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Grain yield and quality of wheat in wheat-legumes intercropping under organic and conventional growing systems

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Abstract: The effect of simultaneous intercropping of winter wheat (*Triticum aestivum* L.) with different legumes of faba bean (*Vicia faba* L.), pea (*Pisum sativum* L.), and purple clover (*Trifolium incarnatum* L.) on selected production and qualitative parameters of wheat was evaluated in field trials conducted both in organic and conventional cropping systems, in comparison with pure sown wheat. Wheat intercropped with legumes achieved higher grain yield compared to pure sown wheat for an average of two years. However, in organic cultivation, the positive effect of intercropping on wheat yields was more pronounced. In addition, a strong influence of the year was noted. In 2021, in the organic cropping system, the most yielding intercropped wheat (especially with pea and bean) achieved 114–117% higher yields compared to pure sown wheat (in the previous year of 2020, it was usually only about 102–106%). In the conventional cropping system, the effect of intercropping on wheat yield was significantly weaker, and in 2021, wheat intercropped with legumes reached even lower yields than pure sown wheat in some cases. In terms of sowing methods (both in organic and conventional cropping systems), mixed sowing with individual legumes significantly exceeded the yields of wheat grown with legumes in separate, alternating rows. As regards quality parameters, wheat intercropped with legumes reached in comparison with pure sown wheat usually had higher crude protein content in wheat grain dry matter and higher values of Zeleny sedimentation.

Keywords: available nitrogen; nutrient; competition; mixed cultures; method of sowing; weather conditions

Intercropping is an old practice in which two or more species are grown simultaneously in the same field over a significant period but may not be sown and harvested at the same time (Lithourgidis et al. 2011, Brooker et al. 2015, Vlachostergios et al. 2018).

Intercropping of cereals with legumes is the most commonly used intercropping system worldwide. The advantages of this intercropping consist mainly of the complementary use of nitrogen (N) sources by the species used in the intercropping (Bedoussac and Justes 2010, Dhima et al. 2014). In the case of a simultaneous intercropping strategy, the growing season of legumes is longer (Bergkvist et al. 2011), and legumes ensure a natural input of exogenous N into the system through symbiotic fixation that allows providing a high amount of fixed N, usable for cereals (Amossé et al. 2014, Neugschwandtner et al. 2021). However, the legumes might also compete with cereals during their growth (Bergkvist et al. 2011). A relay intercropping strategy aims to insert the forage legume before summer without impairing wheat yield and protein content (Bergkvist et al. 2011).

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The productivity of intercropping system depends on factors such as crop species that are used and their variants, sowing density, sowing ratio, spatial arrangements/intercropping pattern of the individual crops, and also the management practices (Hauggard-Nielsen et al. 2001, Bedoussac et al. 2015, Brooker et al. 2015).

Intercropping systems of cereal legumes can allow the optimal use of soil and atmospheric N sources, improve soil conservation and increase yield and protein concentration in the cereal grain, especially under low soil N levels (Gooding et al. 2007, Pelzer et al. 2012). Moreover, these systems help weed control and reduce diseases and pest occurrence (Lithourgidis et al. 2011, Bedoussac et al. 2015, Brooker et al. 2015).

By contrast, some authors have shown that simultaneous intercropping might limit or reduce the cereal yield in case of high growth and/or high density of the legume and the resulting competition for nutrient resources and light (Bergkvist et al. 2011, Mysliwiec et al. 2014). Similarly, according to Lithourgidis and Dordas (2010), intercropping can reduce the yield of mixtures compared with pure cereal crops.

The aim of this work was to evaluate the simultaneous intercropping of winter wheat with selected legumes, implemented in the organic and conventional farming system, and to determine wheat yield, yield composition, and grain quality parameters in relation to legume species, methods of sowing, and harvest years.

