify faba bean intercrop trial (second sowing) (picture from June 26, 2017)

Additional faba bean trial with material from Lebanon (International Center for Agricultural Research in the Dry Areas, ICARDA)

This trial was sown in April 2018 and April 2019. Unfortunately, the cultivars received from ICARDA with origin in dry regions (Lebanon, Syria, Pakistan, Tunisia, Spain) suffered extremely from the wet conditions of 2018 in Austria with high pressure of root diseases. As those cultivars develop several tillers in dry regions, the chosen sowing density was rather low for Austrian conditions. Those circumstances resulted in very low yields and are the reason that this trial will be repeated in 2019.

***Phaseolus* bean mixtures**

The *Phaseolus* bean monocultures were sown on rods as support (4 meters, 3 meters above ground) with one plant per rod. The mixed cultures were sown with corn or sorghum as the supporting crop, where the distance between two rows was 72 cm and the distance within rows 40 cm for corn or

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sorghum and 40 cm for beans. This sowing density for corn equals about 50% of the standard sowing density of corn in our region.

Lodging. Especially in years with high biomass formation of *Phaseolus* beans (wet conditions like 2018), lodging is a major problem in *Phaseolus*-corn mixtures. The data for 2017 and 2018 showed that the sorghum cultivar ES Harmattan as supporting plant showed significantly less lodging than both corn cultivars. Corn cultivar DKC4717 showed better standing ability with all three *Phaseolus* bean cultivars than corn cultivar DKC5007.

Yield. Locally produced *Phaseolus* beans are a high value crop, so focus of *Phaseolus* bean mixed cultures generally is on the bean yield, with corn and sorghum seeds as additional crop used for food. In 2018, monocultures of all three bean cultivars yielded more than twice as high as the mixed cultures. Nevertheless, the advantage of mixed cultures is the strongly reduced work input compared with bean monocultures that need rods or rears as climbing support.

In three out of four trials (two years, two management practices; Table 13), the combination Bonela & DKC4717 yielded better than Bonela & DKC5007, and the combination Blau-Weiße & DKC5007 in all cases yielded better than Blau-Weiße & DKC4717. In 2018 Schwarze & DKC4717 yielded better in high and low input than Schwarze & DKC5007. These results might be an indication of a cultivar-specific response of the *Phaseolus* bean-corn mixed cultures. Bonela and Schwarze are cultivars with a long pod setting period and late maturity whereas DKC4717 is earlier in maturity than DKC5007. Blau-Weiße is a cultivar with a shorter pod setting period and early maturity and yields better with the later corn cultivar DKC5007.

In the hot and dry year of 2017, the *Phaseolus vulgaris* cultivar Blau-Weiße yielded higher than the *Phaseolus coccineus* cultivar Bonela in the mixed cultures; in 2018 with more moderate temperatures and wet conditions the yield rank of those two cultivars is mixed. This finding corresponds with the general argument that *P. vulgaris* is more heat tolerant than *P. coccineus*.

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Table 13

Rank of *Phaseolus* bean monocultures and intercrops (based on average yields of the bean partner) for high and low input.

Yield rank	2018 - High input		Yield rank	2018 - Low input
1	Schwarze		1	Schwarze
2	Bonela		2	Bonela
3	Blau-Weiße		3	Blau-Weiße
4	Schwarze & DKC4717		4	Schwarze & DKC4717
5	Schwarze & ES Harmattan		5	Bonela & DKC4717
6	Bonela & DKC4717		6	Schwarze & ES Harmattan
7	Bonela & DKC5007		7	Schwarze & DKC5007
8	Blau-Weiße & DKC5007		8	Blau-Weiße & DKC5007
9	Schwarze & DKC5007		9	Bonela & DKC5007
10	Bonela & ES Harmattan		10	Blau-Weiße & DKC4717
11	Blau-Weiße & DKC4717		11	Bonela & ES Harmattan
12	Blau-Weiße & ES Harmattan		12	Blau-Weiße & ES Harmattan

