

Article

Cereal–Legume Intercropping: Which Partners Are Preferred in Northwestern Europe?

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Abstract: To increase Europe’s self-sufficiency for protein sources, boosting plant protein production is a prerequisite. Yield variability is one of the main problems regarding the cultivation of protein crops. In this light, cereal–legume intercropping can offer a solution, as well-balanced intercropping systems are less prone to yield variations. Therefore, in this study the effects of (i) species/genotype combination, (ii) intercropping sowing densities and (iii) fertilizer regime were evaluated under Belgian (Northwestern European) conditions over three years (i.e., the 2020–2021, 2021–2022 and 2022–2023 seasons). Regarding the species combinations, winter barley x winter pea, winter wheat x winter faba bean and winter triticale x winter faba bean, it was observed that the best-performing combination varied from year to year depending on the prevailing weather conditions. A reduced sowing density (i.e., 130 seeds/m² for the cereal partner and 20 seeds/m² in the case of faba bean or 40 seeds/m² in the case of pea) was sufficient to achieve competitive yields under the prevailing conditions. Inoculation with commercial *Rhizobium* strains did not result in an increased yield. Fertilization with one or two nitrogen fractions significantly increased the total yield thanks to a yield increase in the cereal partner; however, as a consequence, the proportion of legumes in the mixture decreased. In conclusion, it can be stated that with the investigated cereal–legume combinations, a competitive yield and qualitative protein yield can be achieved with a reduced fertilizer input.

Keywords: intercropping; *Rhizobium*; seed ratios; wheat; triticale; pea; faba bean



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1. Introduction

For decades, Europe has had a structural shortage of protein production, and currently, the demand for plant-based protein is ramping up fast. To reduce Europe’s dependency on imports, plant-based protein production must be increased [1]. Today, soybean, mainly grown in the United States, Brazil and Argentina, is the most popular plant protein with the highest industrial production [2]. Due to the humid weather conditions and moderate to cold temperatures, which delay soybean growth in Northern and Western Europe, and the paucity of water and humidity in Southern Europe, “European soybeans” can, at this moment, not compete with cheaper imports [3].

Although species like faba bean (*Vicia faba* L.) and pea (*Pisum sativum* L.) are well adapted to the environmental conditions in NW Europe and their production has been increased recently, European countries are still far from exploiting their production potential [4]. This is mainly due to the high yield instability of, e.g., pea and faba bean. For pea, this is mainly due to their susceptibility to lodging [5] and more recently to anthracnose (*Colletotrichum* spp.). This disease is becoming a prevalent threat in major crop legume-growing countries, which can, under favorable conditions (elevated temperatures and

humidity), cause from 60 to 100% yield loss in field crop legume production. Anticipated climate changes are likely to foster more severe diseases [6].

Yield variations in faba bean can be attributed to, e.g., the poor flower/pod ratio and their susceptibility to environmental stress [7]. Growing faba bean or pea in combination with a small-cereal crop enables farmers to produce protein crops while decreasing the risks, thanks to the presence of the small cereal. This cereal–legume intercropping is a traditional agricultural practice whose history dates back thousands of years [8], and it is common among farmers in sub-Saharan Africa [9]. In Europe, there is a renewed interest in this ancient cultivation technique, which is reflected by the numerous publications regarding this topic [10]. In this region, cereal–legume intercropping mainly found its entrance in organic agriculture, as this type of farming faces more challenges, e.g., regarding the use of crop protection products and yield stability. In addition, increasing self-sufficiency for food and feed is in agreement with the principles of organic agriculture, and it reduces the risks related to the import of soybean protein that may be admixed with genetically modified soybean [11]. In conventional European agriculture, intercropping is less studied. However, also in conventional agriculture, this cultivation technique offers opportunities in a context where low-input, low-impact, ecological intensification and economically performing systems are required [12], thus its study needs to climb on the research agenda.

In Northwestern Europe, the acreage of winter cereals is much higher compared to spring cereals thanks to their higher yield potential. Furthermore, the germplasm of faba bean and pea can be grouped in spring and winter types according to frost tolerance [13]. Similar to cereals, winter types confer strong yield advantages compared to spring types. Despite the yield advantage over the spring type, the cultivation of winter faba bean remains limited in NW Europe due to the insufficient winter hardiness of current cultivars. Although in the last decades faba bean varieties adapted to the winters of Northwestern Europe have been realized, there is potential for expanding the range of winter faba bean through breeding for improved hardiness [14].

Although nitrogen (N) is an essential and limiting nutrient for plant growth and thus for the achievement of higher yields, excessive application of N fertilizer causes adverse environmental impacts beyond the field and farm boundaries [15]. Intercropping of legumes with cereals has been suggested to be the most promising approach to reducing N fertilizer application worldwide [16] because atmospheric N₂ fixed by legumes can be transferred to neighboring plants. In addition, root exudates from cereals can induce nodulation in the root system of faba bean, thus increasing the symbiotic nitrogen fixation rate of legumes and ultimately increasing the soil nitrogen pool [17]. Concerning the effects of N fertilization in cereal–legume intercropping systems, the results of different studies often conflict. According to the meta-analysis from [18], N fertilization had a non-significant effect on average yield, but it was found to significantly decrease the proportion of legumes in the harvested intercrop mixture.

Next to a reduced need for mineral fertilizer, plenty of advantages have been associated with cereal–legume intercropping, e.g., faster soil coverage, better weed suppression, improved light interception and increased and more stable yields [19]. By leveraging the synergistic interactions between cereals and legumes, this agroecological strategy offers multiple benefits across ecological, agronomical and socio-economical dimensions. However, the beneficial effects of intercrops are often greatly dependent on the end use as well as on the specific species and genotypes being co-cultivated. Although the importance of developing crop genotypes for intercropping has been acknowledged for a long time, most commercial cultivars are optimized for sole cropping and may not perform well when grown in intercrops. Therefore, breeding approaches that take into account the complexity of intercropping systems and that support the development of complementary varieties are necessary [20,21]. Although the benefits of cereal–legume intercropping systems are well-known, most studies focus on the performance of one cereal–legume combination compared to the sole cropping of both components. However, for farmers convinced of the added value associated with intercropping, it is also important to gain insight into the

differences between several crop combinations. In this light, different winter varieties of barley x pea, triticale x faba bean and wheat x faba bean are compared in this study.