MATERIAL AND METHODS

Experimental conditions. The effects of simultaneous intercropping of winter wheat with different legumes on selected production and quality parameters of wheat were evaluated in field trial plots (12 m^2), carried out during the 2019/2020 and 2020/2021 growing seasons at the experimental base of the Czech University of Life Sciences in Prague (central part of Bohemia, 295 m a.s.l., the average annual temperature of 8.3 °C, and average sum of precipitation of 584 mm). As for the weather conditions (Table 1), both evaluated years were similar in average monthly temperatures. As to precipitation, the year 2019/2020 was generally drier, while the year 2020/2021 was richer in precipitation and exceeded the long-term standard. Field trials were performed under both organic and conventional cropping systems using oilseed rape as a preceding crop for trials. No additional fertilisers or pesticides were used in the organically cultivated variants. Nitrogen (40 + 40 kg N/ha using limestone ammonium nitrate) was applied in the spring in two doses, and a fungicide was used in the variants cultivated conventionally.

Experimental design and variants. Simultaneous intercropping consisted of sowing the legumes cultivars at the same time as winter wheat at the beginning of October. Randomised blocks in three replicates were designed with an average experimental plot area

Table 1. The survey of average monthly temperatures and sums of precipitation during the years 2019/2020 and 2020/2021 in comparison with long-term standard

Month	Average temperature (°C)			Σ of precipitation (mm)		
	2019/2020	2020/2021	long-term standard	2019/2020	2020/2021	long-term standard
IX	14.3	14.4	14.0	36.8	38.6	49.2
X	11.5	10.5	8.6	35.6	32.7	41.8
XI	6.1	4.3	3.2	37.2	35.8	34.0
XII	3.0	2.8	–0.5	13.9	18.8	34.6
I	1.8	0.1	–2.1	12.8	42.2	28.4
II	5.5	–0.1	–0.8	59.2	28.5	27.5
III	5.3	4.5	3.4	63.0	33.6	31.8
IV	10.9	7.0	8.2	12.8	23.4	46.9
V	12.3	11.8	13.4	68.0	100.8	65.0
VI	17.5	20.2	16.3	79.4	102.6	74.1
VII	19.7	19.9	18.2	30.8	87.9	74.3
VIII	18.6	17.5	18.0	46.2	77.6	76.5
Average temperature	10.5	9.4	8.3			
Σ of precipitation				495.7	622.5	584.1

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of 12 m^2. In all variants, winter wheat (cv. Butterfly) was sown at a rate of 148 kg/ha (400 seeds/m^2), faba bean (cv. Merkur) at a rate of 200 kg/ha (30 seeds/m^2), spring pea (cv. Avatar) and winter pea (cv. Balltrap) at a rate of 50 seeds/m^2 (125 kg/ha for cv. Avatar and 105 kg/ha for cv. Balltrap), purple clover (cv. Kardinal) at a rate of 14 kg/ha (300 seeds/m^2). A control was also implemented with wheat grown as a pure crop. The field experiment included both variants with mixed sowing of wheat and individual legumes and variants with alternating sowing of wheat and legume in separate rows.

Wheat production and basic quality parameters evaluation. Before the wheat harvest, the number of ears per m^2 was determined. After the harvest, the wheat grain yield and TKW (thousand kernels weight) were determined, and grain samples were taken for quality evaluation. Crude protein content according to the Kjeldahl method (Kjeltec KT 200, FOSS, Hilleröd, Sweden) was determined based upon N × 5.7 (in dry matter (DM)). According to the ICC 116/1, Zeleny sedimentation was also determined.

Statistical analyses. The data obtained were statistically analysed using the ANOVA method in the SAS program (SAS Institute, Cary, USA), version 9.4. The differences between means were evaluated using Tukey's *HSD* (honestly significant difference) test at a level of significance $P \leq 0.05$.