Yield rank	2017 -High input		Yield rank	2017 - Low input
1	Bonela		1	Bonela
2	Bonela & ES Harmattan		2	Blau-Weiße & DKC5007
3	Blau-Weiße & DKC5007		3	Blau-Weiße
4	Blau-Weiße		4	Blau-Weiße & DKC4717
5	Blau-Weiße & DKC4717		5	Bonela & ES Harmattan
6	Blau-Weiße & ES Harmattan		6	Bonela & DKC4717
7	Bonela & DKC5007		7	Blau-Weiße & ES Harmattan
8	Elsterbohne & DKC5007		8	Bonela & DKC5007
9	Bonela & DKC4717		9	Elsterbohne & DKC5007
10	Elsterbohne & DKC4717		10	Elsterbohne & DKC4717
11	Elsterbohne & ES Harmattan		11	Elsterbohne & ES Harmattan
12	Elsterbohne		12	Elsterbohne

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Figure 11

***Phaseolus* bean intercrop trials 2017 and 2018 (pictures from Jul and Sep 2017 and Nov 2018)**

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2.7 Trials run by University of Copenhagen (UCPH), Denmark

In field trials conducted at the University field station outside Copenhagen, we evaluated the performance and compatibility of some of the most commonly used intercrops by Danish farmers. Cultivars of pea-spring barley and faba bean–spring wheat, respectively, were grown as monocrops and in all pair-wise combinations, yielding a total of ten crop mixtures (Table 14).

Table 14

Cultivars used to construct the plant teams of pea and barley, and faba bean and wheat, respectively (country of origin provided in brackets).

Pea	Barley
Audit (NL)	Salome (DE)
Ingrid (SE)	Tamtam (UK)
Mythic (DK)	

Faba bean	Wheat
Boxer (SE)	Cornetto (DE)
Julia (AT)	KWS Alderon (DE)

In 2017 and 2018, spring-sown field trials were established at the UCPH experimental station, one for each plant team (Figure 12). Seeding rate of each crop species in mixtures was half of the monocrop rates. In all four field trials, plots of size 1.25 x 10 m were distributed randomly in a split-plot design in four replications with input level as main factor.

All intercropped plant teams and monocropped cultivars were grown under low and high inputs, respectively. Here, organic and inorganic nitrogen (N) was added to the treatments at rates of 70 kg N/ha and 20 kg N/ha, respectively. Chemicals were used in the high-input treatment to control weeds, fungal pathogens and herbivores. In the low-input treatment, early blind-harrowing was used as weed control.

Several traits were assessed and recorded, following a developed set of standardized protocols (Table 15). In the following, we present results from a subset of agronomic traits measured in the two stakeholder-driven plant teams. Agronomic mixing effect was estimated as the percentage deviation of mixture plots from the expected average of the two monocrop plots.

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Figure 12

Establishment of the pea–barley and faba bean–wheat trials at UCPH in 2017.

Table 15

Plant traits and crop performance measured in 2017 and 2018 during University of Copenhagen field trials. Core traits in italics.

Plant emergence	*Vegetative biomass*	*Days to flowering*
Ground cover	*Disease incidence and severity*	*Lodging*
Canopy height	*Weed biomass*	*Vegetative or grain yield*
Tillering/Branching	*Light interception / LAI*	*Seed weight*
Plant growth habit	Herbivory	Number of nodes
Plant length	Leaf dry matter content	Mature pods/heads
Specific leaf area	Nitrogen content (SPAD)	Stability of pods
Internode length	Canopy reflectance	Seeds per pod
Leaf biomass		Grain quality

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Pea–Barley trials

Substantial variation in grain yields across treatments and years was observed (Figure 13). Higher total grain yields were seen under high input in both monocrops and mixtures, and cereals were more sensitive than legumes to the input level (not shown). Yields were substantially lower in 2018 (very drought-prone) in both treatments, and the yield level of low input plots in 2017 were higher even than the high input plots in 2018. Legumes were significantly more sensitive to drought (not shown).

Over-yielding was detected in all but one pea-barley combination, ranging from 0 to 45%. The over-yielding potential (the maximal observed over-yielding) tended to increase with the expected yield, as did average over-yielding in the four treatment-year combinations. Accordingly, mixtures provided the five highest-ranking yields overall (Table 16).

