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Yield stability of winter wheat in intercrop makes better adaptation to climate conditions

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Abstract: Global climate change is a major issue affecting the agricultural sector worldwide. Hungary is no exception to this, gradual warming, decreasing annual precipitation and increasingly frequent extreme meteorological events affected us as well. These effects significantly tested the adaptive capacity of cultivated plants. In Hungary, two-thirds of the arable land is occupied by cereals. In most cases, there is no crop rotation, and the pre-crop effect remaining unused. Intercrop is a special plant association where two or more crops are grown together on the same field, with complementary utilization of the available resources. This cultivation method enchances weed control, increases resilience against pests and pesticides, and improves soil fertility and conservation. Our experiments were made in 2020/2021 with three winter wheat varieties (GK Szilárd, Celulle, GK Csillag) and a winter pea variety (Aviron) in four repetitions on 10-square-meter random layout plots in Szeged-Öthalom. We tested three different seed densities for each variety in every combination. We found that a higher seed density of wheat resulted in a higher yield regardless of the presence of pea, except for GK Csillag at 75% seed density of wheat and pea. When the pea ratio in the mixture was increased, the wheat yield decreased. However, we observed that GK Szilárd and Cellule achieved higher yield at 75% and 100% mixtures with 75% Aviron. Pure stands showed better values than the combined ones, vice versa for GK Csillag: every seed density with 50% of Aviron gave the highest wheat yield. Growing wheat and pea together provides greater financial stability than a single crop, even in extreme weather conditions.

Keywords: intercrop, climate change, yield advantage, crop failure

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Introduction

Today, global climate change affects our lives in many ways. Over the past century, the average annual temperature in Hungary have gradually risen by 1 °C, while precipitation has decreased with unfavorable distribution. These facts indicate that global climate change is a real phenomenon that affects us directly (Jolankai & Birkás, 2007). Extreme weather events are now more frequent and intense. Today it can be declared that every second year is a dry year. Due to the geographical location of Hungary, continental climate is mixed with oceanic and Mediterranean elements, where the different climatic effects occur simultaneously (Pepó & Sárvári, 2011). These effects are significantly testing the adaptive capacity of cultivated plants. We can mitigate some of the negative effects of climate change by choosing adaptive varieties and using intensive cultivation technology, but we cannot eliminate them entirely. Future crop production opportunities will depend on how we can adapt to these changing climatic conditions

(Jolankai & Birkás, 2007).

Almost two-thirds of the arable land in Hungary is planted with five main crops: maize, wheat, barley, sunflower, and rape (Antal, 2005). The high proportion of cereals created short rotations. Today wheat is sown after one-third of its own, one-third of maize, and one-third of other plants (Pepó & Sárvári, 2011). The agricultural development of the 1960s, the extensive use of mechanization, genetic selection and intensive use of chemicals led to oversimplification of the cropping systems and significant loss of biodiversity (Pankou et al., 2021). To increase efficiency and sustainability, it is essential to redesign the current arable cropping system (Bedoussac et al., 2015; Naudin et al., 2014; Pelzer et al., 2012). One solution solution could be intercropping (Bedoussac & Justes, 2011). It is a special form of plant association, where growing two or more species simultaneously on the same field at the same time (Willey, 1990). There is a growing interest in intercropping, because of the increasing awareness of environmental pollution which comes from the excessive use of chemical inputs (Naudin et al., 2014) and the limited availability and high cost of fertilizers (Thilakarathna et al., 2016). Legumes have the unique ability to fix biologically nitrogen and provide inexpensive and green source of N fertilisers (Voisin et al., 2014). They also reduce synthetic nitrogen fertilizers use (Bedoussac et al., 2015) and break crop-effect in cereal-rich rotations (Neugschwandtner, Kaul, et al., 2021). Legumes, such as field pea are valuable sources of protein, and can be an alternative to soybean (Neugschwandtner, Bernhuber, et al., 2021). However, there was a continous decline in field pea cultivation area explained by a relative low economic competitiveness compared to more profitable crops (Divéky-Ertsey et al., 2022; Kristó et al., 2020a), such as susceptibility against pest, diseases, and weeds, intolerance to water stress, poor strem strength, and unstable yield (Bedoussac et al., 2015; Gollner et al., 2019). These high cultivation risks can almost be eliminated by plant associations.