RESULTS AND DISCUSSION

Effects of legumes on wheat yield. There are contradictory reports related to the effects of legumes in wheat and legumes intercropping on wheat yields. Legumes in a well-chosen mixed culture can contribute to a positive balance of available nitrogen in the soil (Kintl et al. 2015), which is then used by the main crop. This can lead to higher yields of the main crop compared to monoculture (Lithourgidis et al. 2011, Dong et al. 2018). On the other hand, Bergkvist (2003) suggested that it was difficult to achieve a higher yield of wheat growing in a mixture compared to pure sown wheat, and Vrignon-Brenas et al. (2018) stated on the bases of their results, there were no significant differences in wheat yield, intercropped or not. Similarly, Amossé et al. (2013) found that the presence of legumes had, in general, no significant effect on wheat grain yield.

Our results showed that in control (pure sown wheat), the grain yield in the organic cropping system was the lowest and differed significantly from the intercropped wheat yields. At the same time, there were no significant differences in the wheat yields between the wheat intercropped with peas and beans (Table 2). In the conventional cropping system, where the wheat yields were about 1.3–1.8 higher compared to organic cultivation, was a similar situation – the grain yield of pure sown wheat was lower compared to the intercropped wheat yields and differed from them significantly. It is also evident that the resulting grain yield depended on a structure of yield composition (number of ears per m^2, TKW) that varied depending on the year, the cultivation system, and to a lesser extent, the method of sowing. Vrignon-Brenas et al. (2018) stated that systems where the individual components of the mixture (wheat, legumes) are sown in separate, alternating rows are considered to be more promising ways of establishing mixed cultures. With this method of sowing, the auxiliary crop (for instance, legume crop) does not come in close proximity to the main crop, which can lead to the suppression of the main crop (Vandermeer 2012, Ehrmann and Ritz 2014). However, as can be seen from our results, this system of alternating sowing wheat and legumes in separate rows can also lead to a reduction in wheat yield, probably thanks to greater interplant and stalk competition in wheat.

Table 3 provides a more detailed view of the results of individual years. The results show a different effect of intercropping treatments and cultivation systems on both wheat yields and the structure of yield elements in individual years. In 2020, there were, both in organic and conventional cropping systems, no significant differences in the wheat yields between intercropping treatments and pure sown wheat. In 2021, there was no significant difference in wheat yields between intercropped treatments and pure sown wheat only in the conventional cropping system, alternating sowing in individual rows. In the case of mixture sowing, the wheat yield of pure sown wheat differed significantly from the intercropped treatments with pea and bean; but there was no significant difference between them.

In the case of the organic cultivation system, the positive effect of mixed wheat cultivation with legumes on wheat yields was even more pronounced. The effect of the sowing method on wheat yields was minimal, but the differences between pure-sown and intercropped wheat were statistically significant and relatively high (Table 3).

As mentioned above, year-on-year differences in the structure of the yield elements were also found.

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Table 2. Evaluated production and quality parameters of winter wheat depending on the leguminous variant, sowing method, crop year, and cropping system (Tukey's *HSD* (honestly significant difference) test at the level of $P < 0.05$)

