PhD DISSERTATION THESIS

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EXAMINATION OF THE INTERACTION BETWEEN WINTER WHEAT AND WINTER PEA IN MIXED CROPPING

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Background of the research work

The intensification of agriculture took place in the 1960s. Introduction of agrochemical tools, such as a shift to nitrogen fertilizer, chemical plant protection, regulated water supply, increased level of soil tillage and mechanization, and the breeding of high-yielding varieties also contributed to the development of high crop yields and the threefold increase in wheat and maize yields. The short-term profit-oriented approach change the focus on cereals, which inevitably leads to oversimplification of the sowing structure. The narrower range of plant culture caused a decrease in biodiversity and a gradual displacement of legumes from crop rotation, which are able to regenerate soil productivity. The application of limited crop rotation simultaneously increased the probability of an unfavorable pre-crop sequence and the spread of monoculture. This phenomenon still exist today: in Hungary about 60% of the total arable land is cultivated with 5 crops (maize, wheat, sunflower, barley, rape). The reduced number of product range in itself results in vulnerability to the fluctuating market demands, while the negative effects of climate change can significantly influence the level of production. Research work of the last two decades made it clear that the excessive use of fertilizers and pesticides not only causes strong dependence but also has environmental pollution effect. Growing challenges encourage farmers to make difficult decisions, since the current cultivation methods are not sustainable in the long term or it can only be realized at the cost of serious expenses. The effort to solve these problems triggered in increased interest in alternative methods. Such an innovative cultivation system is plant association, which usually means the cultivation of two or more plants at the same time in the same area. One of the greatest advantage of combining winter wheat and pea is that breaking overhelming dominance of cereals without the decrease of their cultivation area. Due to the nitrogen fixing ability of the leguminous plant a natural and suitable nitrogen source is used, which positive effect already prevails in the year of sowing. The cultivation of protein crops can also contribute to increasing national protein base and reducing dependence on imported protein, which is essential for the forage of fodder-need animals.

In the last few years there were many research work have been made in this topic. However these studies focused primarily on the harvested crop and paid little attention to the parallel development of the companion plants and the interactions between the mixing species. At the moment, there is also little knowledge available regarding which varieties, at what sowing density and in what proportion within a mixture should be formed in an effective plant association. Although these parameters can be planned in advance and contribute decisively to the performance of the mixed cropping as a whole. In my thesis as an example, I would like to present the important aspects of creating a plant association with the combination of winter wheat and pea.

Aim of the dissertation

In my dissertation, I was looking for the answers of the following questions:

- Does the plant association have an effect on the value of the yield components of the companion plants?
- What kind of interaction is between the companion plants; whether balanced mixtures are created?
- Can we set up a parallel development process based on the growth rate of the companion plants?
- Is there a difference in height between the pure stands and associated parcels? In plant association, how the height of the companion plants changes compared to each other?
- How much the crop yield in a plant association compared to pure stands both for winter wheat and pea?
- What quality values can be achieved in the case of the companion plants comparison with pure sowing?

Materials and methods

My experiment was conducted for three consecutive growing seasons (2020/2021, 2021/2022, 2022/2023) at the research station of the Hungarian University of Agriculture and Life Sciences in Szeged-Öthalom. In my small-plot field experiment, I used the mixed cropping type of plant association in a random block arrangement, in 4 replication, where each plot size was 9 m^2. The mixed cropping consisted of three sowing densities (according to the local standard paractise in pure stands) of three winter wheat varieties (GK Szilárd, Cellule, GK Csillag) and one winter pea variety (Aviron). The seeds were covered (Rancona i-mix), winter peas were not inoculated. There was no possibility of irrigation at the experimental side, and no fertilizer had been applied in the field except of multi-nutrient autumn fertilizer (15:15:15) before sowing.

In order to observe the parallel development of winter wheat and winter pea, I made plant set reports several times during the experiment using randomly selected plant samples. Then I determined the developmenal phase of the companion plants based on the official BBCH-identification keys, to which I assigned the number of days after sowing and the heat sum (degree days) based on the following equation:

$$\text{heat unit } [°\text{C}] = \frac{\text{daily max.} + \text{daily min.}}{2} - \text{threshold pattern } [°\text{C}]$$

In the third growing season (2022/2023) the height of the companion plants above the ground was measured in the case of wheat by the youngest leaf, in the case of pea, it was done with a tape measure, including the uppermost leaf level.