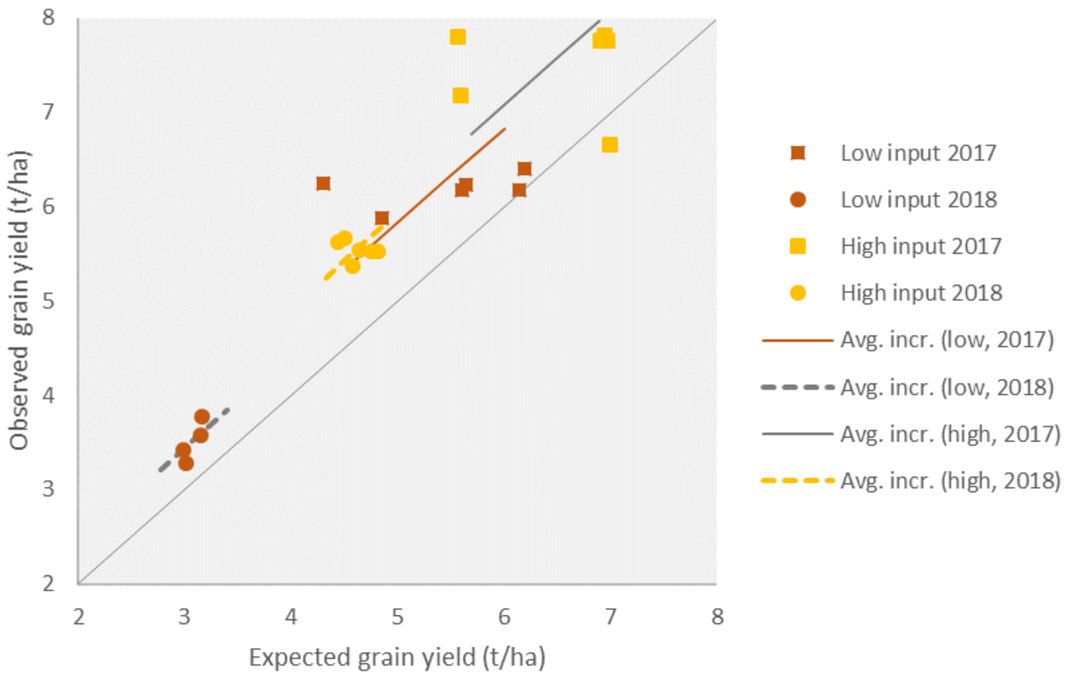

Figure 13

Total grain yield of each pea-barley mixture against their expected yield (average of the two monocrops). Points above the line show over-yielding in mixtures. Lines mark the average over-yielding in each of four treatment-year combinations.

Lodging of pea near maturity is a well-known problem to farmers that was also observed in field trials of 2017 (plentifully rainfed). Results highlighted that intercropping was an effective means to remove the problem (Figure 14), which can impose significant harvest losses. Barley was significantly better

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than pea at suppressing weeds (not shown), which helped provide all six mixtures with a better weed suppression than monocropped pea (Figure 15).

Table 16

Average yield ranks of pea–barley mixtures and monocrops calculated across the four treatment-year combinations.

Rank	Mixture/Monocrop
1	Mythic-Tamtam
2	Audit-Tamtam
3	Audit-Salome
4	Mythic-Salome
5	Ingrid-Salome
6	Ingrid
7	Mythic
8	Ingrid-Tamtam
9	Salome
10	Tamtam
11	Audit

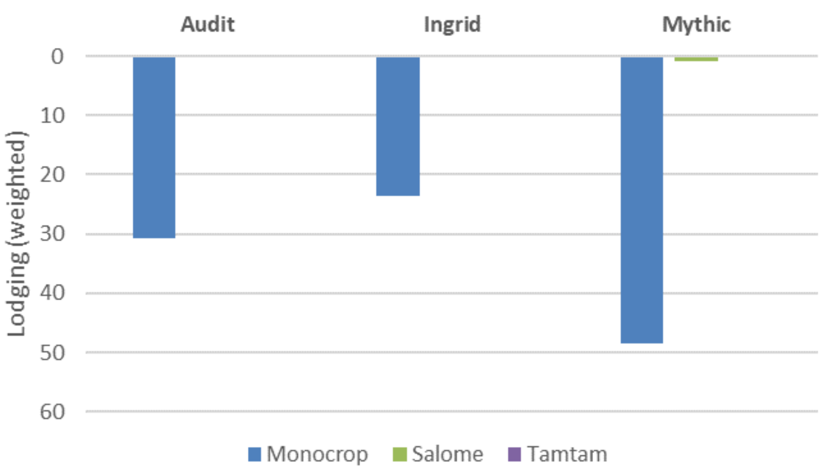

Figure 14

Lodging rates (plot area x degree lodging) of three pea cultivars in monocrops and mixtures in the UCPH 2017 field trial.