The most obvious advantage of intercropping is to achieve greater yield on a given arable land by efficient utilization of available resources than in pure stands (Kristó et al., 2020b; Lithourgidis et al., 2011; Pankou et al., 2021). A yield advantage occurs when niche overlap is minimal between the companion plants and interspecific competition for resources is less than the intraspecific competition. Ideally, intercropping should involve varieties from different families (Pankou et al., 2021), but the selection of the appropriate crop may be challenging (Lithourgidis et al., 2011). Most field crops were bred for sole crop cultivation; therefore, these varieties are not always suitable for intercropping (Nelson et al., 2021). The typical sowing period for field pea for east-central Europe is spring, shifting sowing time from spring to autumn within plant association could be a field management strategy to avoid the critical periods of development, when there is a high probability of drought (Neugschwandtner, Bernhuber, et al., 2021). Winter crops are usually ready to harvest earlier than spring crops, therefore their yield are usually higher and more stable due to their longer growing period and lower dependence on water availability during spring (Naudin et al., 2014). Moreover, the greater variability of spring pea yield can be explained primarily by the amount and distribution of precipitation during plant growth. Spring crops are often characterized by a high soil compaction due to early sowing or lack of water because of delayed sowing. Both factors have significant influence on nitrogen fixation and pea yield, making it difficult to find an ideal sowing time. Yield stability can be attributed also the partial restoration of diversity by intercropping, that is lost under sole crop-

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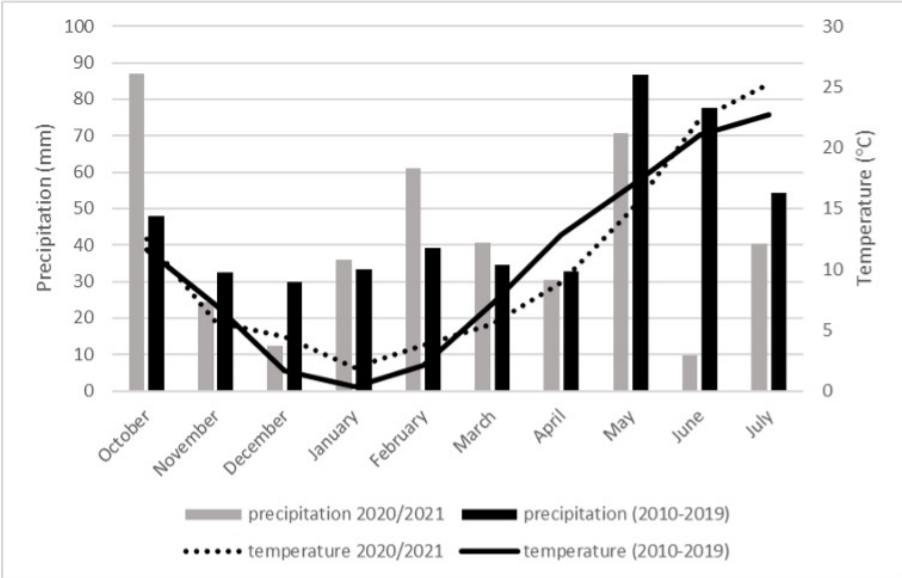

Figure 1: Monthly precipitation and temperature in the year of 2020/2021 and in long term mean (2010-2019) in Szeged-Öthalom

Table 1: Sowing density of winter wheat and winter pea.

		Number of seed of winter pea			
		0 seed ha^{-1}	0.5 million seed ha^{-1}	0.75 million seed ha^{-1}	1 million seed ha^{-1}
Number of seed of winter wheat	0 seed ha-1	-	0:50	0:75	0: 100
	2.5 million seed ha-1	50:0	50:50	50:75	50:100
	3.75 million seed ha-1	75:0	75:50	75:75	75:100
	5 million seed ha-1	100:0	100:50	100:75	100:100

ping (Lithourgidis et al., 2011). Intercropping provides high insurance against crop failure especially in extreme weather conditions such as frost, drought, and flood. When several crops are grown together, farmers are less exposed to total crop failure or fluctuating market demands.

In Hungary only a few studies have been published about intercropping, and little is known about the conditions of plant associations. Therefore, the objectives of the present study were to determine (1) the crop yield of winter wheat in mixtures and compare it with each other and sole crops, (2) the difference between each winter wheat variety, and (3) the difference in sowing density.

Materials and Methods

Our investigations were made in the research station of the Hungarian University of Agriculture and Life Sciences in Szeged-Öthalom in one growing season (2020/2021), with three winter wheat varieties (GK Szilárd, Cellule, GK Csillag) and one field pea variety (Aviron). The experimental design was a randomized complete block design in a split plot arrangement in 4 repeats, where the total size of each plot was 10 square meters.