I collected whole root samples from each parcel directly before harvest from an unit area (1m) using a measuring stick. The ears were threshed with a Wintersteiger LD 180 ST 4 threshing machine. Using Precisa 300C hand scale and a manual sample processing, based on the wheat yield components (plant numbers, shoot numbers, ear numbers, spikelet numbers, grain numbers, grain weight), and the pea yield components (plant numbers, shoot numbers, pod numbers, grain numbers, grain weight) I performed cumulative yield production analysis. After harvesting, crop yield is cleaned with a Pfeuffer SLN3 Sample Cleaner, the quality parameters were measured with Infratec™ NIR Grain Analyser. In the case of winter wheat, I measured crude protein, gluten, sedimentation value, and W-value. In terms of winter peas, the crude protein content was determined.

In my experiment, to measure the interaction between the companion plants, I calculated competition indices and monetary advantages. The land equivalent ratio (LER) indicates the efficiency of intercropping in using environmental resources compared to pure stands. The critical value is 1, above which association, above which pure sowing is more favorable in terms of development and crop yield.

It is calculated using the following equation:

$$\text{LER} = (\text{LERw} + \text{LERp})$$
$$\text{LERw} = (\text{Ywi}/\text{Yw})$$
$$\text{LERp} = (\text{Ypi}/\text{p})$$

where Yw and Yp are the yields of winter wheat and peas, as pure stands. Ywi and Ypi are the yields of winter wheat and peas as mixed cropping.

Aggressivity (A) expresses the relative yield increase of one companion plant against other. If A is 0, both plants are equally competitive. A positive Aw indicates the dominance of wheat, and a negative Aw shows the dominant role of peas. Aggressivity is derived from the following equation:

$$\text{Aw} = \left(\frac{\text{Ywi}}{\text{Yw} \cdot \text{Zwi}}\right) - \left(\frac{\text{Ypi}}{\text{Yp} \cdot \text{Zpi}}\right)$$

$$\text{Ap} = \left(\frac{\text{Ypi}}{\text{Yp} \cdot \text{Zpi}}\right) - \left(\frac{\text{Ywi}}{\text{Yw} \cdot \text{Zwi}}\right)$$

where Zpi is the seeding rate of winter peas sown in the mixture, and Zwi is the seeding rate of winter wheat in the mixture.

The competitive ratio (CR) represents the ratio of the individual LERs of the companion plants, taking into account their seeding rate.
The CR is calculated using the following formula:

$$\text{CR} = \text{CRw} + \text{CRp}$$
$$\text{CRw} = \left(\frac{\text{LERw}}{\text{LERp}}\right) - \left(\frac{\text{Zpi}}{\text{Zwi}}\right)$$
$$\text{CRp} = \left(\frac{\text{LERp}}{\text{LERw}}\right) - \left(\frac{\text{Zwi}}{\text{Zpi}}\right)$$

If CRw <1, there is a positive benefit and the crop can be grown in plant association, if CRw> 1, there is negative benefit. The reverse is true for CRp.

The actual yield loss (AYL) is an indice based on the yield per plant. The AYL can have positive or negative values, indicating the advantage or disadvantage of mixed cropping.
The AYL was calculated as per Equation:

$$\text{AYL} = \text{AYLw} + \text{AYLp}$$

$$\text{AYLw} = [(\text{Ywi}/\text{Zwi})/(\text{Yw}/\text{Zw})] - 1$$

$$\text{AYLp} = [(\text{Ypi}/\text{Zpi})/(\text{Yp}/\text{Zp})] - 1$$

The monetary advantage index (MAI) and the intercropping advantage (IA) provide information on the financial advantage of mixed cropping.
The MAI was calculated based on the LER:

$$\text{MAI} = (\text{value of mixed crops}) \cdot [(\text{LER} - 1)/\text{LER}]$$

The value of mixed crops was calculated as:

$$Ypi \cdot Pp + Ywi \cdot Pw$$

where Pp is the commercial value of winter peas. According to the Central Statistical Office, on the day of harvest the price was 94820 Ft/t in 2021, 116414 Ft/t in 2022, and 98538 Ft/t in 2023. Pw is the commercial value of winter wheat. The price was 75119 Ft/t in 2021, 131687 Ft/t in 2022, and 80515 Ft/t in 2023 at harvest time.