		Grain yield (t/ha)		$HSD_{0.05}$	Number of ears per m^2		$HSD_{0.05}$	TKW (g)		$HSD_{0.05}$	Crude protein content in grain DM (%)		$HSD_{0.05}$	Zeleny sedimentation (mL)		$HSD_{0.05}$
		ECO	CONV		ECO	CONV		ECO	CONV		ECO	CONV		ECO	CONV	
Legum. variant	W + WP	7.27^{aB}	8.63^{aA}	0.19	417.5^{aB}	536.0^{aA}	28.4	51.43^{aA}	46.03^{bB}	2.50	11.36^{aB}	12.29^{aA}	0.18	45.50^{aB}	55.67^{aA}	0.72
	W + SP	7.10^{abB}	8.71^{aA}	0.17	407.5^{aB}	540.8^{aA}	31.7	51.15^{abA}	47.02^{aB}	2.39	11.41^{aB}	12.24^{aA}	0.17	44.25^{bB}	54.42^{abA}	0.86
	W + FB	7.22^{abB}	8.69^{aA}	0.28	416.8^{aB}	537.7^{aA}	31.5	50.94^{abcA}	47.06^{aB}	2.21	11.36^{aB}	12.24^{aA}	0.17	44.08^{bB}	55.50^{aA}	1.34
	W + PC	6.95^{bB}	8.55^{abA}	0.27	405.6^{abB}	533.7^{aA}	34.8	50.66^{bcA}	46.25^{abB}	2.32	11.15^{abB}	12.16^{aA}	0.19	44.33^{bB}	53.67^{abA}	2.21
	control	6.67^{cB}	8.36^{bA}	0.32	387.3^{bB}	525.3^{aA}	35.5	50.58^{cA}	45.96^{bB}	2.30	11.04^{bB}	11.93^{bA}	0.19	41.67^{cB}	53.00^{bA}	1.10
	$HSD_{0.05}$	0.28	0.26	–	19.9	19.3	–	0.54	0.93	–	0.31	0.16	–	1.23	2.01	–
Sowing method	mixture	7.14^{aB}	8.87^{aA}	0.14	416.6^{aB}	558.4^{aA}	18.1	50.72^{bA}	45.80^{bB}	1.37	11.23^{aB}	12.10^{bA}	0.13	43.73^{aB}	53.63^{bA}	0.75
	separate rows	6.91^{bB}	8.31^{bA}	0.16	397.2^{bB}	511.0^{bA}	19.6	51.18^{aA}	47.13^{aB}	1.41	11.30^{aB}	12.25^{aA}	0.10	43.80^{aB}	54.27^{aA}	0.84
	$HSD_{0.05}$	1.13	0.12	–	8.9	8.7	–	0.24	0.42	–	0.14	0.07	–	0.55	0.90	–
Year	2020	7.57^{aB}	8.83^{aA}	0.11	441.2^{aB}	508.0^{bA}	8.5	50.00^{bB}	50.38^{aA}	0.22	11.17^{bB}	11.88^{bA}	0.09	41.20^{bB}	53.00^{bA}	0.87
	2021	6.48^{bB}	8.35^{bA}	0.15	372.6^{bB}	561.4^{aA}	10.7	51.92^{aA}	42.54^{bB}	0.47	11.36^{aB}	12.46^{aA}	0.09	46.33^{aB}	55.90^{aA}	0.55
	$HSD_{0.05}$	1.13	0.12	–	8.9	8.7	–	0.24	0.42	–	0.14	0.07	–	0.55	0.90	–

W – wheat; WP – winter pea; SP – spring pea; FB – faba bean; PC – purple clover; ECO – organic farming; CONV – conventional cropping system; DM – dry matter; TKW – thousand kernels weight. Differences between legume variants, sowing methods and years (in columns) are labelled with small letters; differences between cropping systems (ECO, CONV – in rows) are labelled with capitals

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Table 3. Evaluated production and quality parameters of winter wheat in individual years and sowing methods (Tukey's *HSD* (honestly significant difference) test at the level of $P < 0.05$)

