Thesis of Doctoral (Ph.D.) Dissertation

STUDY OF AGROTECHNICAL RESPONSES IN WINTER WHEAT HYBRIDS AND VARIETIES

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1. INTRODUCTION

Wheat is one of the most important and widely grown crops in the world. Winter wheat is the most popular cereal crop and it is grown on approximately 220 million hectares globally. Due to its high ecological adaptability, it can be grown cost-effectively almost anywhere, fully mechanised. It plays a very important role in human nutrition, as the most important component of winter wheat is protein. According to the current CSO data, the sown area of winter wheat in previous years was around one million hectares. Averaged over the recent years, the yield of winter wheat per unit hectare has been steadily increasing. Inspecting the average of the last 10 years, it can be concluded that, with a yield of 4.9 tons / hectare, winter wheat perfectly provides its characteristic yield potential, which the available technical literature sources estimate to be 4.5-5.5 tons / ha.

Establishing sustainable agriculture is a fundamental global challenge, as the use of balanced nitrogen fertilisers remains an unresolved issue. The success of winter wheat production is fundamentally determined by factors that can be influenced by producers. The choice of the appropriate production site and adaptive genotype, as well as the importance of harmonious nutrient replenishment tailored to the needs of the plant are becoming especially important. In recent years, the goal of production has become not only to achieve relatively high yields, but also to obtain the proper quality.

High climatic variability essentially determines agricultural production. Fluctuations in temperature and rainfall have become a determining factor in recent decades. Due to climate change, Hungary's climate is also undergoing constant changes and is increasingly characterised by extreme weather conditions. Days with more than average rainfall or longer periods of drought are becoming increasingly frequent, resulting in periods of stress. In many cases, conventional varieties are unable to reach their specific genetic potential due to such extreme weather conditions. There is a great difference between the yield potential, yield quality and yield safety indicators of various wheat genotypes in public production. There are almost 150 state-recognised wheat varieties (hybrids) in Hungary, but it is difficult for producers to select the given genotype every year.

2. OBJECTIVES

The results of our research were aimed to reveal the extent to which winter wheat of different genotypes is able to adapt to the characteristics of the given crop year and how this ability is reflected in quantitative and qualitative values. I carried out my research work under the supervision and professional guidance of university professor Prof. Dr. Péter Pepó between 2017 and 2021 at the Látókép Experiment Site of the Centre for Agricultural Sciences of the University of Debrecen. The aim of these experiments and obtained results is to demonstrate new technological solutions in a scientific approach that may be suitable for determining the previous crop and nutrient response of wheat of different genotypes, keeping in mind the elements of sustainable crop production. It is our further goal to develop crop production models and proposals that will make it more efficient for farmers to grow winter wheat, obtaining the proper yield and content despite the changing crop years.

The objectives of my research were:

- to examine the response of wheat of different genotypes to nutrient replenishment,
- to determine the interactive effects of crop year, nutrient supply, and previous crop on the yield and quality of winter wheat,
- to analyse the effect of crop year and nutrient replenishment on the plant pathological properties of the examined genotypes,
- to examine the effect of nutrient supply, crop rotation and crop year on certain plant physiological parameters (LAI, SPAD),
- to examine the relationships between plant physiological parameters, as well as yield and quality values of winter wheat genotypes.

3. MATERIAL AND METHODS

Our research was carried out at the Látókép Experiment Site of the University of Debrecen, Institutes of Agricultural Research and Educational, on the Hajdúság loess ridge. The Látókép Experiment Site is located approximately 15 km from Debrecen along route 33. The soil of the experiment area is flat, balanced, and its genetic soil type is calcareous chernozem. The soil physical type is clay, with an Arany plasticity index of 43 and a near-neutral pH (pH 6.3-6.5 (KCl)). The thickness of the humic layer of the soil varies between 80-90 cm, and the thickness of the uniformly humic layer varies between 40-50 cm, with an average humus content of 2 %.

The soil in the experiment is moderately supplied with nitrogen. The concentration of total nitrogen in the upper soil layer up to 50 cm reaches 0.12-0.15 %. The phosphorus supply of the soil is considered to be medium and its potassium supply to be medium to good. Based on its water management properties, the soil of the experiment can be classified into water management group IV based on the data reported by Várallyay, i.e. medium water absorption capacity.