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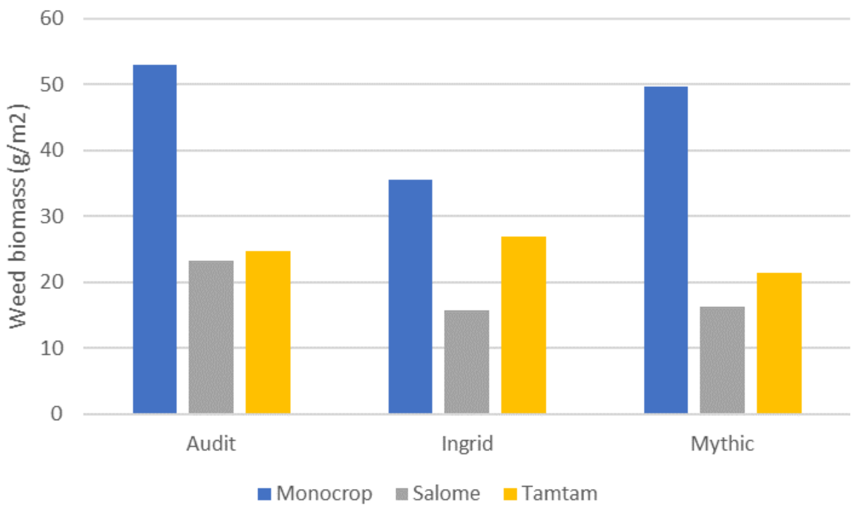

Figure 15

Weed biomass in pea monocrops and in mixtures with barley.

Faba bean-Wheat trials

Overall grain yield patterns were similar to the pea-barley mixtures. Substantial variation in grain yields across treatments and years was observed (Figure 16). Higher total grain yields were seen under high input in both monocrops and mixtures. Yields were substantially lower in 2018 (very drought-prone) in both treatments, and the yield level of low input plots in 2017 were on the same level as the high input plots in 2018. Faba bean was significantly more sensitive to drought, with wheat taking over (not shown).

Over-yielding was detected mainly in 2018 (ranging between 34 and 48%). In the high input treatment in 2017, only negative yield effects of mixing were observed (Figure 16). Total yields across input levels were intermediate in both years in mixtures compared with either species monocropped (Figure 17). The yield of faba bean cultivars ranked highest in 2017 (plentifully rainfed) but lowest in 2018 (drought-prone), whereas the opposite was true for wheat. Across treatments, monocropped faba bean cultivar Boxer and mixtures with this cultivar provided the highest-ranking yields (Table 17), having a more stable performance across environments.