2. Materials and Methods

2.1. Experimental Site

During the 2020–2021, 2021–2022 and 2022–2023 growing seasons, two sets of field experiments were laid out at the Experimental farm of Ghent University and the University College Ghent (50.97 N 3.75 E, Bottelare, Belgium). In 2020–2021 and 2022–2023, the parcels had a light loam soil with pH values of 7.0 and 6.8, respectively, and total organic carbon levels of 1.53% and 1.29%. In 2021–2022, the experiment was located on a sandy loam soil with pH 5.8 and a total organic carbon level of 1.05%.

During the growing season (November–July), data on the weather conditions (minimum, average and maximum air temperature and precipitation) were registered (Figure 1).

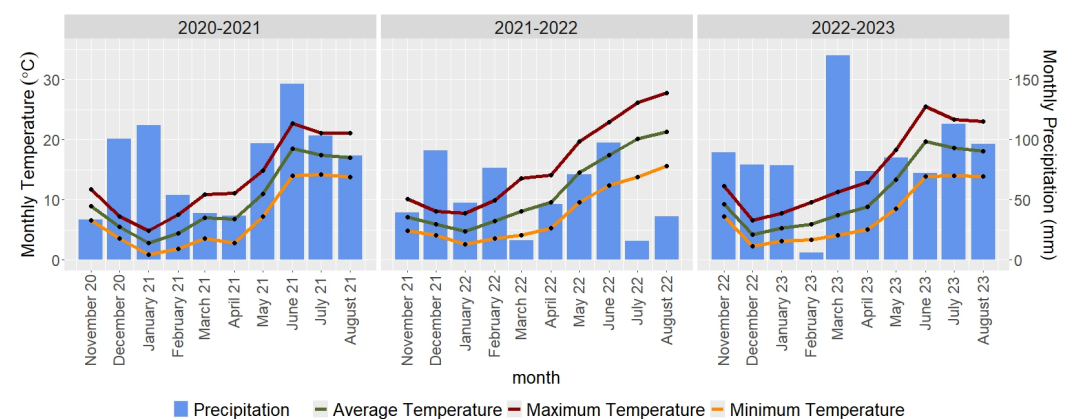


Figure 1. Precipitation (mm) and maximum, average and minimum temperature (°C) in the growing seasons (November–July) of 2020–2021, 2021–2022 and 2022–2023.

2.2. Experimental Design and Crop Management

In the first set of experiments, the effects of sowing density and variety choice were evaluated. These experiments were conducted during the growing seasons of 2020–2021 and 2021–2022 for three intercropping systems: winter barley x winter pea, winter triticale x winter faba bean and winter wheat x winter faba bean. The different combinations and sowing densities are shown in Table 1. During the growing season of 2022–2023, only the most promising varieties and sowing densities were included in the trial.

Table 1. Overview of different varieties and sowing densities (seeds/m² mentioned in parentheses) for the different cereal x legume intercropping trials during growing seasons of 2020–2021 and 2021–2022. Combinations indicated with * were identified as the preferred combinations and were tested during growing season of 2022–2023.

Barley x Pea	Triticale x Faba Bean	Wheat x Faba Bean
Joyau (175) x Flokon (40)	RGT Eleac (175) x Axel (20)	Extase (130) x Nebraska (20) *
Joyau (175) x Fresnel (40)	RGT Eleac (175) x Nebraska (20)	Extase (130) x Nebraska (30)
Jaguar (175) x Flokon (40)	RGT Rutenac (175) x Axel (20)	Extase (175) x Nebraska (20)
Jaguar (175) x Fresnel (40)	RGT Rutenac (175) x Nebraska (20)	Extase (175) x Nebraska (30)
Joyau (130) x Flokon (40)	RGT Eleac (130) x Axel (20)	
Joyau (130) x Fresnel (40)	RGT Eleac (130) x Nebraska (20)	
Jaguar (130) x Flokon (40)	RGT Rutenac (130) x Axel (20) *	
Jaguar (130) x Fresnel (40)	RGT Rutenac (130) x Nebraska (20) *	
Joyau (175) x Flokon (50)	RGT Eleac (175) x Axel (30)	
Joyau (175) x Fresnel (50)	RGT Eleac (175) x Nebraska (30)	
Jaguar (175) x Flokon (50)	RGT Rutenac (175) x Axel (30)	

Table 1. Cont.

Barley x Pea	Triticale x Faba Bean	Wheat x Faba Bean
Jaguar (175) x Fresnel (50)	RGT Rutenac (175) x Nebraska (30)	
Joyau (130) x Flokon (50)	RGT Eleac (130) x Axel (30)	
Joyau (130) x Fresnel (50)	RGT Eleac (130) x Nebraska (30)	
Jaguar (130) x Flokon (50) *	RGT Rutenac (130) x Axel (30) *	
Jaguar (130) x Fresnel (50)	RGT Rutenac (130) x Nebraska (30)	

Joyau, Jaguar, RGT Eleac, Rutenac, Axel and Extase are from Jorion Philip-Seeds; Flokon, Fresnel and Nebraska are from Agri-Obtentions.

Fertilization of these trials was performed according to the advice obtained upon soil sample analysis. P_2O_5 and K_2O were supplied, respectively, as triple superphosphate and chlorinated potash. A detailed overview of the fertilization for the first set of experiments is presented in Table A1, and the crop protection measures applied for both sets of experiments are summarized in Appendix A.

A second set of experiments was carried out to assess whether different fertilization strategies and inoculation with specific *Rhizobium* strains can increase the protein yield of these intercrops. These experiments were performed during the growing seasons of 2021–2022 and 2022–2023 with the intercrops winter barley (Joyau (130 seeds/m²)) x winter pea (Flokon (40 seeds/m²)) and winter wheat (Extase (130 seeds/m²)) x winter faba bean (Nebraska (20 seeds/m²)). As for fertilization, P_2O_5 and K_2O were again applied to all treatments according to the advice based on soil sample analysis. Nitrogen supply varied according to the treatment: no nitrogen supply, one fraction (N1) or two fractions (N1 + N2). The first fraction of nitrogen was supplied at BBCH 21–23, the second fraction at BBCH 31–32. Two commercial *Rhizobium* inoculants (LEGUMEFIX Pea and LEGUMEFIX Vetch from Legume Technology, Nottingham, UK) were tested, although the Belgian soils historically contain *Rhizobium* nitrogen-fixing bacteria in association with pea and faba bean. These inoculants are indicated in Table 2, respectively, as *Rhizobium* strain 1 and *Rhizobium* strain 2.