The experimental area is located in the northern part of Szeged, next to the junction of the M5 motorway and the road 5. Our trial field is easily accessible, the soil type is deep salt meadow chernozem soil, it is well supplied with nutrients. The montly precipitation and temperature characteristics are shown in Figure 1. We can highlight that the precipitation in June was significantly below than the 10 year average precipitation (2010-2019), which affected crop development.

We used three different seed densities in every species, in every combination. We chose the most commonly used and ideal sowing density either for winter wheat and pea, where 100% was 5 million seed ha^{-1} in case of wheat, and 1 million seed ha^{-1} for winter pea (Table 1). Besides that, 75% sowing density of winter wheat was 3.75 million seed ha^{-1} and 750 thousand seeds of winter pea. 50% sowing density of winter wheat was 2.5 million seed ha^{-1} and 500 thousand seeds of winter pea.

GK Szilárd was a medium-ripe winter wheat variety with a good adaptibility to environmental conditions and high yield productivity. It has great stem strength, which is suitable for pea support. Crop yield: 7.5–9.5 t/ha. Cellule was a medium-ripe strong tillering variety with high yield stability and nutrient utilization. It has high yield productivity even in dry conditions. Crop yield: 9–12 t/ha. GK Csillag was an early-ripe winter wheat with high balanced yield, homogen ripening and easy threshing. It is one of the varieties which has grown in the largest area in Hungary. Crop yield: 6.5–8 t/ha. Aviron was a semi-leafless winter pea variety with tendrils. It is suitable for both feeding and human consumption. It is characterized by medium growing and excellent cold resistance. It has rapid initial development and good disease resistance. Crop yield: 4.5–5 t/ha.

Preceding crop was winter wheat. All of the varieties were sown simultaneously on 21st October 2020. We use process seed without inoculation in the case of winter pea. Crops received no fertilizer in the experimental period. Single harvest was on 2nd July 2021. Following the grains were separated with a grain separator for each parcel. After grain yield was measured, data from field experiments were analyzed by two-way analysis of variance.

Results

In our investigation we examined crop yield of winter wheat. In the case of mixed plots we added the yield of the two companion plants, because yield advantage occurs when we define them together. In Table 2 we can see, that in many cases the values of the associated plots surpassed the control plot. All mixtures of the GK Csillag variety has higher yield than in pure stands. In the case of GK Szilárd 2.5 million seed ha^{-1} and all of the sowing densities of winter pea gave higher values than in monoculture, and it was the same in GK Szilárd 5 million seed ha^{-1} and Aviron 0.75 million seed ha^{-1} combination. For the Cellule variety we also find high crop yields, although these only approached the values of the control plot.

In every case we considered winter pea sowing density as an independent application. Thus, in the first case we observed whether there were differences between the number of seeds of winter wheat and the applications. At GK Szilárd variety higher seed density made higher yield regardless of winter pea (Table 3). There was a statistical difference between the 2.5 million seed ha^{-1} and the 5 million seed ha^{-1}. In pure wheat the highest value was the sowing density of 3.75 million seed ha^{-1}, so without winter pea it was more ideal for GK Szilárd variety. The lowest grain yield has the GK Szilárd 2.5 million seed ha^{-1}and Aviron 1 million seed ha^{-1} combination of the mixtures, by comparison the best grain yield was in the mix of GK Szilárd 5 million seed ha^{-1} and Avi-

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Table 2: The total yield of the plant association (winter wheat and pea together) and yield in pure stands (t ha^{-1})

			Applications		
		Pure wheat	Aviron 0.5 million seed ha^{-1}	Aviron 0.75 million seed ha^{-1}	Aviron 1 million seed ha^{-1}
GK Szilárd	2.5 million seed ha^{-1}	4.73	5.00	5.06	5.03
	3.75 million seed ha^{-1}	5.55	4.98	5.40	5.12
	5 million seed ha^{-1}	5.51	5.45	5.85	5.48
Cellule	2.5 million seed ha^{-1}	5.76	5.50	5.63	5.45
	3.75 million seed ha^{-1}	6.35	5.88	5.80	5.67
	5 million seed ha^{-1}	6.59	6.03	6.21	6.15
GK Csillag	2.5 million seed ha^{-1}	5.25	5.69	5.71	5.47
	3.75 million seed ha^{-1}	5.65	6.05	6.00	6.01
	5 million seed ha^{-1}	5.47	6.49	5.88	6.08

Table 3: Grain yield of the variety GK Szilárd (t ha^{-1})