Our research was conducted in the form of a long-term experiment between October 2017 and July 2020. The field experiment was performed in 4 replications and a split plot design where the plots were 10 m^2 in size. The fertiliser doses used in the experiment are shown in Table 1. In all cases, the fertiliser was spread manually. NPK compound fertiliser was used with proportions of 10:15:18.

Table 1. Applied fertilizer dosages of the experimental treatments (Debrecen-Látókép, 2017-2020)

Nutrient supply level	**N**	**P_2O_5**	**K2O**
	Yield Kg ha^{-1}		
Controll	0,0	0,0	0,0
N_{30}+PK	30,0	22,5	26,5
N_{60}+PK	60,0	45,0	53,0
N_{90}+PK	90,0	67,5	79,5
N_{120}+PK	120,0	90,0	106,0
N_{150}+PK	150,0	112,5	132,5

In our research, we examined the effects of three different previous crops: sweet maize, maize, and sunflower. In our analyses, we used winter wheat genotypes bred in four different periods: wheat varieties GK Öthalom, Mv Ispán, Ingenio, and the wheat hybrid Hyland.

Physiological measurements were performed on the crop in the growing seasons of 2018, 2019 and 2020. During the performed physiological measurements, the relative chlorophyll content and leaf area index of the plant were determined. Measurements were performed at untreated control, N_{90}+PK and N_{150}+PK nutrient levels at the phenological stages determined during the growing season.

In the 2018, 2019 and 2020 growing seasons, we examined the plant height and lodging values of wheat of different genotypes measured with different previous crops and nutrient treatments. In addition, crops were examined for Fusarium head blight, leaf rust, HTR, powdery mildew, and yellow rust. The winter wheat experiment populations were harvested using a Sampo small-plot combine harvester in all three examined growing seasons. Quality parameters of winter wheat (moisture content, gluten and protein content, sedimentation value) were measured using a Pfeuffer Granolyser NIR rapid grain analyser. The quality parameters of winter wheat were examined at control, N_{30} + PK, N_{60} + PK, N_{90} + PK, N_{120} + PK and N_{150} + PK nutrient levels.

Analysis of variance and distribution of variance coefficients, as well as the repeated measurement model were performed with R 3.5.2., with the RStudio graphical interface, using the “gplots”, “car” and “agricolae” packages. Correlation analysis was performed using IBM SPSS Statistic 22. The obtained results were plotted with Ms Office 2010.

4. RESULTS

4.1. The effect of agrotechnical factors and crop year on the height and lodging of winter wheat

Comparing the results of the three examined years, it was found that crop height was the highest (80.1-89.0 cm) in the 2020 growing season. However, the adverse effects of the intense growth in the autumn months were also noticeable. As a result of heavy rainfall in June, the extent of lodging increased, ranging from 19.3 % to 33.6 %, averaged over the different genotypes, previous crops, and fertiliser values. The highest height results (84.1-91.8 cm) were observed after sweet maize, while the extent of lodging (27.2-40.3 %) was also the highest for this previous crop, averaged over the different genotypes and fertiliser levels in all three examined growing seasons. The effect of various agrotechnical factors (previous crop, nutrient supply, genotype) on agronomic factors and yield was examined with Pearson's correlation analysis, averaged over the three examined years. The obtained results are shown in Table 2. Of the different agrotechnical elements, the previous crop had a weak negative correlation with crop height [r = -0.275 (**)] and the extent of lodging [r = -0.141 (**)]. Nutrient treatment had a moderately positive [r = 0.659 (**)] effect on crop height and lodging [r = 0.487 (**)]. As the applied nutrient doses were increased, the crop height and, at the same time, the extent of lodging increased significantly. No statistically significant difference was found between genotype and agronomic traits with Pearson's correlation analysis. Examining the average of the three years, a strong positive correlation [r = 0.721 (**)] was found between yield and crop height, while there was a medium positive correlation [r = 0.420 (**)] between lodging and yield.