Table 2. Overview of the different fertilizer/*Rhizobium* treatments in the winter barley x winter pea and winter wheat x winter faba bean trials during 2021–2022 and 2022–2023.

Treatment
Control
<i>Rhizobium</i> strain 1
<i>Rhizobium</i> strain 2
<i>Rhizobium</i> strain 1 + N1 (30 kg N/ha)
<i>Rhizobium</i> strain 2 + N1 (30 kg N/ha)
N1 (30 kg N/ha) + N2 (30 kg N/ha)
<i>Rhizobium</i> strain 1 + N1 (30 kg N/ha) + N2 (30 kg N/ha)
<i>Rhizobium</i> strain 2 + N1 (30 kg N/ha) + N2 (30 kg N/ha)

All field trials were set up in a randomized complete block design, with four plots (1.5 m width and 5.0 m length) as replicates. Sowing was performed by means of a plot sowing machine (Hege 80 with tool carrier type 75; Wissembourg, France) with 12.5 cm row spacing on 26 November 2020, 19 November 2021 and 27 October 2022. The preceding crop was whole-crop maize in the 2020–2021 season and potato in the 2021–2022 and 2022–2023 seasons. Barley and pea seeds were mixed prior to sowing at a depth of 3–4 cm; the intercrops of triticale or wheat with faba bean were sown in two stages, in rows above each other: first the faba beans were sown at a depth of 7–8 cm and afterwards wheat or triticale was sown at a depth of 3–4 cm. All seeds were coated with fungicides: the peas, faba beans and cereal seeds were treated with Wakil XL 325 WG (cymoxanil, fludioxonil and metalaxyl-M), Apron XL 350 WG (metalaxyl-M) and Redigo 100 FS (prothioconazole), respectively.

2.3. Assessments

In March, the plant densities for the protein crop were determined, as this mixing partner is most vulnerable to frost damage. The number of pea or faba bean plants was counted in four squares of 30 cm × 30 cm per plot. In July or August (combinations with wheat or triticale in 2023), all plots were threshed to determine the total seed yield of the intercrop. On the harvested material, the proportions of cereal and legume seeds were determined, as well as the moisture content (ISO 6496:1999 [22]) and the protein content (ISO16634-1:2008 [23]) of both seed types.

2.4. Statistical Analysis

For statistical evaluation, the R software package version 4.3.0 was used. Since the normality assumption (Shapiro–Wilk test p -values > 0.05) and homoscedasticity assumption (Levene test p -values > 0.05) were met, an ANOVA (function `aov` R-package `stats`) was used to test for a potential treatment effect. If there was a significant treatment effect (p -value < 0.05), a Tukey test (function `HSD.test`, R-package `agricolae`) was performed to see where the differences were situated.

The data are visualized as boxplots, which provide a graphical view of the median (horizontal line) and quartiles (Q1–Q3, box). The upper whisker is located at the smaller of the maximum x value and $Q3 + 1.5 \times$ interquartile range, whereas the lower whisker is located at the larger of the smallest x value and $Q1 - 1.5 \times$ interquartile range. An outlier is defined as a data point that is located outside the whiskers of the boxplot, outside 1.5 times the interquartile range above the upper quartile and below the lower quartile (black dots in the graphs).

3. Results

3.1. Plant Density

Enumeration of the protein crops in March indicated that both winter pea and winter faba bean survived the Belgian winter conditions (temperatures up to -9°C in February 2021) very well during all three growing seasons.

3.2. Effect of Variety Combination on Yield

3.2.1. Winter Barley x Winter Pea

From Figure 2, it can be concluded that the yields in 2021 were clearly lower compared to 2022 and 2023. The latter years were characterized by a warmer and drier period in April–June. In 2021, no significant differences were observed between the different combinations of varieties and sowing densities (p -value ANOVA = 0.858). In 2022, the differences were significant (p -value ANOVA = 0.000): the barley x pea combination Flokon (50 seeds/m²) x Jaguar (130 seeds/m²) resulted in significantly higher yields than Fresnel (40 seeds/m²) x Jaguar (130 seeds/m²), Fresnel (40 seeds/m²) x Joyau (130 seeds/m²) and Fresnel (40 seeds/m²) x Joyau (175 seeds/m²). Figure 2c,d show that these yield differences can be attributed to the yield differences between both pea varieties, where Flokon resulted in higher yields than Fresnel. The sowing density and the barley variety did not significantly impact the yield. Thanks to the higher yield of Flokon and the higher protein content, the combinations with Flokon resulted in the highest protein yields (Figure 2b). It can also be remarked that in 2023, the pea yield was very low for the combination Flokon (50 seeds/m²) x Jaguar (130 seeds/m²), whereas the barley yield was quite high. In 2023 the peas suffered severely from anthracnose damage (*Colletotrichum* spp.), and the barley plants produced more tillers due to the very low incidence of pea plants, compensating for the low pea yields. As a result of the low proportion of peas in the harvested mixture, the protein yield in 2023 was low (Figure 2b).