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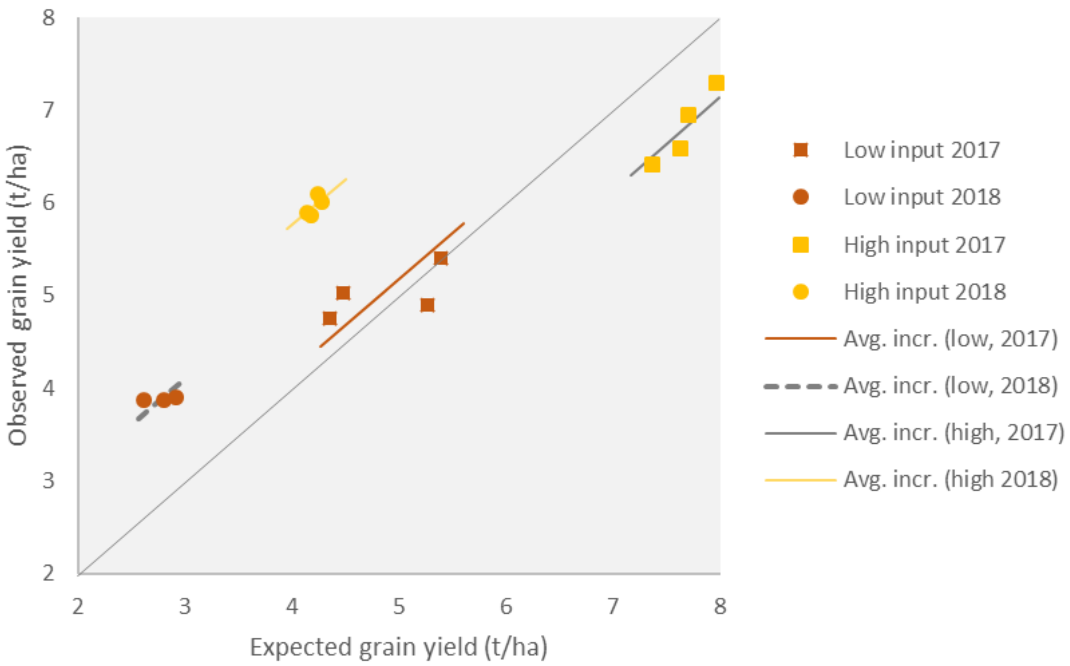

Figure 16

Total grain yield of each faba bean-wheat mixture against their expected yield (average of the two monocrops). Points above the line show over-yielding in mixtures. Lines mark the average over-yielding in each of four treatment-year combinations.

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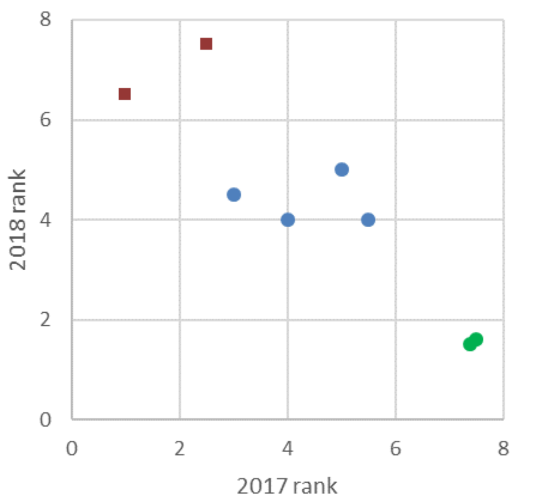

Figure 17

Rank order of yield performance of wheat-faba bean mixtures (blue) and wheat (green) and faba bean (red) monocrops in the two trial years. Lower rank means comparably higher yield in each year.

Table 17

Average yield ranks of faba bean–wheat mixtures and monocrops calculated across the four treatment-year combinations.

Rank	Mixture/Monocrop
1	Boxer
2	Boxer-KWS Alderon
3	Boxer-Cornetto
4	Cornetto
5	KWS Alderon
6	Julia-Cornetto
7	Julia
8	Julia-KWS Alderon

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2.8 Grassland trials in Portugal (FERTIPRADO/ITQB)

In the DIVERSify project, trials with annual forage mixtures were set up. These trials aimed to investigate productivity and harvest quality in monoculture components and optimized multi-species mixtures.

During two years, four annual forage mixtures, plus their nine monoculture components were repetitively compared in a field trial located at Vaiamonte in the South of Portugal. Here, we summarize results from the first year, while mixtures for the second year are growing now (sown on the 10th October 2018).

For comparing the mixtures and their monocultured species components, the production, botanical composition and quality were evaluated with two approaches: multiple cuts during the growing season, and a single final cut (Figure 18).

Figure 18

Vaiamonte Field trial during 2017/2018 season

In the multiple cuts approach (three cuts), the most productive mixture was Mix 4, with 9,032 kg DM/ha (Figure 19). Mix 3 had lower production compared with all the other tested mixtures, which were very similar. *Trifolium michelianum* was the most productive individual component with 9,817 kg DM/ha.

The botanical composition analysis showed that the mixtures were very balanced in their components (legumes and grasses) with a low proportion of other species (Figure 20).