Table 2. Study of agrotechnical factors affecting winter wheat agronomical parameters using of Pearson correlation analysis

(Debrecen, 2018-2020, crop year average)

Factors	Plant height	Lodging
Forecrop	-0,275(**)	-0,141(**)
Nutrition treatment	0,659(**)	0,487(**)
Genotype	0,045(Ns)	-0,040(Ns)
Yield	0,721(**)	0,420(**)

(**) Correlation of significant at a level of LSD $_{1\%}$ confidence interval, (*) Correlation of significant at a level of LSD $_{5\%}$ confidence interval (Ns) Not significant

4.2. Effect of agrotechnical factors on the phytosanitary status of winter wheat

The effect of different previous crops affected the diseases appearing in the winter wheat population in different ways. The highest levels of powdery mildew and HTR infection were observed after sweet maize, leaf rust infection was observed after sweet maize and sunflower, while the highest degree of fusarium infection was observed if the previous crop was maize. Based on these results, it can be concluded that high levels of infection are a consequence of sweet maize as a previous crop, which creates a favourable microclimate for diseases, as well as the difficult-to-manage stem residues (sunflower, grain maize).

Pearson's correlation analysis was used to evaluate the effect of agrotechnical factors on the plant pathological parameters of winter wheat, averaged over the three examined years (Table 3.). A positive moderate correlation [r = 0.446-0.579 (**)] was found between the examined plant pathological parameters and fertiliser treatments. With increasing nutrient doses, the susceptibility of winter wheat to diseases also increased. A negative, weak relationship was found between genotype and HTR, leaf rust, and fusarium infection, while a negative moderate [r = -0.575 (**)] relationship was found between genotype and powdery mildew. According to the results of the analysis, there was a weak positive correlation [r = 0.105-0.385 (**)] between yield and plant pathological parameters.

Table 3. The study of agrotechnical elements affecting plant pathological trait of winter wheat using of Pearson correlation analysis

(Debrecen, 2018-2020, crop year average)

Factors	Powdery mildew	HTR	Leaf rust	Fusarium
Forecrop	-0,053(Ns)	-0,062(Ns)	0,047(Ns)	0,080(Ns)
Nutrition treatment	0,446(**)	0,579(**)	0,462(**)	0,475(**)
Genotype	-0,575(**)	0,172(**)	-0,377(**)	-0,103(**)
Yield	0,225(**)	0,385(**)	0,189(**)	0,105(**)

(**) Correlation of significant at a level of LSD $_{1\%}$ confidence interval, (*) Correlation of significant at a level of LSD $_{5\%}$ confidence interval (Ns) Not significant

4.3. Analysing the plant physiological parameters of winter wheat in the growing seasons of 2018-2020

Winter wheat leaf area index values and relative chlorophyll content varied for each previous crop, genotype, and fertiliser treatment. In the examined growing seasons, maximum leaf area index values for different genotypes were observed in different phenophases. As the plant developed, LAI values increased, followed by a strong or moderate decrease from the onset of the "waxy" maturity stage. Averaged over the different genotypes and nutrient treatments, the highest LAI values were measured in the growing seasons of 2018 and 2020 after sweet maize as previous crop (3.3-4.7 m^2m^{-2}), while the highest value in 2019 was measured after sunflower as previous crop (1.6-2.5 m^2m^{-2}). In the case of the relative chlorophyll content, the highest values were observed after sweet maize in all three examined years (6.8-57.1). SPAD values increased moderately with plant aging, but reached their maximum values depending on the given previous crop and genotype. Towards the end of the growing season, the relative chlorophyll content of winter wheat began to decrease moderately or strongly after the onset of the "waxy" maturity stage. Both plant physiological indicators improved with increasing nutrient doses. Of the examined agrotechnical elements, nutrient replenishment had the greatest effect on the development of the leaf area index values of winter wheat and on its relative chlorophyll content.

Positive medium correlations were found between the leaf area size [r = 0.475 (**), 0.577 (**), 0.597 (**), 0.647 (**), 0.621 (**)] and the relative chlorophyll content of the plant and nutrient treatment [r = 0.575 (**) 0.585 (**) 0.633 (**)] (Table 4). Between the LAI values measured at early stages, i.e. at the beginning of the stalking stage and the end of the "waxy" maturity stage, positive medium correlations were found between the leaf area index values and yield [r = 0.568 (**); 0.697 (**), respectively]. However, for chlorophyll content, averaged over the three examined years, a positive medium correlation was found between chlorophyll content measured in all phenological phases and yield [r = 0.651 (**), 0.643 (**), 0.571 (**), 0.623 (**), 0.315 (**)].