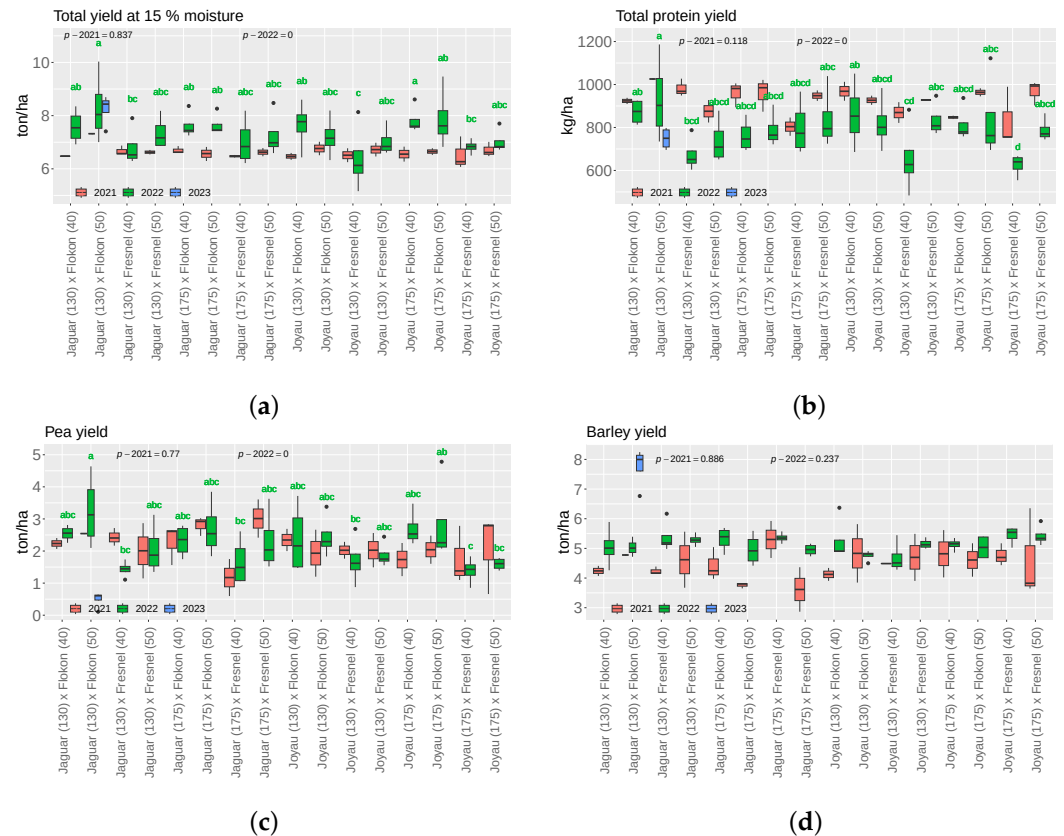


Figure 2. Total grain yield of both intercropping partners (a). Total protein yield of both intercropping partners (b). Yield of the winter peas (c) in the harvested mixture and the barley yield (d) in the harvested mixture. Above, the p -value from the ANOVA to test the treatment (variety combination and sowing density) effect is given per year. In case this p -value is < 0.05 , the output from the Tukey test is also given, where different letters point to significant differences between treatments.

3.2.2. Winter Triticale x Winter Faba Bean

Similar to the winter barley x winter pea trial, the 2021–2022 growing season was also more favorable for winter triticale x winter faba bean compared to the 2020–2021 season. Significant differences in total yield could not be reported for any of the growing seasons (p -values ANOVA > 0.05). However, for the yields of both intercropping partners separately, significant differences were observed for the 2020–2021 season: the combinations Axel (20 seeds/m²) with Eleac (130 seeds/m²) and Nebraska (30 seeds/m²) with Eleac (175 seeds/m²) resulted in significantly higher faba bean yields than the combination of Nebraska (20 seeds/m²) with Rutenac (130 or 175 seeds/m²); the triticale yield for the combinations with RGT Eleac was lower compared to the combinations with RGT Rutenac. The protein yields of 2021 and 2022 are similar; in 2021, the faba bean yields were higher than in 2022, but the triticale yields were clearly lower, resulting in a lower total yield compared to 2022 (Figure 3).

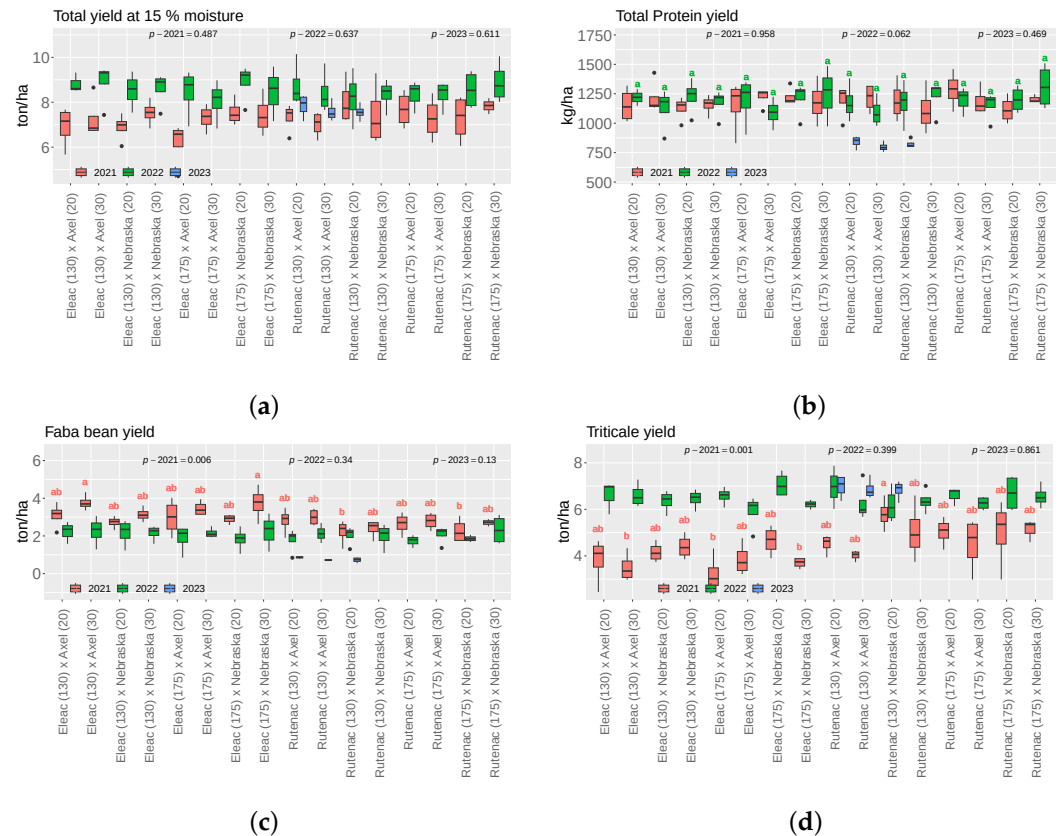


Figure 3. Total grain yield of both intercropping partners (a). Total protein yield of both intercropping partners (b). Yield of the winter faba bean (c) in the harvested mixture and the triticale (d) yield in the harvested mixture. Above, the p -value from the ANOVA to test the treatment (variety combination and sowing density) effect is given per year. In case this p -value is <0.05 , the output from the Tukey test is also given, where different letters point to significant differences between treatments.