The index of intercropping advantage (IA) was calculated as follows:

$$IA = IAw + IAp$$
$$IAw = AYLw \cdot Pw$$
$$IAp = AYLp \cdot Pp$$

The higher the index value, the more profitable the whole cropping system.

The statistical analysis of the yield quantity and quality values, as well as the values of competitive indices were carried out using multivariate analysis of variance (MANOVA), where the factors were the variety of winter wheat, the seeding rate of winter peas and the seeding rate of winter wheat in the mixture. The overall MANOVA was evaluated based on the unexplained variance rate expressed by Wilk's lambda. Then subsequent three-way random block design univariate ANOVA tests were performed. The normality of the model residuals was accepted based on the absolute values of their skewness and kurtosis, the homogeneity of variances was tested using Levene's test ($p > 0.05$). In the case of significant factors, post hoc tests for wheat and pea yield and wheat quality values were used Games-Howell method, and in the case of pea crop quality and competition indices post hoc tests were done according to Tukey's method. All statistical analyses were performed using the statistical software IBM SPSS v.29.

Results

In the graphical representation of the Sváb cumulative yield analysis, I compared the yield components of the associated plots with the pure stands. The relative development of the plant association represented different results for the companion plants. At the beginning of the generative stage, the values of the winter pea yield components started to decrease roughly, regardless of the selected wheat variety. There was no difference between the first two years, although the second year had a strong drought. In the third year, during the entire development process, the pea yield components were far below to the pure sowing. Evaluate of winter wheat represented mixed results: in the first two years, but especially in the drought year, I measurred higher values of the yield components than in pure stands. The highest grain weight values were at the seeding rate of GK Szilárd 250 db/m^2–Aviron 75 db/m^2 (pure stand+24%), Cellule 500 db/m^2–Aviron 50 db/m^2 (pure sowing+17%) and GK Csillag 375 db/m^2–Aviron 50 db/m^2 (pure stand+19%). In the third year–similarly to pea–all associations achieved better results in pure sowing, except for the combination of GK Csillag 375 db/m^2–Aviron 50 db/m^2.

The most commonly used and well-known method for measuring the interaction between the companion plants is the land equivalent ratio (LER)(Figure 1.). According to the graphical representation of the partial LERw and LERp values, most of these results fell into one square, which indicated the dominance of wheat. Although in most cases the total LER>1, and more yield per unit area were shown in mixed cropping, these mixtures were unbalanced due to excessive competition between the companion plants. In the case of 6 associations, there was complementarity and cooperation between the species: with Cellule/Aviron 50:100, 75:50 (in 2021 and 2022), 50:75 és az 50:50 (only in 2022). In the third year, almost all of the mixtures had LER values less than 1, indicating that the mixed cropping in this year was disadvantageous for the companion plants.

1. Figure: A graphical representation of the partial LER values of the two companion plants swhows all the possible interactions. The LERw=LERp diagonal separates the areas where wheat or pea dominate. The part above the LER=1 diagonal shows yield advatage. Values below partial LER=0.5 indicate that the yield of the association is lower than in pure sowing. The opposite is true in the area below the partial LER=0.5 line.

In terms of agressivity and competitive ratio, except of one mixture (Cellule/Aviron 75:50), each examinal year wheat had higher values, while the opposite was true for peas. The more I increased the proportion of pea in the mix, the more aggressive I experienced from wheat, and the same time the competitiveness of pea increased.

The mixed cropping as a whole showed a negative picture in the case of actual yield loss and intercropping advantage index. The composition of the mixed cropping was favorable only for wheat, the significant yield loss of pea had a negative effect on the overall performance of the plant association.

In the first two years, the mixed parcels had a significant economic advantage, the most profitable association in the first year was the 100:75 mixture of GK Csillag/Aviron (124 265 Ft), in the second year it was the 75:50 seeding rate of Cellule/Aviron (191 987 Ft). In contrast, the third year indicated a strong financial disadvantage, which was not performed in the case of only 4 associations: at the 50:50 mixture of GK Szilárd/Aviron, at the 50:75 seeding rate of Cellule/Aviron, and in the case of 50:50 and 50:75 association of GK Csillag/Aviron.