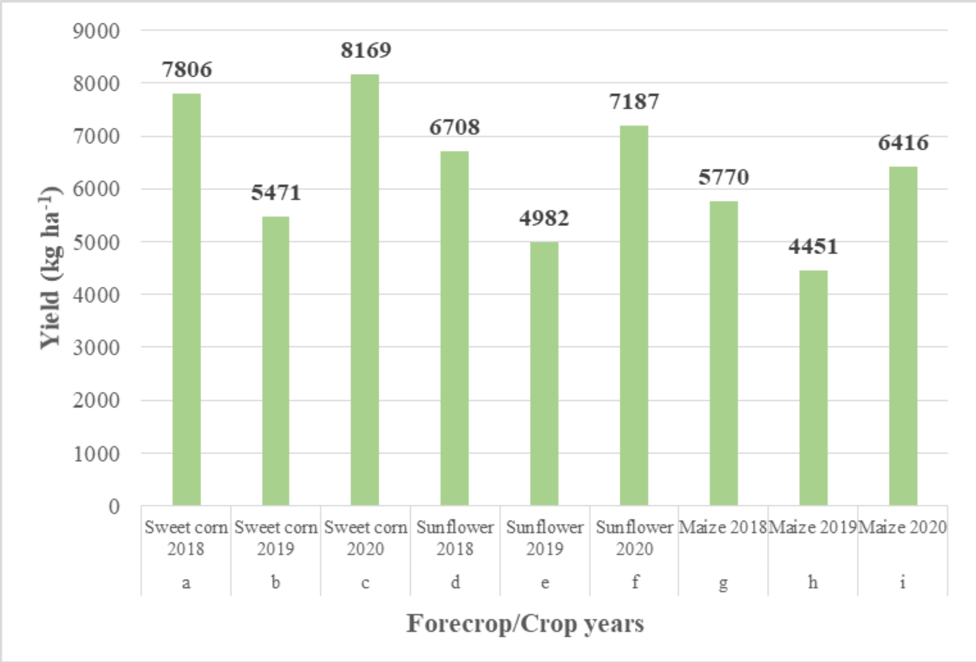
Table 4. The study of agrotechnical elements affecting chlorophyll content of winter wheat using of Pearson correlation analysis (Debrecen, 2018-2020)

Factors	**SPAD**				
	BBCH 32-37	**BBCH 45-59**	**BBCH 65-69**	**BBCH 85-87**	**BBCH 83-89**
Forecrop	-0,206(**)	-0,133(**)	-0,097(*)	-0,038(ns)	-0,021(Ns)
Genotype	0,319(**)	0,246(**)	0,223(**)	0,438(**)	0,240(**)
Nutrition treatment	0,575(**)	0,585(**)	0,633(**)	0,540(**)	0,322(**)
Yield	0,651(**)	0,643(**)	0,571(**)	0,623(**)	0,315(**)

(**) Correlation of significant at a level of LSD $_{1\%}$ confidence interval, (*) Correlation of significant at a level of LSD $_{5\%}$ confidence interval (Ns) Not significant

4.4. The effect of agrotechnical elements on the yield of winter wheat

The obtained yield values depended on the given crop year, previous crop, nutrient level and genotype. Based on the examination of yields per previous crop and crop year, the 2020 crop year was shown to be the most favourable for all three previous crops (6416–8169 kg ha^{-1}) (Figure 1.). This above-average yield is partly due to the favourable weather in November-December. Furthermore, the flowering biological-fertilisation processes were positively affected in terms of grain saturation by the abundant rainfall and cold weather in May, but especially in June. Averaged over the three examined years, a significant difference was found between the yields of all three crop years and all three different previous crops. In addition, in all three years, the yields of winter wheat sown after sweet maize were the highest (5471-8169 kg ha^{-1}).