3.2.3. Winter Wheat x Winter Faba Bean

For the 2020–2021 growing season, significant differences in yield and protein yield were observed in winter wheat x winter faba bean. Combinations with a reduced sowing density of faba bean (Nebraska 20 seeds/m²) seemed to result in higher total yields (Figure 4a), attributable to higher yields of wheat (Figure 4d). For the protein yields, there were no significant differences between the different sowing densities (Figure 4b) due to the increased faba bean yield (Figure 4c). In the 2021–2022 growing season, there were no significant differences in yield or in protein content between the different combinations. Furthermore, it can be noted that yields of the selected combination Nebraska (20 seeds/m²) x Extase (130 seeds/m²) in the 2022–2023 growing season are clearly lower compared to the preceding growing seasons. This can probably be explained by the delayed harvest in 2023 due to the extremely wet conditions in July 2023.

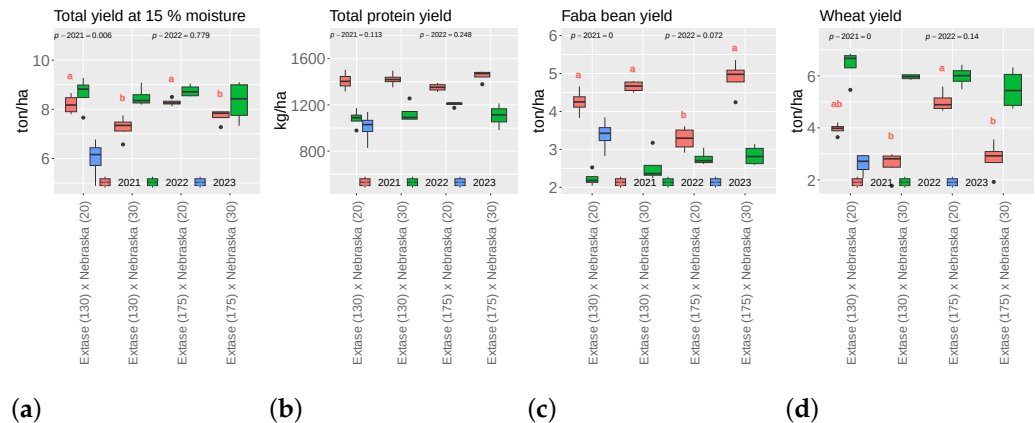


Figure 4. Total grain yield of both intercropping partners (a). Total protein yield of both intercropping partners (b). Yield of the winter faba bean (c) in the harvested mixture and the wheat yield (d) in the harvested mixture. Above, the p -value from the ANOVA to test the treatment (variety combination and sowing density) effect is given per year. In case this p -value is <0.05 , the output from the Tukey test is also given, where different letters point to significant differences between treatments.

3.3. Comparison of the Different Species Combinations

The species combination with the highest yield varied according to the growing seasons. In 2020–2021 and 2021–2022, there were no significant yield differences between the different species combinations. At harvest in 2023 (2022–2023 growing season), however, the combination winter barley x winter pea recorded the highest yields. When a high cereal yield is preferred, triticale seemed the best choice in 2021 and 2022, but in 2023 the highest cereal yields were found for barley. Faba bean grown in combination with wheat showed higher yields than in combination with triticale (Figure 5). The protein yield is highly correlated with the amount of legumes in the harvested intercrop mixture. In 2021 and 2023, there were significant differences between the species combinations, where winter wheat x winter faba bean gave rise to the highest total protein yields. In 2022, there were no significant differences between the species combinations concerning the protein yield.

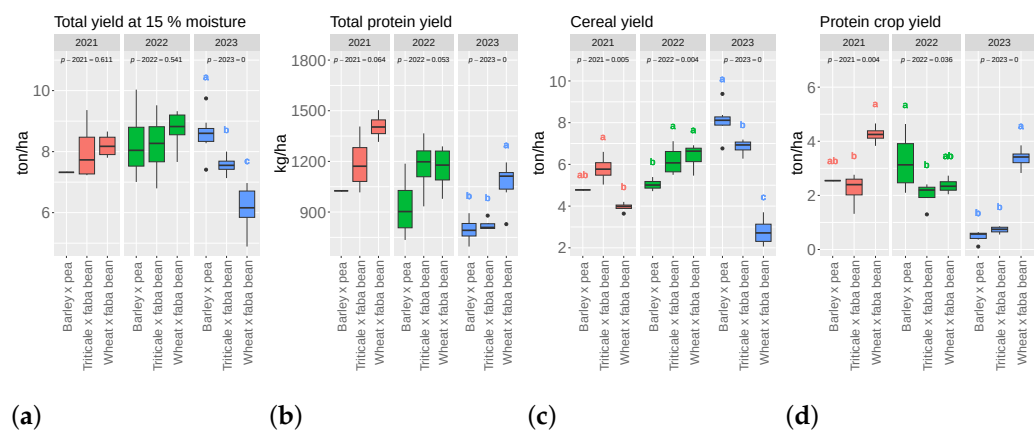


Figure 5. Total yield of both intercrop partners (a), total protein yield (b) of both intercrop partners and separate yields of cereals (c) and protein crops (pea or faba bean) (d). At the top of the graphs, the p -values from the ANOVA to test the treatment (cropping combination) effect are given per growing season (2020–2021, 2021–2022 and 2022–2023). In case this p -value is <0.05 , the output from the Tukey test is given, where different letters point to significant differences between treatments.