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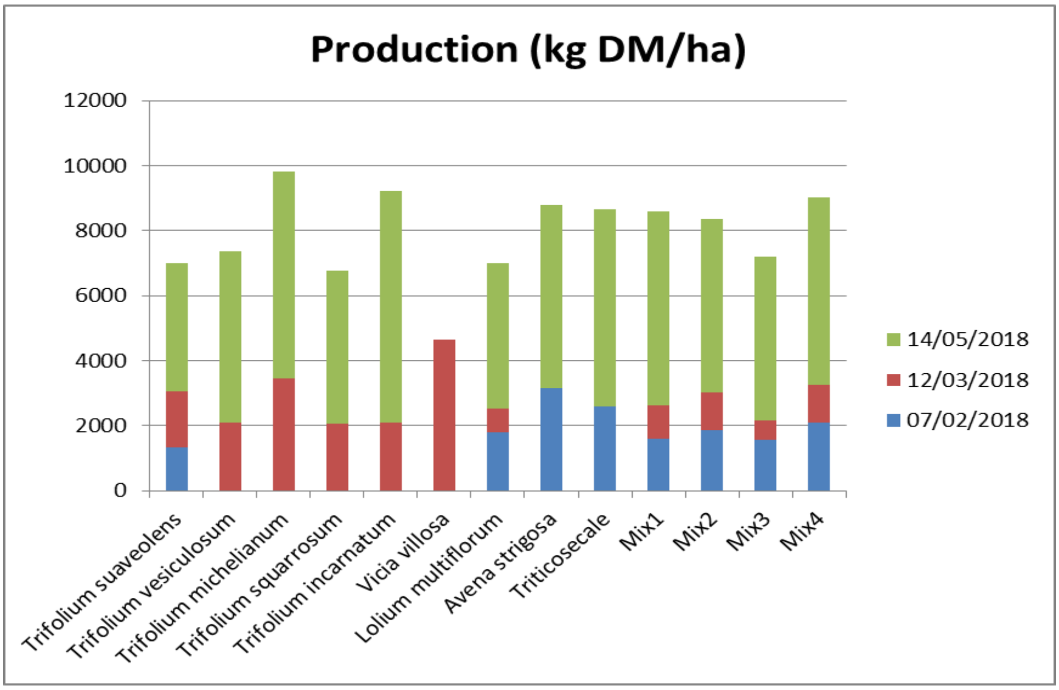

Figure 19

Average production (dry matter) values for three mixtures and different annual forage species, measured in three multiple cuts.

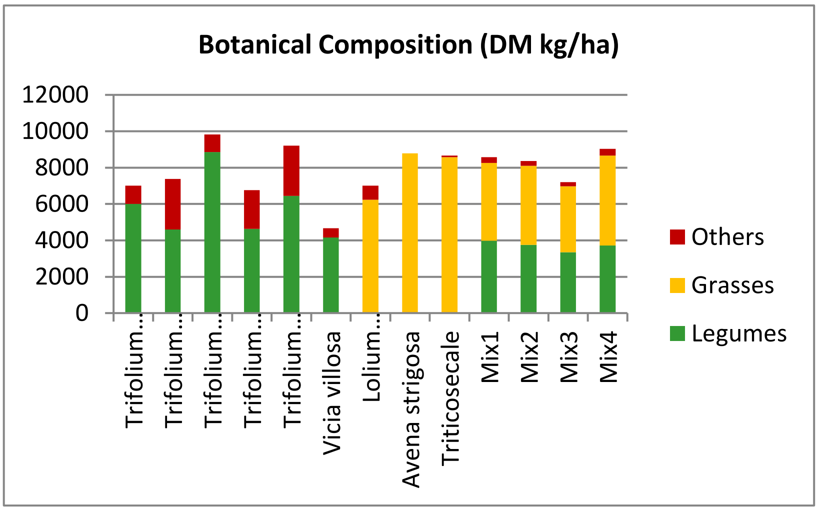

Figure 20

Average botanical composition (legumes, grasses or other species) for three mixtures and different annual forage species, measured in three multiple cuts.

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The crude protein trait among the four mixtures varied between 21.7% and 9.8% and the crude fibre between 27.4% and 16.1%, depending on the date of cut (Figure 21).