The quality parameter values sharing the same letter do not differ significantly from one another at level of P<0,05

Figure 1. Winter wheat yield parameters of forecrops in different crop years

(On average of nutrition treatment and genotypes)

(Debrecen, 2018-2020)

Evaluating the three growing seasons altogether, it was found that the natural nutrient conversion rate of the various genotypes was the most favourable after sweet maize as previous crop (4852-6410 kg ha^{-1}), while the lowest yield averages were obtained in the control treatment after maize as previous crop (2581-2678 kg ha^{-1}). The highest yield values were obtained after sweet maize (7423-8777 kg ha^{-1}) that is considered to be a favourable previous crop, while the lowest yield was measured in the wheat sown after maize (7140-7986 kg ha^{-1}). Optimal fertiliser doses varied between the different previous crops. The highest yields were achieved with the lowest fertiliser doses (N_{80-110} + PK) after sweet maize. The maximum yield of wheat after sunflower (7852 kg ha^{-1}) and maize (7575 kg ha^{-1}) could only be realised with higher fertiliser doses ($N_{130-150}$ + PK).

Pearson's correlation analysis confirmed (Table 5.) the moderate [r = 0.577 (**)] positive effect of fertilisation on yield, averaged over the 2018-2020 growing seasons.

Averaged over the examined years, no significant correlation was found between previous crop, genotype and yield.

Table 5. Evaluation the agrotechnical factors for winter wheat yield with Pearson's correlation (Debrecen, 2018-2020)

Factors	**2018-2020 Yield**
Forcrop	-0,168(**)
Nutrition treatment	0,577(**)
Genotype	0,090(**)

(**) Correlation of significant at a level of LSD $_{1\%}$ confidence interval, (*) Correlation of significant at a level of LSD $_{5\%}$ confidence interval (Ns) Not significant

By dividing the variance components, we evaluated the effect of various agrotechnical elements on yield, averaged over the three examined years (Figure 2.). We also examined the percentage of involvement of the given previous crop, genotype, and nutrient replenishment in forming the maximum yield of winter wheat. Based on the obtained results, we found that fertilisation (71%) had the greatest effect on yield, followed by previous crop (19%) and genotype (10%), averaged over the growing seasons of 2018-2020.

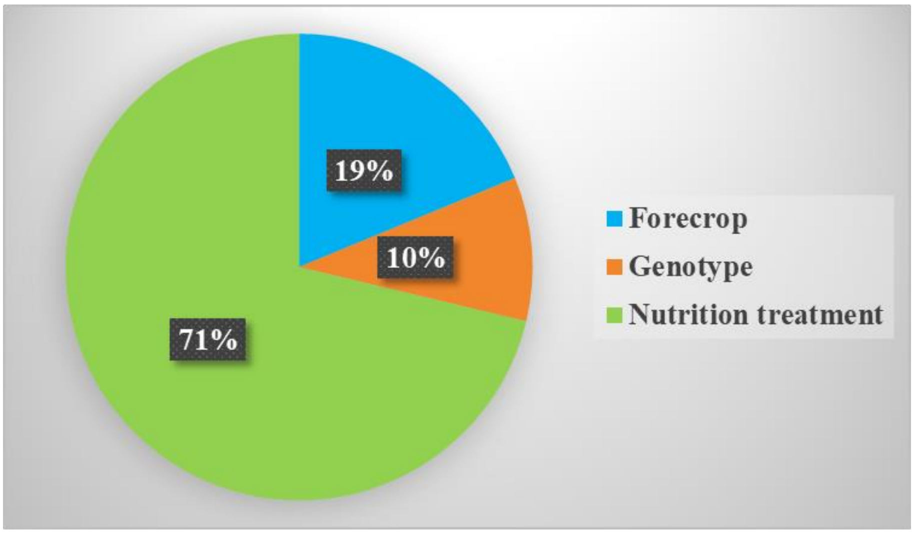


Figure 2. The role of forecrop, genotype, nutrition treatment in the sharing of winter wheat yield by partitioning the components of variance

(2018-2020 crop year average)

(Debrecen, 2018-2020)

4.5. The effect of agrotechnical factors (previous crop, nutrient supply, genotype) on the quality of winter wheat

Based on the results obtained from the three examined growing seasons after different previous crops, it was found that the examined quality parameters of winter wheat (protein, wet gluten, sedimentation value) were the most favourable after sweet maize, averaged over the different fertiliser treatments and genotypes. Comparing the wet gluten content and yield results measured at the control and optimal nutrient supply levels, it was found that, in the case of a favourable previous crop (sweet maize), maximum yields can be achieved by applying a much lower nutrient dose (N_{80-110} + PK) (). In contrast, winter wheat could only achieve higher gluten content at the N_{150} + PK fertiliser dose (Table 6.). In the case of maize and sunflower previous crops, winter wheat could produce its maximum gluten content even at a lower nitrogen dose ($N_{120-150}$ + PK) in almost all cases. In addition, in order to reach the maximum yields, the average fertiliser dose of $N_{130-150}$ + PK was required for the three examined years.