3.4. Effect of Nitrogen Fertilization and/or Rhizobium Inoculation on Yield

3.4.1. Winter Barley x Winter Pea

Figure 6a shows that mineral N application favors the total yield of the winter barley x winter pea intercrop during both the 2021–2022 and the 2022–2023 growing seasons.

These higher yields are the result of a higher barley yield in the intercropping system, since applying mineral N favored increased barley yields and reduced pea yields. The inoculation of seeds with commercial *Rhizobium* strains prior to sowing did not have an effect on the total intercrop yield, nor on the yields of both species separately. In 2021–2022, the total protein yield was the highest in the combinations without mineral nitrogen supply, attributable to the higher proportion of legumes in the harvested intercrops for these treatments; however, the differences were not significant (Figure 6b).

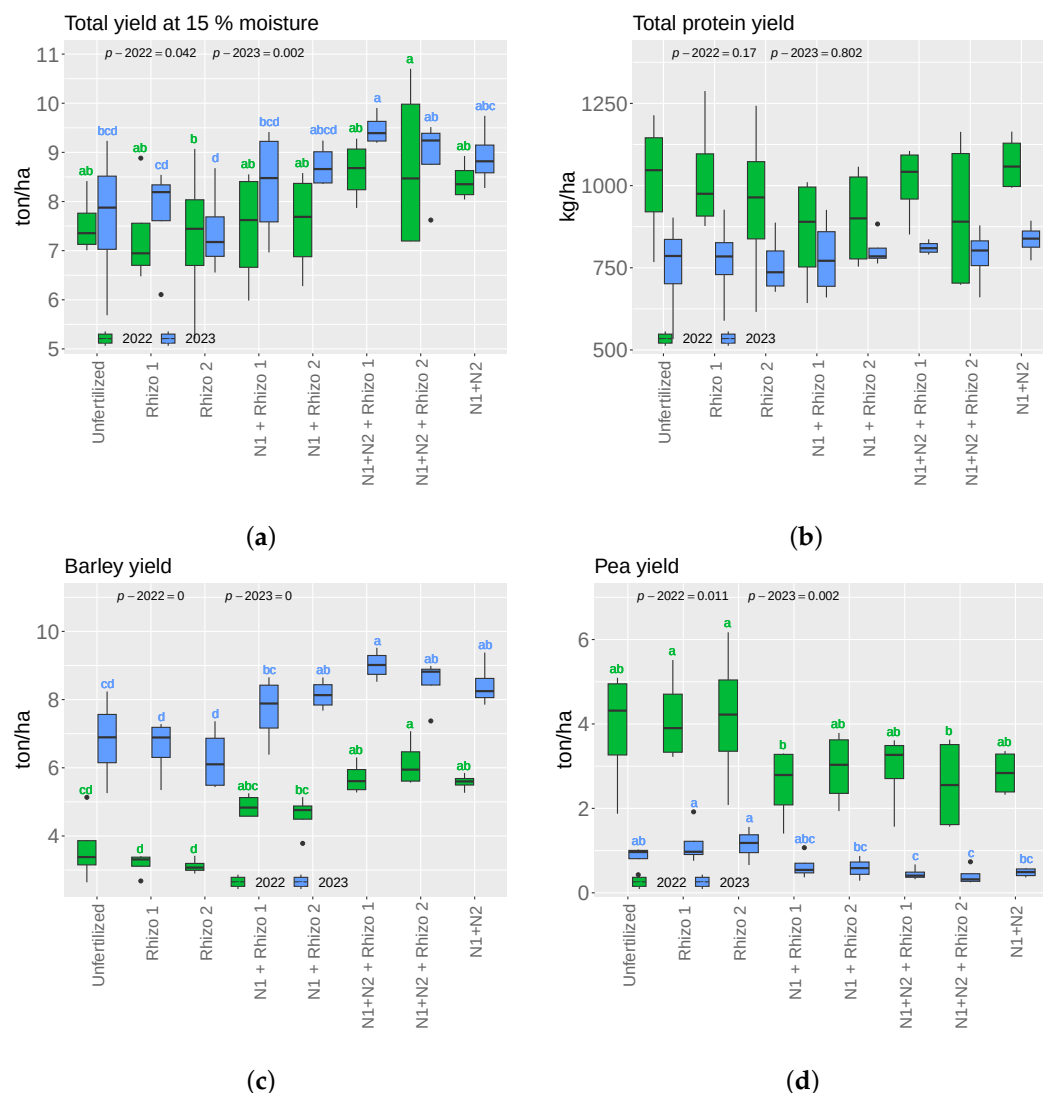


Figure 6. Total grain yield of both intercrop partners (a), total protein yield of both intercrop partners (b) and separate yields of the winter barley (c) and winter pea (d). At the top of the graphs, the p -values from the ANOVA to test the treatment (nitrogen/*Rhizobium*) effect are given per harvest year (with respect to 2021–2022 and 2022–2023 growing seasons). In case this p -value is <0.05 , the output from the Tukey test is given, where different letters point to significant differences between treatments.

3.4.2. Winter Wheat x Winter Faba Bean

From the winter wheat x winter faba bean trials, similar conclusions concerning the effect of *Rhizobium* species can be drawn. Inoculation of the faba bean seeds with the commercial *Rhizobium* strains did not significantly increase intercrop yields. Fertilization with one or two nitrogen fractions did significantly increase total intercrop yield during the 2021–2022 season due to an increased wheat yield. However, for 2022–2023, the effect of mineral nitrogen seemed to be absent. Like for the winter wheat x winter faba bean trial described above, it is important to notice that the cereal yields were extremely low in

2023 due to a delayed harvest due to the rainfall during July 2023. Concerning the protein yield, there were no significant differences between treatments. The untreated plots, which did not receive mineral N or a *Rhizobium* inoculant, resulted in the highest protein yields, attributable to the higher proportion of faba beans in the mixture. At harvest in 2023, there were no significant differences in protein yield, nor significant differences in faba bean yields (Figure 7).