GK Szilárd	pure wheat	Aviron 0.5 million seed ha^{-1}	Aviron 0.75 million seed ha^{-1}	Aviron 1 million seed ha^{-1}	Average
2.5 million seed ha^{-1}	4.73^{AB}	4.44^{AB}	4.42^{AB}	4.15^{A}	4.43^{a}
3.75 million seed ha^{-1}	5.55^{B}	4.54^{AB}	4.83^{AB}	4.37^{AB}	4.82^{ab}
5 million seed ha^{-1}	5.51^{B}	5.00^{B}	5.42^{B}	4.87^{AB}	5.20^{b}
Average	5.26^{b}	4.66^{a}	4.89^{ab}	4.46^{a}	

LSD = 0.67 between the sowing density of winter wheat, LSD = 0.77 between the applications, LSD = 0.95 between any two. Values marked with different letters are significantly different at the $p = 0.05$ significance level. Capital letters indicate significance between any two.

Table 4: Grain yield of the variety Cellule (t ha^{-1})

GK Szilárd	pure wheat	Aviron 0.5 million seed ha^{-1}	Aviron 0.75 million seed ha^{-1}	Aviron 1 million seed ha^{-1}	Average
2.5 million seed ha^{-1}	5.76^{AB}	4.99^{AB}	4.89^{AB}	4.51^{A}	5.04^{a}
3.75 million seed ha^{-1}	6.35^{B}	5.08^{AB}	5.36^{AB}	5.07^{AB}	5.46^{a}
5 million seed ha^{-1}	6.59^{B}	5.66^{AB}	5.69^{AB}	5.43^{AB}	5.84^{a}
Average	6.23^{b}	5.24^{a}	5.31^{ab}	5.00^{a}	

LSD = 0.82 between the sowing density of winter wheat, LSD = 0.95 between the applications, LSD = 1.65 between any two. Values marked with different letters are significantly different at the $p = 0.05$ significance level. Capital letters indicate significance between any two.

ron 0.75 million seed ha^{-1}. Obviously higher pea ratio in mixture made less grain yield for winter wheat, except of the application of Aviron 0.75 million seed ha^{-1}with the sowing density of winter wheat in 3.75 million and 5 million respectively. By $p = 0.05$ there was significant difference only between the pure wheat parcel and its combination with the smallest and the largest sowing density of winter pea. We observed a significant difference between any two applications for the Aviron 1 million seed ha^{-1} GK Szilárd 2.5 million seed ha^{-1} mixture and all associations with 5 million seed ha^{-1} (without the highest sowing density of Aviron) and for pure wheat with 3.75 million seed ha^{-1}.

We observed that for the winter wheat variety Cellule (Table 4), the yield was higher in pure wheat than in mixture. By concentrating the sowing of wheat, a higher yield was obtained. In contrast, there was no statistical difference between the sowing densities. We have noticed two combinations where grain yield was remarkably high: Cellule seed density in 3.75 million seed ha^{-1} and 5 million seed ha^{-1} with Aviron 0.75 million seed ha^{-1}. In these two cases, grain yield did not decrease despite the plant density. In terms of the applications there was a deviation between the control plot and all of the mixed parcels with winter pea. This could have happened because the Cellule variety does not tolerate overdensity, therefore crop depression is created. By $p = 0.05$ there were significant differences between Aviron's 1 million ha^{-1} sowing density with Cellule 2.5 million ha^{-1} sowing density and the pure stands with 3.75 and 5 million ha^{-1} sowing density.

GK Csillag was a new variety in our intercrop experiment. Highlighted in this variety (Table 5) that in the case of control and Aviron 0.75 million seed ha^{-1} with GK Csillag 3.75 million seed ha^{-1}combination resulted higher grain yield than denser mixed trial fields. This shows thatthis mixture ratio was more advantageous for winter wheat than the others. The best yield was in the mix of GK Csillag in a sowing density of 5 million seed ha^{-1} and Aviron 0.5 million seed ha^{-1}. It represents much higher values than all the others. Although we could not prove this deviation from the others statistically. The lowest crop yield we got in the mixture of winter wheat in 2.5 million seed ha^{-1} and Aviron 1 million seed ha^{-1}. By increasing the density of winter pea in plant association we got lower grain yield, except of the 5 million seed ha^{-1}GK Csillag and Aviron 1 million seed ha^{-1} couple. There was no significant difference between any two treatments.