Table 6. Wet gluten content and yield of winter wheat at the level of control and optimal nutrient supply (Debrecen, 2018-2020, crop year average)

2018-2020. crop year average		Wet gluten content (%)	Yield (kg ha^{-1})	Wet gluten content (%)	Yield (kg ha^{-1})	Wet gluten content (%)	Yield (kg ha^{-1})
Genotype	Nutrition treatment	Sweet corn		Maize		Sunflower	
GK Öthalom	Controll	19,8	4852	17,6	2652	19	3426
	NPK Optimum	29,7	7423	28,8	7140	28,2	7281
		N_{150}+PK	N_{110}+PK	N_{140}+PK	N_{150}+PK	N_{130}+PK	N_{150}+PK
Ingenio	Controll	23,4	5177	18	2585	20,3	3760
	NPK Optimum	32,3	7717	28,2	7986	28,7	8254
		N_{150}+PK	N_{100}+PK	N_{140}+PK	N_{150}+PK	N_{120}+PK	N_{150}+PK
Mv Ispán	Controll	20,5	6410	19,8	2581	20,7	3586
	NPK Optimum	28,1	8777	30,8	7340	30,3	7830
		N_{150}+PK	N_{90}+PK	N_{120}+PK	N_{140}+PK	N_{150}+PK	N_{130}+PK
Hyland	Controll	19,9	5864	18,7	2678	17,8	3437
	NPK Optimum	26,7	8548	26,7	7833	25,6	8043
		N_{150}+PK	N_{80}+PK	N_{140}+PK	N_{140}+PK	N_{120}+PK	N_{140}+PK

Pearson's correlation analysis was used to evaluate the relationship between quality parameters and yield. Based on the results of the correlation analysis, a weak positive correlation was found between yields and the examined quality indicators [r = 0.365 (**) 0.304 (**) 0.365 (**)] (Table 7.). There was a weak negative correlation between previous crops and quality characteristics [r = -0.236 (**) -0.225 (**) -0.162 (**)]. A strong positive correlation was found between nutrient supply and protein content [r = 0.669 (**)], wet gluten content [r = 0.651 (**)] and sedimentation [r = 0.688 (**)] based on the three-year average.

Table 7. The study of agrotechnical elements affecting quality parameters of winter wheat using of Pearson correlation analysis

(Debrecen, 2018-2020, crop year average)

Factors	**Protein content**	**Wet gluten content**	**Sedimentation**
Yield	0,365(**)	0,304(**)	0,365(**)
Forecrop	-0,236(**)	-0,225(**)	-0,162(**)
Nutrition treatment	0,669(**)	0,651(**)	0,688(**)
Genotype	-0,049(Ns)	-0,039(Ns)	-0,090(Ns)

(**) Correlation of significant at a level of LSD $_{1\%}$ confidence interval, (*) Correlation of significant at a level of LSD $_{5\%}$ confidence interval (Ns) Not significant

The results of examining the relationship between pathological parameters and quality parameters are shown in Table 8. Based on the obtained results, a weak positive relationship was found between plant height and lodging parameters and winter wheat quality. We found a weak positive correlation between the quality characteristics of winter wheat and powdery mildew, leaf rust and Fusarium head blight, while there was a positive moderate correlation with heminthosporium infection [r = 0.507 (**) 0.509 (**) 0.506 (**)] based on three-year data.