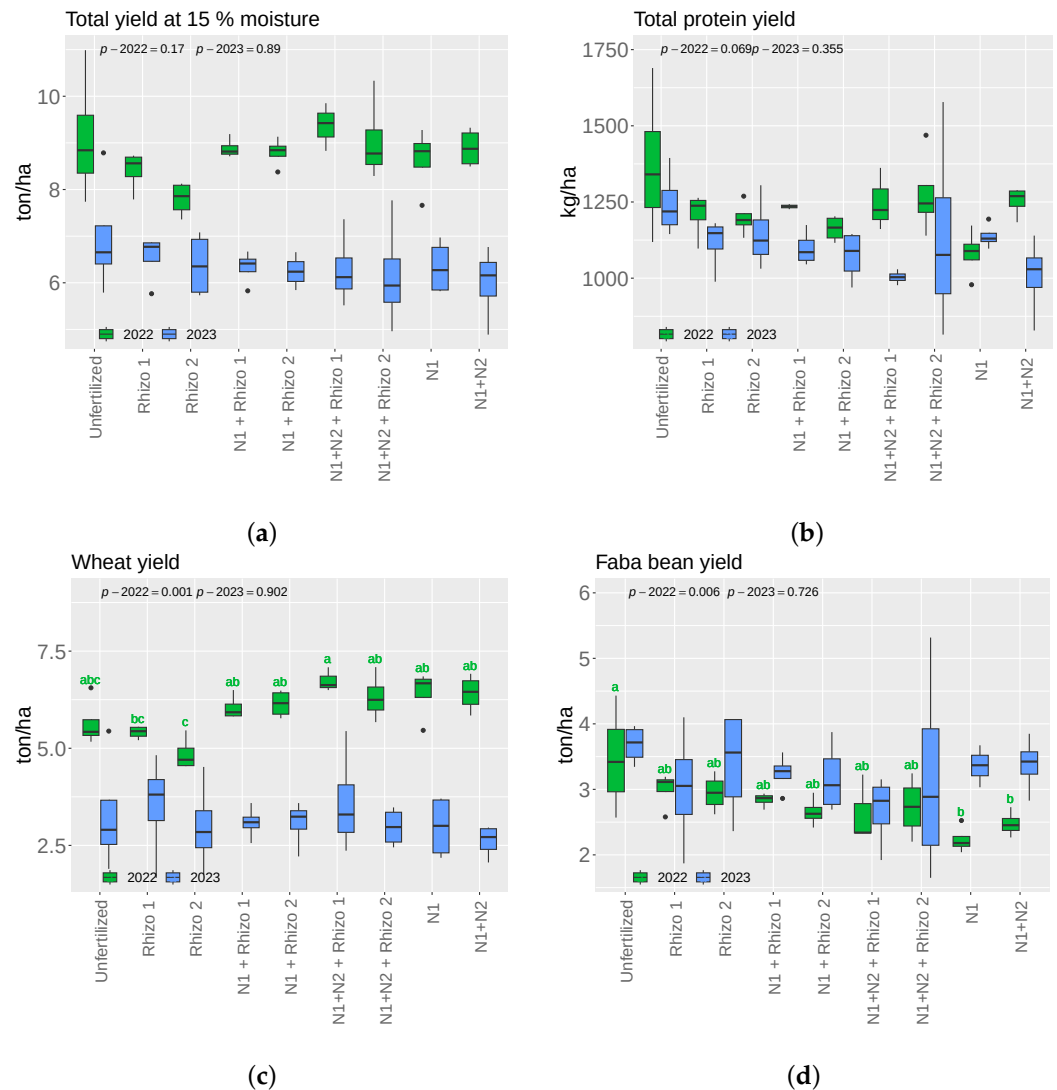


Figure 7. Total grain yield of both intercrop partners (a), total protein yield (b) of both intercrop partners and separate yields of wheat (c) and faba bean (d). At the top of the graphs, the p -values from the ANOVA to test the treatment (nitrogen/*Rhizobium*) effect are given for the 2021–2022 and 2022–2023 growing seasons. In case the p -value is < 0.05 , the output from the Tukey test is given, where different letters point to significant differences between treatments.

4. Discussion

Cereal–legume intercropping, a traditional agricultural practice, involves growing cereals and legumes simultaneously on the same field. This agroecological strategy holds immense promise for enhancing sustainability in agricultural systems by leveraging complementarities between the two plant groups, offering multiple benefits that contribute to enhanced sustainability and resilience in farming systems. As global challenges such as climate change, resource scarcity and food insecurity intensify, there is growing interest in harnessing the potential of intercropping as a viable solution to address these complex issues.

It has been shown that the performance of intercropping systems is dependent on the mixture x genotype effect [24]. In this light, the selection of appropriate species/genotype combinations as well as adapted crop husbandry is important for profitable large-scale adoption for cereal x legume intercropping [25]. In this research, the performance of several cereal x legume intercropping systems at different sowing densities and under varying fertilizer regimes was assessed. With regard to sowing densities, intercrop experiments are designed within either an additive or a replacement design: an additive design is defined as at least one component species in the intercrop having the same density as the sole crop, whereas in a replacement design, the density of one sole crop species is proportionally (based on sole crop densities) replaced by the other species in the intercrop. Our experiments can be regarded as replacement designs, since the cereal partner is sown at 130 or 175 seeds/m², which is half of the normal sowing density of 250–350 seeds/m². The density of the legume partners was the same or slightly reduced compared to monocropping. Concerning the effect of sowing density, the conclusion for the different species/variety combinations was unanimously that an increased sowing density did not result in higher yields. This can be explained by the fact that depending on the tillering potential of the cereal genotype, an increased number of tillers can compensate for the lack of plants [26]. It should be noted that in this way, the cost of seeds should also not be needlessly increased, which is interesting for the farmer.

Cereal–legume intercropping can also boost the protein content of animal feed. Although cereals are highly important for feeding ruminant animals thanks to their high dry-matter production and low cost, they are poor in protein content, and thus protein supplements are needed [27]. Since legumes are a good protein source, cereal–legume intercropping can increase the protein content of the produced feed and thus improve the nutritional value. Depending on the growing season, the protein yield of wheat x faba bean ranged between 1.41 ton/ha (2021) and 1.01 ton/ha (2023). To reach these values with winter wheat grown in monoculture, high levels of N fertilizer are required. Pure faba beans under low N fertilizer application can also reach these values. However, as mentioned above, pure faba bean cultivation suffers from yield instability. The meta-analysis from Li et al. [28] confirmed that cereal x legume intercropping can provide similar or even higher protein yields, especially with modest N fertilizer application. In addition, enriching cereal products with legumes has nutritional advantages, e.g., improving the amino acid balance [29].