Our other aspect of this study was whether there were differences between the varieties of winter wheat and the applications (Table 6). We could prove statistical difference between GK Szilárd and GK Csillag. Although Cellule was better in monoculture than GK Csillag, this statement no longer applies to mixture. The highest value in the case of 2.5 million seed ha^{-1} of winter wheat we can find the variety of GK Csillag and the Aviron 0.5 million seed ha^{-1} mix. It was 5.36 t ha^{-1}, which is 1.21 tones more than the lowest grain yield in the mix of GK Szilárd and the Aviron 1 million seed ha^{-1}. There was no difference in the treatments. As the proportion of winter peas increased, the grain yield of each winter wheat variety within the mixtures decreased. Significant difference was measured between the mixture of GK Szilárd with 0.75 and 1 million seed ha^{-1} of Aviron and the pure wheat of Cellule.

In table 7 we can see the grain yield of winter wheat in a sowing density of 3.75 million seed ha^{-1}. Based on the examination of the varieties we can make the following findings: (1) there was no difference between the yield of the mixed winter wheat and pure plots; (2) there was a significant difference between GK Szilárd and GK Csillag in terms of wheat varieties. Although the Cellule vari-

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Table 5: Grain yield of the variety GK Csillag (t ha^{-1})

GK Szilárd	pure wheat	Aviron 0.5 million seed ha^{-1}	Aviron 0.75 million seed ha^{-1}	Aviron 1 million seed ha^{-1}	Average
2.5 million seed ha^{-1}	5.26^{A}	5.36^{A}	5.28^{A}	4.89^{A}	5.20^{a}
3.75 million seed ha^{-1}	5.65^{A}	5.79^{A}	5.62^{A}	5.60^{A}	5.66^{a}
5 million seed ha^{-1}	5.47^{A}	6.29^{A}	5.58^{A}	5.67^{A}	5.75^{a}
Average	5.46^{a}	5.81^{a}	5.49^{a}	5.39^{a}	

LSD = 0.92 between the sowing density of winter wheat, LSD = 1.06 between the applications, LSD = 1.84 between any two. Values marked with different letters are significantly different at the $p = 0.05$ significance level. Capital letters indicate significance between any two.

Table 6: Grain yield of winter wheat in a sowing density of 2.5 million seed ha^{-1} (t ha^{-1})

2.5 million seed ha^{-1}	pure wheat	Aviron 0.5 million seed ha^{-1}	Aviron 0.75 million seed ha^{-1}	Aviron 1 million seed ha^{-1}	Average
GK Szilárd	4.73^{AB}	4.44^{AB}	4.42^{A}	4.15^{A}	4.43^{a}
Cellule	5.76B	4.99^{AB}	4.89^{AB}	4.51^{AB}	5.04^{AB}
GK Csillag	5.26^{AB}	5.36^{AB}	5.28^{AB}	4.89^{AB}	5.20^{b}
Average	5.25^{a}	4.93^{a}	4.86^{a}	4.52^{a}	

LSD = 0.66 between the varieties of winter wheat, LSD = 0.76 between the applications, LSD = 1.32 between any two. Values marked with different letters are significantly different at the $p = 0.05$ significance level.
Capital letters indicate significance between any two.

Table 7: Grain yield of winter wheat in a sowing density of 3.75 million seed ha^{-1} (t ha^{-1})

3.75 million seed ha^{-1}	pure wheat	Aviron 0.5 million seed ha^{-1}	Aviron 0.75 million seed ha^{-1}	Aviron 1 million seed ha^{-1}	Average
GK Szilárd	5.55^{AB}	4.54^{A}	4.83^{AB}	4.37^{A}	4.82^{a}
Cellule	6.35^{B}	5.08^{AB}	5.36^{AB}	5.07^{AB}	5.46^{ab}
GK Csillag	5.65^{AB}	5.79^{AB}	5.62^{AB}	5.60^{AB}	5.66^{b}
Average	5.85^{a}	5.14^{a}	5.27^{a}	5.01^{a}	

LSD = 0.8 between the varieties of winter wheat, LSD = 0.93 between the applications, LSD = 1.6 between any two. Values marked with different letters are significantly different at the $p = 0.05$ significance level.
Capital letters indicate significance between any two.

ety had higher grain yield in the sowing density of 3.75 million seed ha^{-1} than the others in pure stands, it has already achieved less good results in intercrop. This phenomenon is still due to the sensitivity of the Cellule variety to density. GK Szilárd variety reached higher yield in the pea rate of 75% in plant association than in the other sowing density, which is also true for the Cellule variety. By $p = 0.05$ there were significant difference between the Aviron 0.5 million and 1 million sowing density with GK Szilárd and the pure stand of Cellule winter wheat variety.
Table 8 shows the crop yield of winter wheat varieties at a sowing density of 5 million seed ha^{-1}. There was no realized significant difference between winter wheat varieties. The GK Csillag variety reached its maximum yield in this sowing density. It was 6.29 t ha^{-1}, which is 11% higher than the yield of the Cellule, and 25% higher than the GK Szilárd variety. In addition Cellule was achieved the highest yield of the variety in plant association with a 75% proportion of winter pea, but we could not prove it statistically. The GK Szilárd variety also reached the maximum of the variety in this mixture ratio. Increasing the sowing ratio of both the companion plants to 100% only resulted in a higher yield for GK Csillag variety. There was a significant deviation between only the 1 million seed ha^{-1} Aviron with GK Szilárd mixture and the pure stand of Cellule.