Table 8. Study of quality parameters and pathological parameters of winter wheat using of Pearson correlation analysis

(Debrecen, 2018-2020, crop year average)

Factors	**Protein content**	**Wet gluten content**	**Sedimentation**
Plant height	0,426(**)	0,384(**)	0,422(**)
Lodging	0,305(**)	0,231(**)	0,337(**)
Powdery mildew	0,321(**)	0,289(**)	0,374(**)
HTR	0,507(**)	0,509(**)	0,506(**)
Leaf rust	0,462(**)	0,470(**)	0,451(**)
Fusarium	0,262(**)	0,242(**)	0,260(**)

(**) Correlation of significant at a level of LSD $_{1\%}$ confidence interval, (*) Correlation of significant at a level of LSD $_{5\%}$ confidence interval (Ns) Not significant

The correlation between the quality parameters of winter wheat and the plant physiological characteristics is shown in Table 9. Based on Pearson's correlation, we found a positive medium correlation between leaf area index and protein content and sedimentation values, and a weak positive correlation between wet gluten content and LAI results. There was a medium positive correlation between the chlorophyll content at the time of stalking (BBCH 32-37), at the time of earing (BBCH 45-59) and at the time of flowering (BBCH 65-69) and the examined quality parameters based on the data of the three examined years. A weak relationship was shown between SPAD values measured in the initial (BBCH 85-87) and late (BBCH 83-89) stages of the "waxy" maturity stage and quality parameters.

Table 9. Study of plant psychological and quality parameters of winter wheat using of Pearson correlation analysis (Debrecen, 2018.-2020, crop year average)

Factors	LAI			SPAD		
	Protein content	**Wet gluten content**	**Sedimentation**	**Protein content**	**Wet gluten content**	**Sedimentation**
BBCH 32-37	0,437(**)	0,392(**)	0,428(**)	0,486(**)	0,472(**)	0,452(**)
BBCH 45-59	0,445(**)	0,363(**)	0,445(**)	0,479(**)	0,485(**)	0,471(**)
BBCH 65-69	0,479(**)	0,414(**)	0,472(**)	0,591(**)	0,586(**)	0,528(**)
BBCH 85-87	0,472(**)	0,389(**)	0,446(**)	0,378(**)	0,345(**)	0,337(**)
BBCH 83-89	0,442(**)	0,398(**)	0,402(**)	0,218(**)	0,229(**)	0,203(**)

(**) Correlation of significant at a level of LSD $_{1\%}$ confidence interval, (*) Correlation of significant at a level of LSD $_{5\%}$ confidence interval (Ns) Not significant

Based on the obtained results, it was concluded that, averaged over the growing seasons of 2018-2020, the protein content formation was most influenced by genotype (50%), while wet gluten content (77%) and the sedimentation value (84%) was most affected by nutrient replenishment (Fig. 3).

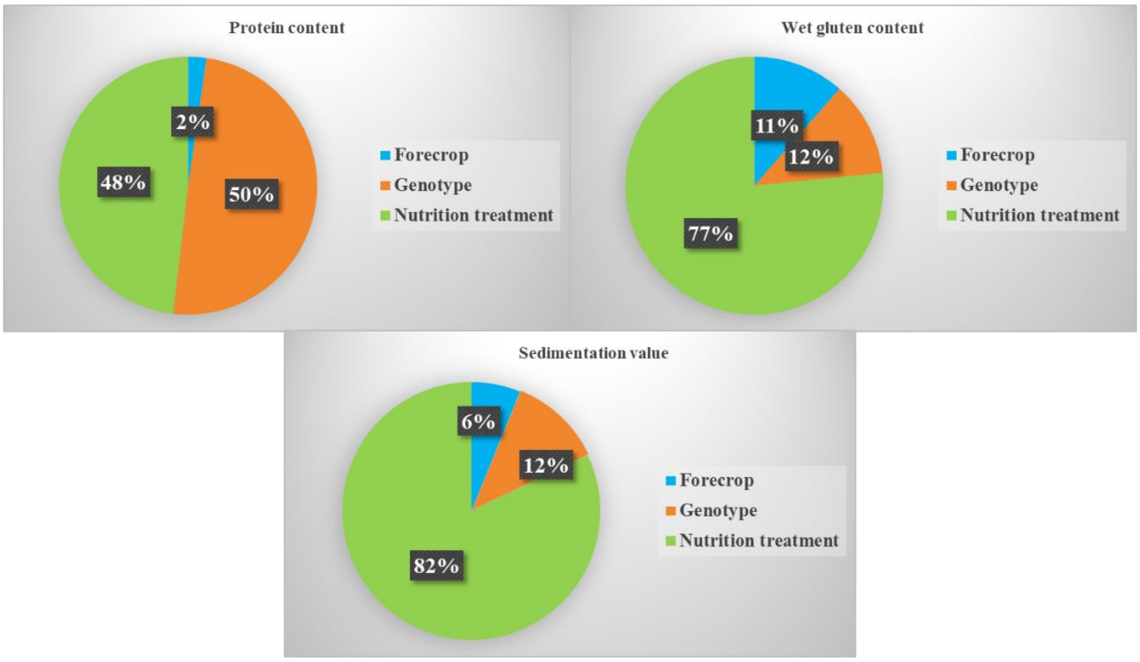


Figure 3. The role of forecrop, genotype, nutrition treatment in the development of winter wheat quality by partitioning the components of variance