It has also been shown that intercrop performance depends on the genotypes/varieties used. The review of Demie et al. [24] found a tendency towards higher intercrop performance with short cereal genotypes. For triticale, it was indeed seen that RGT Eleac, having a “half long to long” straw length, resulted in higher yields than RGT Rutenac, which is a “long straw” variety. However, for barley, there was no significant difference in performance between the short-straw variety Joyau and the variety Jaguar with a moderate straw length. Here, the pea variety Flokon, which had a shorter harvest height (approx. 45 cm), outperformed Fresnel, having a harvest height of approximately 50 cm.

Next to the effect of sowing density and genotype/variety, the effect of *Rhizobium* inoculation with commercial strains on yield and protein content was also studied. Inoculation of legumes is generally considered to increase yield and to lower the need of nitrogen (N) fertilization, especially in semi-arid regions and on sandy soils [30]. According to Youseif et al. [31] and Genetu et al. [32], *Rhizobium* inoculation improves faba bean yield with respect to Egypt and Northwestern Ethiopia. However, only a few recent studies have focused on the effect of inoculation of faba bean under Northern European conditions. According to Fogelberg et al. [30], inoculation of *Rhizobium* did not have any significant effect on yield or protein content of faba beans, nor on subsequent spring wheat yields under Scandinavian cropping conditions. According to the authors, this can be attributed to a long history of faba bean cropping that most likely has resulted in natural and native *Rhizobium* strains, together with the high N content in the soil. This explanation also holds for Flemish conditions, since *Rhizobium leguminosarum* bv. *viciae* is widely distributed in

agricultural soils in Europe, so good nodulation of pea and faba bean can be achieved without seed inoculation [33]. In contrast to exogenous *Rhizobium* application, the application of mineral nitrogen significantly increased total yields thanks to an increased cereal yield. In the study of BenYoussef et al. [34] assessing the effect of nitrogen fertilization on forage yields and quality of hairy vetch x triticale mixtures, it was observed that the total yield increased with increasing nitrogen levels, but the proportion of hairy vetch in the mixture decreased.

5. Conclusions

It can be concluded that competitive yields in cereal x legume intercropping systems can be achieved with a sowing density of 130 seeds/m² for the cereal component (barley, triticale or wheat) combined with 40 seeds/m² for pea or 20 seeds/m² for faba bean. Under Flemish conditions, there is no need to inoculate faba bean or pea seeds with commercially available *Rhizobium*. One or two low nitrogen fractions (30 kg N/ha per fraction) can increase grain yields in the mixtures. Concerning the best species combination (barley x pea, wheat x faba bean or triticale x faba bean), no clear conclusions could be drawn, since the best-performing species combination varied according to the growing season, i.e., weather conditions. Barley x pea was the combination most susceptible to lodging, and under conditions in favor of lodging, the yield of this combination was lower. In contrast, this species combination can be harvested earlier than the others (i.e., in June), so in seasons with a delayed harvest (due to, e.g., wet conditions) barley x pea can outperform the other species combinations.

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Appendix A

Table A1. Fertilization for the first set of experiments.

Season	Date and Nitrogen Dosage (kg/ha)	Date and K ₂ O and P ₂ O ₅ (kg/ha)
2020–2021	13 April 2021; 30 kg N/ha 18 May 2021; 30 kg N/ha	21 April 2021; 60 kg K ₂ O/ha 21 April 2021; 0 kg P ₂ O ₅
2021–2022	21 March 2022; 30 kg N/ha 25 April 2021; 30 kg N/ha	14 March 2021; 64 kg K ₂ O/ha 14 March 2021; 0 kg P ₂ O ₅
2021–2022	16 March 2022; 40 kg N/ha 12 April 2022; 30 kg N/ha	20 March 2022; 100 kg K ₂ O/ha 20 March 2022; 30 kg P ₂ O ₅

2020–2021 Season

- **Herbicide** (barley x pea; triticale x faba bean; wheat x faba bean): Stomp Aqua 455 CS (pendimethalin) 1.8 L/ha (10 December 2020).

- **Fungicide** (barley x pea): Caramba 60 SL (metconazole) 1.2 L /ha (20 May 2021).
- **Fungicide** (triticale x faba bean; wheat x faba bean): Caramba 60 SL (metconazole) 1.2 L /ha (8 June 2021).
- **Insecticide** (barley x pea): Fury 120 SC (zetacypermethrin) 0.125 L/ha (20 May 2021).
- **Insecticide** (triticale x faba bean; wheat x faba bean): Insectine 500 EC (cypermethrin) 0.050 L/ha (08 June 2021).

2021–2022 Season

- **Herbicide** (barley x pea; triticale x faba bean; wheat x faba bean): Stomp Aqua 455 CS (pendimethalin) 1.8 L/ha (20 November 2021.).
- **Fungicide** (barley x pea; triticale x faba bean; wheat x faba bean): Caramba 60 SL (metconazole) 1.2 L /ha (12 May 2022).
- **Insecticide** (barley x pea; triticale x faba bean; wheat x faba bean): Insectine 500 EC (cypermethrin) 0.050 L/ha (12 May 2022).

2022–2023 Season

- **Herbicide** (barley x pea; triticale x faba bean; wheat x faba bean): Stomp Aqua 455 CS (pendimethalin) 1.8 L/ha (3 November 2022).
- **Fungicide** (barley x pea; triticale x faba bean; wheat x faba bean):
 - Amistar 250 SC (azoxystrobin) 0.250 kg/ha (27 April 2023).
 - Caramba 60 SL (metconazole) 1.2 L/ha (2 May 2023).
 - Caramba 60 SL (metconazole) 1.2 L/ha (30 May 2023).
- **Insecticide** (barley x pea; triticale x faba bean; wheat x faba bean):
 - Karis 100 CS (lambda-cyhalothrin) 0.0075 kg/ha (2 May 2023).
 - Karate Zeon 250 CS (lambda-cyhalothrin) 0.0075 kg/ha (30 May 2023).

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