Discussion

Global climate change leads to constant exposure of our cultivated plants to the negative effects of extreme weather events (Jolankai & Birkás, 2007). Intensive agriculture provides high yields but the excessive use of pesticides and fertilizers can cause environmental pollution (Pelzer et al., 2012). Therefore, it is important to seek innovative cropping systems that can exploit technological advances and prevent the loss of varietal diversity (Bedoussac et al., 2015). Cereal-legume intercropping contribute to the mitigation to climate change, might reduce dependence on artificial fertilizers and the nitrogen fixing ability of legumes improves yield and crop security (Naudin et al., 2014; Pankou et al., 2021). Due to the complementer use of available resources, total yields are often higher compared to the sole crops, especially when N fertilization is low (Bedoussac et al., 2015; Justes et al., 2021; Księżak et al., 2023; Pelzer et al., 2012). In our investigation, we found similar results where the associated plots generally surpassed the control plots. However, the winter wheat varieties achieved different crop surplus at different sowing densities and different combinations. Yield advantage was observed in all mixtures of the GK Csillag variety, and all pea combinations with GK Szilárd in the sowing density of 2.5 million seed ha^{-1}. Similarly, the same phenomenon was observed in GK Szilárd 5 million seed ha^{-1}associated with Aviron 0.75 million seed ha^{-1}. Different results were reported the Cellule variety, where the control plots have higher crop yield, and pea mixtures were slightly below this. In summary the yield advantage appears only at the combination of the GK Szilárd and GK Csillag varieties.

According to Hauggaard-Nielsen et al. (2006), because of the efficient utilization of the available growth resources, companion plants can tolerate much denser stands than the recommended crop plant density. Moreover, Neumann et al. (2007) experienced that the highest intercrop advantages were achieved in mixtures with densities above the optimal rate of the sole crop. We used the conventional sowing rates for wheat and pea, which were considered to be 100% treatment. Additionally, we set mixed parcels at rates of 75% and 50%. Mixtures with different pea proportions were considered as a separate application. First we examined the

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Table 8: Grain yield of winter wheat in a sowing density of 5 million seed ha^{-1} (t ha^{-1})

5 million seed ha^{-1}	pure wheat	Aviron 0.5 million seed ha^{-1}	Aviron 0.75 million seed ha^{-1}	Aviron 1 million seed ha^{-1}	Average
GK Szilárd	5.51^{AB}	5.00^{AB}	5.42^{AB}	4.87^{A}	5.20^{a}
Cellule	6.59^{B}	5.66^{AB}	5.69^{AB}	5.43^{AB}	5.84^{a}
GK Csillag	5.47^{AB}	6.29^{AB}	5.58^{AB}	5.67^{AB}	5.75^{a}
Average	5.86^{a}	5.65^{a}	5.56^{a}	5.32^{a}	

LSD = 0.82 between the varieties of winter wheat, LSD = 0.94 between the applications, LSD = 1.63 between any two. Values marked with different letters are significantly different at the $p = 0.05$ significance level.
Capital letters indicate significance between any two.