Year	Sowing method	Leguminous variant	Grain yield (t/ha)		Number of ears per m^2		TKW (g)		Crude protein content in grain DM (%)		Zeleny sedimentation (mL)	
			ECO	CONV	ECO	CONV	ECO	CONV	ECO	CONV	ECO	CONV
2020	Separate rows	W + WP	7.65^{a}	8.69^{a}	442.0^{a}	490.0^{a}	50.43^{a}	51.03^{b}	11.01^{ab}	11.88^{c}	43.00^{a}	53.33^{a}
		W + SP	7.27^{a}	8.72^{a}	425.0^{a}	486.0^{a}	50.35^{a}	51.83^{a}	10.98^{ab}	12.18^{a}	42.00^{a}	52.33^{a}
		W + FB	7.57^{a}	8.49^{a}	432.0^{a}	480.0^{a}	50.27^{a}	51.09^{b}	11.11^{ab}	12.14^{ab}	41.00^{ab}	54.33^{a}
		W + PC	7.43^{a}	8.41^{a}	431.3^{a}	476.7^{a}	50.37^{a}	51.15^{b}	11.27^{a}	11.98^{bc}	41.00^{ab}	49.67^{a}
		control	7.19^{a}	8.29^{a}	420.0^{a}	470.0^{a}	50.01^{a}	50.96^{b}	10.83^{b}	11.62^{d}	39.00^{b}	51.00^{a}
		$HSD_{0.05}$	0.56	0.44	40.3	42.6	0.64	0.34	0.31	0.20	2.94	7.04
	Mixture	W + WP	7.78^{a}	9.18^{a}	451.0^{a}	536.0^{a}	50.23^{a}	49.22^{b}	11.24^{b}	11.79^{a}	43.00^{a}	54.00^{ab}
		W + SP	7.69^{a}	9.25^{a}	453.0^{a}	539.0^{a}	49.83^{ab}	50.20^{a}	11.26^{b}	11.86^{a}	42.00^{ab}	54.00^{ab}
		W + FB	7.92^{a}	9.29^{a}	463.0^{a}	542.0^{a}	49.12^{c}	49.87^{ab}	11.56^{a}	11.93^{a}	40.00^{bc}	54.67^{a}
		W + PC	7.68^{a}	9.08^{a}	460.0^{a}	535.0^{a}	49.59^{bc}	49.41^{b}	11.22^{b}	11.84^{a}	42.00^{ab}	53.67^{ab}
		control	7.49^{a}	8.88^{a}	435.0^{a}	525.3^{a}	49.76^{ab}	49.07^{b}	11.16^{b}	11.59^{b}	39.00^{c}	53.00^{b}
		$HSD_{0.05}$	0.55	0.51	46.2	32.8	0.56	0.42	0.32	0.17	2.40	1.55
2021	Separate rows	W + WP	6.81^{a}	8.04^{a}	388.0^{a}	538.0^{a}	52.70^{a}	42.95^{a}	11.88^{a}	12.78^{a}	48.00^{a}	58.00^{a}
		W + SP	6.62^{a}	8.07^{a}	361.0^{a}	548.0^{a}	52.84^{a}	43.27^{a}	11.98^{a}	12.65^{ab}	46.00^{bc}	56.00^{ab}
		W + FB	6.71^{a}	8.00^{a}	378.0^{a}	527.0^{a}	52.29^{ab}	43.97^{a}	11.42^{b}	12.49^{abc}	47.33^{ab}	56.00^{ab}
		W + PC	6.00^{b}	8.24^{a}	355.0^{a}	544.0^{a}	51.19^{c}	41.96^{a}	11.23^{b}	12.48^{bc}	46.00^{bc}	58.00^{a}
		control	5.80^{b}	8.17^{a}	340.0^{a}	550.0^{a}	51.39^{bc}	43.03^{a}	11.25^{b}	12.28^{c}	44.67^{c}	54.00^{b}
		$HSD_{0.05}$	0.53	0.62	51.3	47.1	1.01	2.70	0.28	0.29	1.96	2.08
	Mixture	W + WP	6.83^{a}	8.61^{ab}	389.0^{a}	580.0^{ab}	52.43^{a}	40.91^{a}	11.32^{a}	12.72^{a}	48.00^{a}	57.33^{a}
		W + SP	6.83^{a}	8.79^{ab}	391.0^{a}	590.0^{ab}	51.58^{a}	42.77^{a}	11.42^{a}	12.28^{b}	47.00^{a}	55.33^{b}
		W + FB	6.67^{a}	8.99^{a}	394.0^{a}	601.7^{a}	52.10^{a}	43.29^{a}	11.31^{a}	12.38^{b}	48.00^{a}	57.00^{a}
		W + PC	6.70^{a}	8.47^{bc}	376.0^{a}	579.0^{ab}	51.49^{a}	42.47^{a}	10.88^{b}	12.35^{b}	44.33^{b}	53.33^{c}
		control	5.81^{b}	8.10^{c}	354.0^{a}	556.0^{b}	51.14^{a}	40.78^{a}	10.92^{b}	12.21^{b}	44.00^{b}	54.00^{c}
		$HSD_{0.05}$	0.45	0.39	54.1	45.5	1.48	2.72	0.29	0.24	1.84	1.20