The height measures of the companion plants were proved that the growth of winter wheat is not affected by the presence of peas, while the height of pea exceeds the value of pure stands. Finally, wheat outgrows pea at the heading developmental phase, and pod filling phase of pea, at this time the nodule-forming bacteria dies and the role of nitrogen supply eliminated.

The parallel development process of winter wheat and winter pea was completed based on the plant set reports (Figure 2.), on which I assigned the heat sum (degree days) and the number of days after sowing next to the developmenal phase of the companion plants. In all cases, the emergence of wheat preceded pea, then the development process parallel to each other up to the stage of stem elongation. After that the pea entered the generative stage earlier, while the wheat was in booting stage. Then, by the time of pod filling, the wheat also began on anthesis. Finally, the pea reached the physiological maturity one and a half-two weeks earlier than the wheat, and it was definitely entered the overripe phase by the time of harvest.

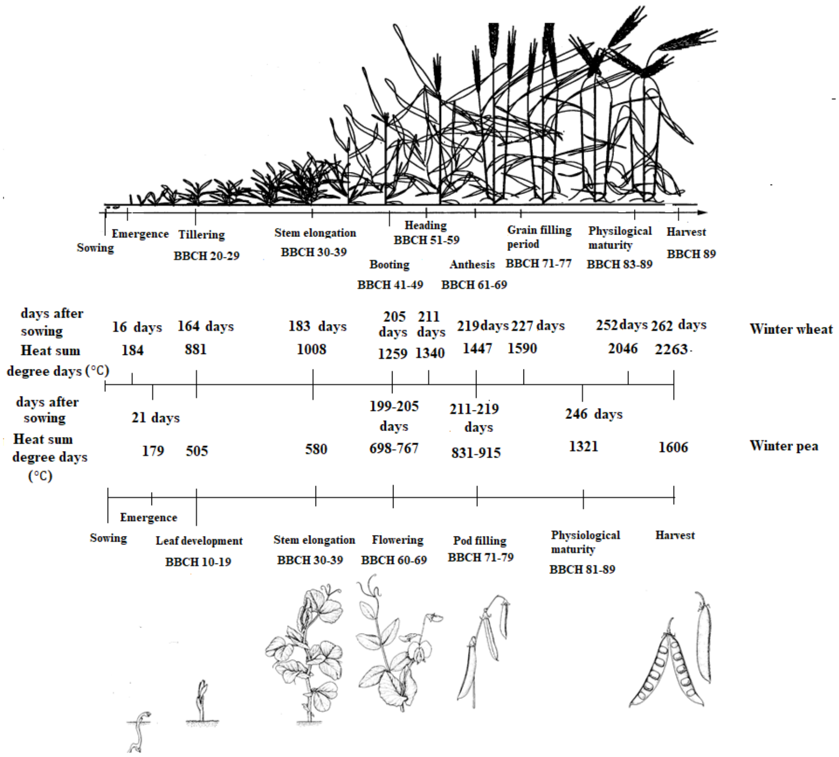

Figure 2: Development phases of winter wheat and winter pea assigned with the number of days since sowing and the heat sum (degree days) for both species in the case of mixed cropping

In terms of yield of winter wheat, there was a surplus in the first two years. The maximum value was the 100:50 mixture of GK Csillag/Aviron seeding rate in the first case, then the second year it was realized with an 50:50 mixture of GK Szilárd/Aviron. The second, drought year did not affect the yield of wheat as much as the recurring lack of rainfall in the key phases in the third year. Unfavorable growing conditions obviously contributed to a significant decrease in yield values.

In the first year, the quality parameters of winter wheat were uniformly around the level of pure sowing, while in the second, critical year, they significantly exceeded it in many cases. As long as the 50: 100 mixture of GK Szilárd/Aviron had outstanding values for protein, Zeleny index and the W-value, until then the 50:50 seeding rate of Cellule/Aviron association had higher values for gluten. In the third year, with only a few exceptions, the quality parameters reached the maximum value of the experimental years.

The winter pea yield during the entire experiment reached a small part of the values of pure stands. During the years, the pea yield showed a decreasing trend and reached its lowest point in the third year. There was a significant difference between the wheat varieties: the pea plant has less yield loss in the mixtures of Cellule.