relationship between sowing density and pea combination according to winter wheat varieties. Nelson et al. (2021) mentioned that most arable crops have been bred for sole cropping, thus not all varieties are suitable for plant association. The balance between the companion plants during the growing season depends on various factors, including the sowing density, plant architecture, rooting patterns, competitive advantages, and the dynamics of the nitrogen availability Fujita et al. (1992); Lithourgidis et al. (2011). In our experiment, we observed differences between pure sowing and plant association in winter wheat varieties. GK Szilárd has a good adaptibility to environmental conditions. In combination with all proportion of pea, a higher wheat sowing rate resulted in higher yields. GK Szilárd reached its maximum yield by the pea rate in 75% and wheat rate in 100%. The lowest grain yield was reached in the mixture of GK Szilárd 2.5 million seed ha^{-1} and Aviron 1 million seed ha^{-1}. In our observations, the monocrop of the Cellule variety produced significantly higher yields compared to intercrop. By the higher proportion of winter wheat we observed higher yield. We obtained two outstanding values in the seed density of 3.75 million seed ha^{-1}and 5 million seed ha^{-1} in combination with Aviron 0.75 million seed ha^{-1}. Cellule has high tillering ability, which makes it sensitive to overdensity. For this reason, a 75% combination of winter pea seems to be the most suitable for this variety. GK Csillag is a new variety in our experiment. Based on the recommendations, we did not expect a very high yield from this winter wheat variety. However we included it among our experimental varieties because of its balanced yield and homogen ripening. In the combination of GK Csillag in a sowing density of 3.75 million seed ha^{-1}and Aviron 0.75 million seed ha^{-1}resulted a little bit higher yield than the denser association. This variety reached its maximum yield by the pea rate in 50% and the wheat proportion in 100%, which also gave the highest value of the mixtures. In all three varieties we observed that if the peas dominate in the mixtures, the wheat reaches the lowest yield. Only the GK Csillag variety can withstand 100% density of both species without yield loss.

Our second study aspect is the relationship between the winter wheat vareties and the applications. At a sowing density of 50% for winter wheat the GK Csillag clearly achieved a higher yield than in monocrop. It was the opposite of the previous one for the Cellule and the GK Szilárd varieties. At a sowing density of 3.75 million seed ha^{-1} there was only a slight difference between GK Csillag and Cellule varieties, which is smaller than the difference between GK Szilárd and GK Csillag varieties in the pea rate in 50% and 100%. Similar to the previous sowing density, the Cellule variety was significantly higher in monoculture, than in the mixtures. The GK Csillag variety also reached the highest values. Finally at the highest sowing density of 5 million seed ha^{-1} provides the best results for all the three winter wheat varieties. For the GK Csillag variety with the pea rate in 50%, and for GK Szilárd and Cellule with the pea proportion in 75%.

According to Nelson et al. (2021), most plant breeding programs focus on developing varieties for monoculture, leaving a gap in knowledge about how these varieties perform in plant associations. Plant traits required for intercropping can maximalize the yield advantages and avoid competition (Lithourgidis et al., 2011). The greatest potential to increase the efficiency of intercrops lies in experimenting with crop cobinations. Intercropping can be a safer alternative for farmers than single-crop cultivation due to the complementary use of resources (Lithourgidis et al., 2011), and can be a tool to achieve stable grain yields in a sustainable and environmentally friendly form.

References

Antal, J. (2005). Növénytermesztéstan 1. Budapest: Mezőgazda Kiadó.

Bedoussac, L., Journet, E.-P., Hauggaard-Nielsen, H., Naudin, C., Corre-Hellou, G., Jensen, E. S., … 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**(3), 911-935. doi: 10.1007/s13593-014-0277-7

Bedoussac, L., & Justes, E. (2011). A comparison of commonly used indices for evaluating species interactions and intercrop efficiency: Application to durum wheat–winter pea intercrops. Field Crops Research **124**(1), 25-36. doi: 10.1016/j.fcr.2011.05.025

Divéky-Ertsey, A., Gál, I., Madaras, K., Pusztai, P., & Csambalik, L. (2022). Contribution of Pulses to Agrobiodiversity in the View of EU Protein Strategy. Stresses **2**(1), 90-112. doi: 10.3390/stresses2010008

Fujita, K., Ofosu-Budu, K. G., & Ogata, S. (1992). Biological nitrogen fixation in mixed legume-cereal cropping systems. Plant and Soil **141**(1), 155-175. doi: 10.1007/BF00011315

Gollner, G., Starz, W., & Friedel, J. K. (2019). Crop performance, biological N fixation and pre-crop effect of pea ideotypes in an organic farming system. Nutrient Cycling in Agroecosystems **115**(3), 391-405. doi: 10.1007/s10705-019-10021-4

Hauggaard-Nielsen, H., Andersen, M., Jørnsgaard, B., & Jensen, E. (2006). Density and relative frequency effects on competitive interactions and resource use in pea–barley intercrops. Field Crops Research **95**(2), 256-267. doi: 10.1016/j.fcr.2005.03.003

Jolankai, M., & Birkás, M. (2007). Global climate change impacts on crop production in Hungary. Agriculturae Conspectus Scientificus **72**(1), 17-20.