W – wheat; WP – winter pea; SP – spring pea; FB – faba bean; PC – purple clover; DM – dry matter; TKW – thousand kernels weight; ECO – organic farming; CONV – conventional cropping system

The year 2021 was characterised by a low number of ears per m^2 but high TKW in the organic cultivation system, while in the conventional system, the evaluated treatments achieved a very high number of ears per m^2 – especially when sowing the mixture, but the TKW was very low. In 2020, the values of the yield elements were more balanced.

Overall, it can be stated that in 2021 in the organic cropping system, the effect of used legumes on wheat yields was obvious and more significant than in the previous year of 2020 – differences between the least yielding variants, which were usually controlled without legumes, and the most yielding variants, which were mostly the variants with winter or spring peas, were around 0.6–0.8 t/ha, in some cases, they reached about 1 t/ha (in the previous year of 2020 it was usually only about 0.2–0.4 t/ha). In the conventional cropping system, the effect of using legumes on yields was significantly weaker, and in some cases, variants with legumes achieved even lower yields than the control without legumes (in the previous year 2020, the differences between the most yielding and least yielding variants were similar to the organic system between about 0.2–0.4 t/ha). We presuppose that the atypical course of spring vegetation in 2020 may have affected the fact that in 2020, both in the organic and conventional cropping systems, the effect of intercropping with legumes

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on wheat yields was not very pronounced. There were two waves of late spring frosts that hit legumes significantly more than wheat – legumes practically stopped growing, wheat significantly suppressed them, and this suppression continued during the next vegetation. In 2021, on the other hand, the growth of legumes in the organic cropping system was relatively intense in the spring; wheat could not suppress them too much, which probably had a positive effect on wheat yield. Better illumination and sun exposure of legumes in organic wheat growth (compared to "conventional" wheat growth) could also have a positive effect. In the conventional cropping system, however, the situation was different in 2021 compared to the organic cultivation – wheat grew very intensively here and strongly suppressed legumes. The result was a wheat growth with a very high final density (number of ears per m^2 at the level of up to 600 ears or more); in such a dense stand, the probability that the benefits of legumes could be more pronounced was no longer high.

Effects of legumes on quality parameters of the wheat grain. Some previous studies have shown that intercropping cereals and grain legumes can increase the nitrogen (or crude protein) concentrations in cereal grains (Knudsen et al. 2004, Ghaley et al. 2005). Our results given in Table 2 are consistent with these findings and showed that both in organic and conventional cropping systems, the lowest crude protein content in wheat grain DM was found in control – pure sown wheat and was significantly different from the intercropped wheat. The highest crude protein content in grain DM was usually found in the wheat intercropped with peas or beans, but the differences in the protein content in the wheat grain DM between the individual intercropping treatments were usually statistically insignificant. A more detailed view of the results of individual years is provided in Table 3. The results showed that even in this evaluation, the control usually achieved the lowest crude protein content in the wheat grain DM, but the differences between the sole crop wheat and wheat intercropped with some legumes were not significant in all cases. Our findings are in accordance with the conclusions of Gooding et al. (2007), who evaluated the effect of intercropping wheat with a faba bean and wheat with a pea in field experiments during the three growing seasons and found that intercropping wheat with grain legumes regularly increased the nitrogen concentration of the cereal grain. Similarly, Dordas and Lithourgidis (2011) concluded that nitrogen concentration was higher for the cereals when faba bean was included in the mixture, and Kamalongo and Cannon (2020) found that the concentration of nitrogen in a grain of wheat intercropped with bean was about 17% higher in comparison with pure sown wheat. Our results also showed, in accordance with the conclusions of Gooding et al. (2007), that wheat intercropped with legumes reached higher values of Zeleny sedimentation and usually significantly differed from the separately cropped wheat. The differences in Zeleny sedimentation values between the sole-cropped wheat and wheat intercropped with legumes in the organic cultivation system were mostly higher in comparison with conventional ones. On the other hand, our results did not confirm the findings of Gooding et al. (2007) and Kamalongo and Cannon (2020) that the increase in protein concentration in the wheat grain intercropped with faba bean was associated with a 25–30% yield reduction of the wheat, compared to sole cropped wheat. But, the wheat yield reduction was probably affected by its lower share in the mixture.