Compared to the yield, the protein content of pea represented an outstandingly high value during the experiment. While in the first year the protein surpus was between 1 and 10%, in the second year, these values exceeded the level of the pevious year as well (pure sowing+17%). However there was a difference between the wheat varieties of the mixture providing the maximum protein value: the 75:75 seeding rate of Cellule/Aviron mixture was replaced by the GK Szilárd/Aviron 50:75 combination in ranking between years. Finally, in the third year with a lack of rainfall the Cellule wheat variety again performed better (pure stands+15%) in the case of the 75:50 and 100:50 seeding rate.

Discussion

One of the advantages of the Sváb-type cumulative yield analysis is that it graphically represents the yield components in relation to pure stands, which makes it possible to observe the effect of the companion plants on each other in some development phases. In the case of winter pea, at the beginning of the generative stage, the suppression, which comes from the wheat dominance, was perfectly visible through the negative development curve. In plant association, the amount of nitrogen from the atmosphere, which fixed by the leguminous plant is higher than in pure sowing. This nitrogen surplus caused a strong wheat growth, which shaded the pea culture and suppressed its development. The height of the wheat and the high seeding density resulted in lower illumination, thereby the strength of thickness of the pea stalk decreased, especially in the case of GK Csillag wheat variety. In the third year, the entire development process of the pea was negative, which may have been caused by a strong lack of precipitation at the time of emergence. At the same time, undeveloped inflorescence levels, short flowering period and shortened growing season, which detected in the drought year (2022) was rather a symptom of heat stress or lack of water, rather than the effect of mixed cropping. The high temperature above the threshold pattern appeared during the flowering stage, due to the basal thermotolerance the pea was able to produce crop. The high teperature and drought in the key phase also had a negative impact on wheat production. In the critical year (2022), the development phases were shortened and the plant showed the signs of forced ripening. The temperature above the threshold pattern hit the plant in the ripening phase punctually, symptoms of early drought (before flowering) were shown in the reduction of the number of grains, mainly in the Cellule variety. Yield components, which had higher values than pure sowing, appeared mostly in the second year, this phenomenon allows us to conclude, that the plant association was able to partially mitigate the negative effect of climate change. In contrast, in the third year the repeated lack of rainfall in the key phases of wheat strongly set back the development of the plant.

In a mixed cropping of winter wheat and winter pea, the water, nutrient and light requirements of the companion plants appear at the same time. As a result of the same resource needs, competition definitely turn up within the plant association. Even though the land equivalent ratio (LER) showed a yield advantage in every year, when the partial LER values were represented graphically, most of the values fell in the square where wheat dominated. Efficient resource utilization raises the possibility of complementarity, but this interaction based on a fine balance, which appeared only in the case of 6 mixtures and very easily transformed into competition. I could see this in the third year, where favorable assocations were created due to the increasing competition between the companion plants. It is likely that the interactions vary during the development process, and may even occur at the same time, but all of them can equally affect the performance of mixed cropping. In plant association, we used varieties which bred for monoculture, and this species reacted differently to the presence of a companion plant. As a result, their performance may change in a stressful environment such as competition. Competitiveness is not a permanent characteristic, but rather a response to a specific situation, which is significantly influenced by the genotype, the environment and the occuring interaction. According to some authors, in order to preserve the yield advantage, it is necessary to increase the proportion of the weaker competitor within the mixture, and for the reason of complementarity the seeding density of the companion plants may exceed the values of pure stands. In my experiment, on the one hand there was no compensation regarding the seeding rate of pea, on the other hand, the high cereal proportion led to the strengthening of the dominant role and had a clear influence on the dynamics of competition. The more I increased the plant density of the mixed cropping, the more aggresivity of the wheat became. The suppression of pea was reflected in actual yield loss. Especially in the third year, where yield loss affected almost the entire crop. The economic advantage of mixed cropping varied from year to year: the fluctuating world market price showed a profitable association with the LER values only in the first two years. The economic deficit of the third year could have been created both by unfavorable growing condition and the presence of competition. The advantage of mixed cropping was shown primarily in the case of wheat, on the part of peas, without exception, it were disadvantageous. However, the overall performance of the association was determined by the less competitive pea.