Justes, E., Bedoussac, L., Dordas, C., Frak, E., Louarn, G., Boudsocq, S., … Li, L. (2021). The 4C approach as a way to understand species interactions determining intercropping productivity. Frontiers of Agricultural Science and Engineering **8**(3), 387-399. doi: 10.15302/J-FASE-2021414

Kristó, I., Tar, M., Irmes, K., Vályi-Nagy, M., & Szalai, D. (2020a). Különböző gyomszabályozási technológiák fitotoxikus hatása a takarmányborsó terméselemeire és fehérjetartalmára. In A. Haltrich & Á. Varga (Eds.), 66. Növényvédelmi Tudományos Napok (p. 76). Budapest: Magyar Növényvédelmi Társaság.

Kristó, I., Vályi-Nagy, M., Jancsó, K., Irmes, K., Rácz, A., & Tar, M. (2020b). Egy lehetőség a fehérje növények vetésterületének növelésére. In K. Kiss, L. Komarek, & T. Monostori (Eds.), Mezőgazdasági és Vidékfejlesztési kutatások a jövő szolgálatában (p. 147-156). Szeged: Innovariant Nyomdaipari Kft.

Księżak, J., Staniak, M., & Stalenga, J. (2023). Restoring the Importance of Cereal-Grain Legume Mixtures in Low-Input Farming Systems. Agriculture **13**(2), 341. doi: 10.3390/agriculture13020341

Lithourgidis, A., Dordas, C., Damalas, C. A., & Vlachostergios, D. (2011). Annual intercrops: an alternative pathway for sustainable agriculture. Australian Journal of Crop Science **5**(4), 396-410.

Naudin, C., van der Werf, H. M., Jeuffroy, M.-H., & Corre-Hellou, G. (2014). Life cycle assessment applied to pea-wheat intercrops: A new method for handling the impacts of co-products. Journal of Cleaner Production **73**(1), 80-87. doi: 10.1016/j.jclepro.2013.12.029

Nelson, W., Siebrecht-Schöll, D., Hoffmann, M., Rötter, R., Whitbread, A., & Link, W. (2021). What determines a productive winter bean-wheat genotype combination for intercropping in central Germany? European Journal of Agronomy **128**(1), 126294. doi: 10.1016/j.eja.2021.126294

Neugschwandtner, R. W., Bernhuber, A., Kammlander, S., Wagentristl, H., Klimek-Kopyra, A., Lošák, T., … Kaul, H.-P. (2021). Nitrogen Yields and Biological Nitrogen Fixation of Winter Grain Legumes. Agronomy **11**(4), 681. doi: 10.3390/agronomy11040681

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 & Plant Science **71**(3), 182–190. doi: 10.1080/09064710.2020.1869819

Neumann, A., Schmidtke, K., & Rauber, R. (2007). Effects of crop density and tillage system on grain yield and N uptake from soil and atmosphere of sole and intercropped pea and oat. Field Crops Research **100**(2), 285-293. doi: 10.1016/j.fcr.2006.08.001

Pankou, C., Lithourgidis, A., & Dordas, C. (2021). Effect of Irrigation on Intercropping Systems of Wheat (*Triticum aestivum* L.) with Pea (*Pisum sativum* L.). Agronomy **11**(2), 283. doi: 10.3390/agronomy11020283

Pelzer, E., Bazot, M., Makowski, D., Corre-Hellou, G., Naudin, C., Al Rifaï, M., … Jeuffroy, M.-H. (2012). Pea–wheat intercrops in low-input conditions combine high economic performances and low environmental impacts. European Journal of Agronomy **40**(1), 39-53. doi: 10.1016/j.eja.2012.01.010

Pepó, P., & Sárvári, M. (2011). Gabonanövények termesztése. Agrármérnöki MsC szak tananyagfejlesztése. TÁMOP-4.1.2-08/1/A-2009-0010 Projekt. Debrecen: Debreceni Egyetem.

Thilakarathna, M. S., McElroy, M. S., Chapagain, T., Papadopoulos, Y. A., & Raizada, M. N. (2016). Belowground nitrogen transfer from legumes to non-legumes under managed herbaceous cropping systems. A review. Agronomy for Sustainable Development **36**(4), 58. doi: 10.1007/s13593-016-0396-4

Voisin, A.-S., Guéguen, J., Huyghe, C., Jeuffroy, M.-H., Magrini, M.-B., Meynard, J.-M., … Pelzer, E. (2014). Legumes for feed, food, biomaterials and bioenergy in Europe: a review. Agronomy for Sustainable Development **34**(2), 361-380. doi: 10.1007/s13593-013-0189-y

Willey, R. (1990). Resource use in intercropping systems. Agricultural Water Management **17**(1), 215-231. doi: 10.1016/0378-3774(90)90069-B