In conclusion, the findings of the present work indicated that wheat intercropped with legumes (especially peas and faba bean) reached higher grain yields in comparison with pure sown wheat. However, there were significant differences between the experimental years – in 2021, differences between the pure sown wheat and wheat intercropped with legumes were significant and relatively high; in 2020, they were insignificant. The effect of wheat-legume intercropping on wheat yields was higher in the organic cropping system compared to the conventional one. Regarding the sowing method, both in organic and conventional cropping systems, yields of wheat grown with legumes in mixed culture exceeded significantly yields of wheat cultivated with legumes in separate, alternating rows. Regarding the quality parameters, wheat intercropped with legumes reached in comparison with pure sown wheat usually had higher crude protein content in wheat grain dry matter and higher values of Zeleny sedimentation.

REFERENCES

Amossé C., Jeuffroy M.-H., David Ch. (2013): Relay intercropping of legume cover crops in organic winter wheat: effects on performance and resource availability. Field Crops Research, 145: 78–87.

Amossé C., Jeuffroy M.-H., Mary B., David Ch. (2014): Contribution of relay intercropping with legume cover crops on nitrogen

https://doi.org/10.17221/276/2022-PSE

dynamics in organic grain systems. Nutrient Cycling in Agroecosystems, 98: 1–14.

Bedoussac L., Journet E.-P., Hauggard-Nielsen H., Naudin C., Corre-Hellou G., Jensen E.S., Prieur L., Justes E. (2015): Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. Agronomy for Sustainable Development, 35: 911–935.

Bedoussac L., Justes E. (2010): Dynamic analysis of competition and complementarity for light and N use to understand the yield and the protein content of a durum wheat-winter pea intercrop. Plant and Soil, 330: 37–54.

Bergkvist G. (2003): Effect of white clover and nitrogen availability on the grain yield of winter wheat in a three-season intercropping system. Acta Agriculturae Scandinavica, Section B – Soil and Plant Science, 53: 97–109.

Bergkvist G., Stenberg M., Wetterlind J., Båth B., Elfstrand S. (2011): Clover cover crops under-sown in winter wheat increase yield of subsequent spring barely – effect of N dose and companion grass. Field Crops Research, 120: 292–298.

Brooker R.W., Bennett A.E., Cong W.-F., Daniell T.J., George T.S., Hallett P.D., Hawes C., Iannetta P.P.M., Jones H.G., Karley A.J., Li L., McKenzie B.M., Pakeman R.J., Paterson E., Schöb C., Shen J.B., Squire G., Watson C.A., Zhang C.C., Zhang F.S., Zhang J.L., White P.J. (2015): Improving intercropping: a synthesis of research in agronomy, plant physiology and ecology. New Phytologist, 206: 107–117.

Dhima K.V., Vasilakoglou I.B., Keco R.Xh., Dima A.K., Paschalidis K.A., Gatsis T.D. (2014): Forage yield and competition indices of faba bean intercropped with oat. Grass and Forage Science, 69: 376–383.

Dong N., Tang M.M., Zhang W.P., Bao X.G., Wang Y., Christie P., Li L. (2018): Temporal differentiation of crop growth as one of the drivers of intercropping yield advantage. Scientific Reports, 8: 3110.

Dordas C.A., Lithourgidis A.S. (2011): Growth, yield and nitrogen performance of faba bean intercrops with oat and triticale at varying seeding ratios. Grass and Forage Science, 66: 569–577.