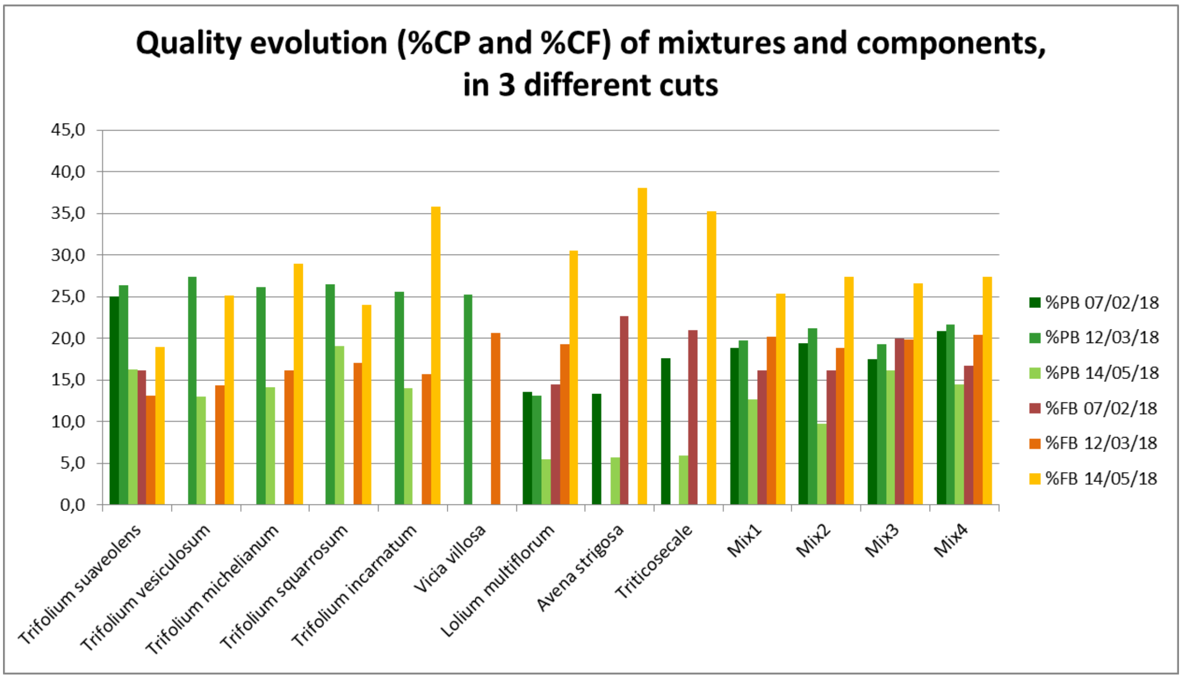

Figure 21

Average quality in terms of percentage of crude protein and crude fibre for three mixtures and different annual forage species, measured in three multiple cuts.

In the single cut approach, the most productive mixture was Mix 3 with 11,420 kg DM/ha, but the other mixtures were very close to this value, except Mix 1 (Figure 22).

The Triticosecale was the individual component with higher production but with the lowest percentage of crude protein (3.5 %; Figure 23). The Botanical composition analysis showed that the proportion of other species was a little higher than in the multiple cuts, as well as the percentage of grasses. However, in general the individual legumes had a higher content of crude protein.