The composition of a plant association is firstly determined by the purpose and the conditions of cultivation. However, in the case of a leguminous complanion plant, the phenomenon of yield fluctuations must be taken into account. The shift in cultivation areas resulting from climate change, the replacement of traditional spring culture to winter and the earlier sowing time increases the chance to avoid critical phases for pea. Similar to this, the use of semi-leafless type of pea allows greater incident solar radiation and air movement, and decrease pathogen presence and lodging tendency. In mixed cropping, the competition for light arising from the different heights of the companion plants is constantly present during the devopment process. But the competitive hierarchy is not a permanent state, as exemplified by the varying height values. With the gradual elimination of the role of nitrogen supply, wheat took a leader position and outgrow pea in height. In plant association, winter pea had an unique pattern and its height exceeded the values of pure sowing. The different ripening time of the companion plants favored the development of wheat, the nitrogen fixed by pea realized the balance between the demand and the supply of the wheat. In addition, the earlier sowing time caused an earlier pea flowering, which was highlighted by the heat sum calculation.

Many research work consider the increase in yield to be one of the basic advantages of plant association. At the same time, these experiments, mostly nitrogen fertilizer is used both in the mixture and in the control parcel. The increased yield effect of nitrogen fertilizer occurs mainly in wheat, while the pea yield is significantly reduced. In this case, the total yield is almost the same as the value of pure stands, but the proportion of the companion plants shifts in the direction of wheat. A similar result can be observed if the mineral nitrogen supply of the soil is already at a high level, or the competitive balance between the companion plants is change due to the overcompression. In my experiment, the high plant density increased the competition between the companion plants, which strengthened the role of the dominant species. The greater proportion of wheat led to the reduction of pea, thus not only the benefits provided by a leguminous plant is realized in less extent, but the efficiency of the whole mixed cropping was also damaged. In terms of wheat the lack of nitrogen supply is not noticeable, however as a result of the constant competition, the wheat plant has less energy on crop production. In my research worh there was no nitrogen fertilizer applied, therefore the results showed the performance of mixed cropping alone. In the first two years, the values of the mixtures exceeded pure stands only in some cases, and in the third year there was a higher yield in monoculture. In the case of the most wheat varieties, there is a negative correlation between yield and quality. This reverse ratio was observed mainly in the third year, where with a few exceptions, all quality indicators had high values. In contrast, in the first two years a higher quality value appeared randomly.

The critical cultivation elements of winter pea are less empasized in plant association, thus the security of yield can also reach a higher level. A low pea seeding rate in the mixture also results in a smaller proportion of the harvested crop, which definitely reduces the level of nitrogen fixation, and the plant becomes prone to yield fluctuations. This was realized in my experiment, where the unequal proportion of the companion plants in the mixture made pea sensitive to environmental factors and caused a drastic yield reduction. A decreasing trend was observed between the yield of crop years, which could be both due to the climate sensitivity of pea and the dominance resulted in the excessive proportion of wheat. Thanks to the development advantages of wheat, the balance between the companion plants was decided in favor of wheat, thereby this was severely limited the production of pea. Today, protein-producing areas in Hungary show a decreasing trend, currently the increase of protein base could be realized by the decrease of the cultivation area of another culture. Therefore any cultivation methods, that promote the national protein production may be valuable in the future. In mixed cropping, the protein content of winter pea exceeded the level of pure stands in all associations. However, this high protein value was accompanied by a very small quantity, which in this form would not be able to fulfill the demand of fodder mixtures, or even partially replace the role of soybean as the most important protein plant. By the improvement of mixed cropping, a certified GMO-free cultivation method, that requires significantly less inputs in terms of plant protection can be evolved, which can provide an alternative way to traditional cultivation in the future.

New Scientific Research

Based on my experiment, I would highlight the following new scientific results:

1. The competition for light between winter wheat and winter pea is decided in favor of wheat during the heading phase (BBCH 50-53), meanwhile the pea is in the pod filling phase (BBCH70-72). The GK Csillag wheat variety is an exception to this statement, where the vary in height is aleady done in booting stage (BBCH 41-45) and during in pea flowering (BBCH 67-69). The further growth of wheat overshadows the pea, thus it remains lower than in pure stands. The rapid change of the generative phases of pea results in early maturity compared to wheat.
2. The first two experimental years showed a yield advantage for all associations, whereas in the third year unbalanced mixtures predominated. The graphical representation of the partial LER values showed the dominance of wheat, however, the 50:100, 75:50 seeding rate of Cellule/Aviron (in 2021 and 2022) and the 50:75, 50:50 seeding rate of the same species in 2022 proved the presence of cooperation and complementarity.
3. From the competitive indices, the agressivity (A) and the competitive ratio (CR) mainly empasized the dominance of wheat, only in the year of 2021, in the case of 75:50 seeding rate of Cellule/Aviron mixture did the ratio turn in favor of pea. Monetary advantage index (MAI) showed a profitability of the associations in the first two experimental years, where the greatest economic value represented by the mixtures of Cellule. In contrast, the third year showed a strong economic deficit. In the case of actual yield loss (AYL) and the intercropping advantage (IA) despite the positive partial results of wheat, mixed cropping as a whole showed yield loss and a disadvantageous association.
4. The yield of winter wheat in mixture in the first year with the GK Csillag wheat variety exceeded the values of pure sowing (except of the 50:100 seeding rate). While in the second year the other two species performed better in the case of GK Szilárd/Aviron 50:50, 50:100, 100:50 and Cellule/Aviron 75:100, 100:50 seeding rates. The high plant density and the high seeding rate of wheat within the mixture helped to maintain the competition between the companion plants, as a result, the proportion of pea in the harvested crop decreased to a lower level.
5. Despite the specific microclimate of the plant association, the small proportion of winter pea in the harvested crop increased its sensitivity of climate change, and a gradual decrease in yield can be observed between of each experimental years. In contrast, its protein content exceeded the level of pure sowing in all mixtures, regardless of the experimental years. The excessive competition experienced during the development process reduced

the efficiency of plant association, therefore in the case of mixed cropping, adjusting the balance of the seeding rate is an envitable task already in the time of composing the mixture.

List of publications which related to the dissertation

Scientific Journal articles in international journal in English

1. Vályi-Nagy Marianna, Kristó István, Tar Melinda, Rácz Attila, Szentpéteri Lajos, Irmes Katalin, Kovács Gergő Péter, Ladányi Márta (2024): Competition Indices and Economic Benefits of Winter Wheat and Winter Peas in Mixed Cropping. *Agronomy*. 14 (4), 786.

2. Vályi-Nagy Marianna, Rácz Attila, Irmes Katalin, Szentpéteri Lajos, Tar Melinda, Kassai Katalin Mária, Kristó István (2023): Evaluation of the Development Process of Winter Wheat (Triticum aestivum L.) and Winter Pea (Pisum sativum L.) in Intercropping by Yield Components. *Agronomy*. 13 (5), 1323.

3. Vályi-Nagy Marianna, Tar Melinda, Irmes Katalin, Rácz Attila, Kristó István (2021): Winter wheat and winter pea intercrop: an alternative technology of crop management preserves high yiled quality and stability at low input. Research Journal of Agricultural Science 53(1), 120-127 p.

4. Kristó István, Vályi-Nagy Marianna, Rácz Attila, Tar Melinda, Irmes Katalin, Szentpéteri Lajos, Ujj Apolka (2022): Effects of Weed Control Treatments on Weed Composition and Yield Components of Winter Wheat (Triticum aestivum L.) and Winter Pea (Pisum sativum L.) Intercrops. *Agronomy*. 12 (10), 2590.

5. Kristó István, Tar Melinda, Jakab Péter, Milánkovics Martina, Imres Katalin, Rácz Attila, Vályi-Nagy Marianna (2021): The influence of winter wheat and winter pea intercrop on grain yield and profitability. *Research Journal of Agricultural Science*. 53 (1), 81-88 p.

Scientific Journal article in hungarian journal in English

6. Vályi Nagy Marianna, Tar Melinda, Rácz Attila, Irmes Katalin, Kristó István (2023): Yield stability of winter wheat in intercrop makes better adaptation to climate conditions. *Columella: Journal of Agricultural And Environmental Sciences*. 10 (2), 25-35p.

Scientific Journal articles in hungarian journal in Hungarian

7. Vályi-Nagy Marianna, Tar Melinda, Irmes Katalin, Rácz Attila, Kristó István (2021): Az őszi borsó hatása az őszi búza termésmennyiségére és fehérje hozamára együtt vetési kísérletben. *Acta Agronomica Óváriensis*. 62 : Különszám 2. 159-173 p.

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