Ghaley B.B., Hauggard-Nielsen H., Høgh-Jensen H., Jensen E.S. (2005): Intercropping of wheat and pea as influenced by nitrogen fertilization. Nutrient Cycling in Agroecosystems, 73: 201–212.

Gooding M.J., Kasyanova E., Ruske R., Hauggard-Nielsen H., Jensen E.S., Dahlmann C., von Fragstein P., Dibet A., Corre-Hellou G., Crozat Y., Pristeri A., Romeo M., Monti M., Launay M. (2007): Intercropping with pulses to concentrate nitrogen and sulphur in wheat. Journal of Agricultural Science, 145: 469–479.

Ehrmann J., Ritz K. (2014): Plant: soil interactions in temperate multi-cropping production systems. Plant and Soil, 376: 1–29.

Hauggard-Nielsen H., Ambus P., Jensen E.S. (2001): Interspecific competition, N use and interference with weeds in pea-barley intercropping. Field Crops Research, 70: 101–109.

Kamalongo D.M.A., Cannon N.D. (2020): Advantages of bi-cropping field beans (*Vicia faba*) and wheat (*Triticum aestivum*) on cereal forage yield and quality. Biological Agriculture and Horticulture, 36: 213–229.

Kintl A., Elbl J., Záhora J., Kynický J., Brtnický M., Mikajlo I. (2015): Evaluation of grain yield in mixed legume-cereal cropping systems. AD ALTA: Journal of Interdisciplinary Research, 5.1: 96–98.

Knudsen M.T., Hauggard-Nielsen H., Jornsgard B., Jensen E.S. (2004): Comparison of interspecific competition and N use in pea-barley, faba bean-barley and lupin-barley intercrops grown at two temperate locations. Journal of Agricultural Science, 142: 617–627.

Mysliwiec M., Wanic M., Michalska M. (2014): Response of spring wheat to the growth with undersown of persian clover under controlled conditions. Acta Scientiarum Polonorum, Agricultura, 13: 29–44.

Neugschwandtner R.W., Kaul H.-P., Moitzi G., Klimek-Kopyra A., Lošák T., Wagentristl H. (2021): A low nitrogen fertiliser rate in oat-pea intercrops does not impair N_2 fixation. Acta Agriculturae Scandinavica, Section B – Soil and Plant Science, 71: 182–190.

Lithourgidis A.S., Dordas C.A. (2010): Forage yield, growth rate, and nitrogen uptake of faba bean intercrops with wheat, barley, and rye in three seeding ratios. Crop Science, 50: 2148–2158.

Lithourgidis A.S., Vlachostergios D.N., Dordas C.A., Damalas C.A. (2011): Dry matter yield, nitrogen content and competition in pea-cereal intercropping systems. European Journal of Agronomy, 34: 287–294.

Pelzer E., Bazot M., Makowski D., Corre-Hellou G., Naudin C., Al Rifai M., Baranger E., Bedoussac L., Biarnes V., Boucheny P., Carrouée B., Dorvillez D., Foissy D., Gaillard B., Guichard L., Mansard M.-C., Omon B., Prieur L., Yvergniaux M., Justes E., Jeuffroy M.H. (2012): Pea-wheat intercrops in low input conditions combine high economic performances and low environmental impacts. European Journal of Agronomy, 40: 39–53.

Vandermeer J.H. (2012): The Ecology of Intercropping. Cambridge, Cambridge University Press. ISBN: 9780511623523

Vlachostergios D.N., Lithourgidis A.S., Dordas C.A. (2018): Agronomic, forage quality and economic advantages of red pea (*Lathyrus cicera* L.) intercropping with wheat and oat under low-input farming. Grass and Forage Sciences, 73: 777–788.

Vrignon-Brenas S., Celette F., Piquet-Pissaloux A., Corre-Hellou G., David Ch. (2018): Intercropping strategies of white clover with organic wheat to improve the trade-off between wheat yield, protein content and the provision of ecological services by white clover. Field Crops Research, 224: 160–169.

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