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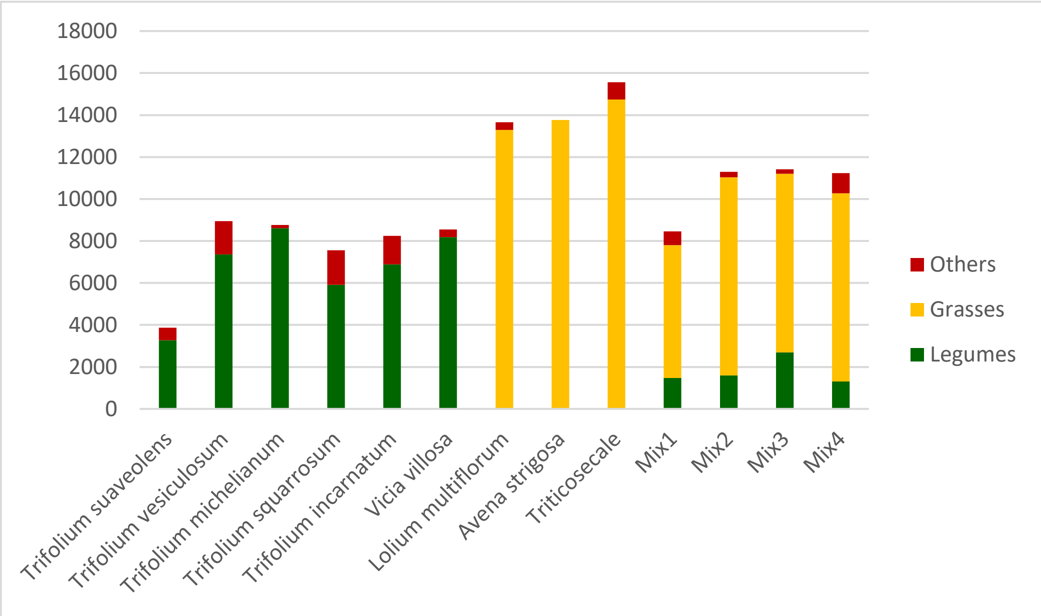

Figure 22

Average production and botanical composition values for three mixtures and different annual forage species, measured in the single cut approach.

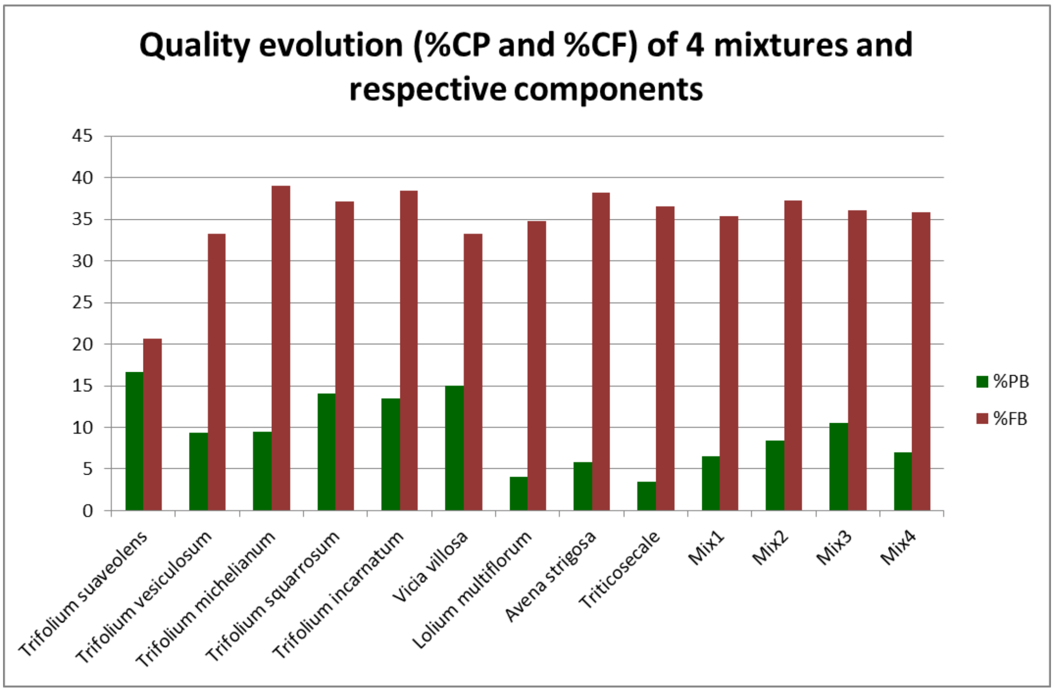

Figure 23

Average quality in terms of crude protein and crude fibre in three mixtures and different annual forage species, measured in the single cut approach.

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3. Conclusions and outlook

The trials conducted at eight different sites across pedoclimatic regions in Europe clearly show that specific combinations of cultivars in wheat/faba bean and barley/pea systems are promising candidates for high-yielding crop mixtures under low and/or high input conditions. In addition, grassland trials showed how forage mixtures can be optimized for yield and nutritive value. In the future, data across all trials will be analyzed in a joint statistical analysis. These results will help design optimized plant teams for European farming systems.

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