(2018-2020, crop year average)

(Debrecen, 2018-2020)

5. NEW SCIENTIFIC FINDINGS

1. The highest degree of infection over the examined years was caused by helminthosporium leaf spot (15.0-20.9%), all other diseases (powdery mildew, leaf rust, fusarium) occurred only to a small extent in the examined growing years. The strongest correlation was observed in the case of diseases (helminthosporium leaf spot [r = 0.579 (**)], fusarium head blight [r = 0.475 (**)], leaf rust [r = 0.462 (**)], powdery mildew [r = 0.446 (**)]) and nutrient supply.
2. A closer correlation was found between leaf area index and yield [r = 0.568 (**) 0.711 (**) 0.749 (**) 0.760 (**) 0.697 (**)] than between the relative chlorophyll content and yield [r = 0.651 (**) 0.643 (**) 0.571 (**) 0.623 (**) 0.315 (**)]. Primarily, the results of the leaf area index (LAI) measured in the relatively early phases, such as in earing [r = 0.711 (**)] and flowering [r = 0.749 (**)], can be used more effectively in yield forecasting than SPAD values.
3. The given crop year determined the maximum yield of wheat. Despite the effects of the contradictory weather of the 2018 growing season (mild and rainy autumn-winter months, winter cold in February-March, warm and dry April-May-June), in this crop year, the examined wheat genotypes gave a better-than-average yield [Mv Ispán: (7291 kg ha^{-1})]. Due to the extremely dry drought autumn and spring period of the 2019 crop year, as well as the cold and rainy May, the yields of the examined genotypes were at or below average [Mv Ispán variety (5898 kg ha^{-1})]. The rainy autumn and early winter period of the 2020 crop year, as well as the abundant rainfall in May, were favourable for the development of winter wheat. As a result, in this year, better-than-average yields were obtained [Hyland winter wheat hybrid (7753 kg ha^{-1})]. A strong positive correlation was found between yield and plant height [r = 0.721 (**)].
4. Genotypes adapted differently to favourable and unfavourable previous crops. According to the order of preference of previous crops, the most favourable previous crop for winter wheat was sweet maize. After a favourable previous crop, the Hyland winter wheat hybrid (9547-10012 kg ha^{-1}) showed the best yield maximum values in the 2018 and 2020 growing seasons, while the Mv

Ispán winter wheat variety (7408 kg ha^{-1}) showed the best yield maximum values in 2019. After maize, which is considered to be an unfavourable previous crop, the Hyland wheat hybrid (8760-9332 kg ha^{-1}) showed the highest yield in the 2018 and 2020 growing seasons, while the highest value of 2019 was shown by the Mv Ispán variety (6448 kg ha^{-1}). Averaged over the three examined years, after sweet corn as previous crop, the yield of wheat exceeded that of sunflower (as a previous crop) by 0.8 t / ha, and that of maize by 1.6 t / ha.

5. Assessing the three growing seasons together, it was found that the examined wheat genotypes differ significantly in their natural nutrient conversion ability. The natural nutrient conversion ability of the various genotypes was shown to be the best after sweet maize as a previous crop (4852–6410 kg ha^{-1}), while the lowest yield averages were obtained in the control treatment after maize (2581–2678 kg ha^{-1}). The optimal N + PK nutrient dose was different for each genotype and previous crop. Depending on the given previous crop, GK Öthalom ($N_{110-150}$ + PK) and Ingenio ($N_{100-150}$ + PK) cultivars reached their highest yields at higher fertiliser doses, while Mv Ispán (N_{90-140} + PK) and the Hyland winter wheat hybrid (N_{80-140} + PK) reached their highest yields at lower nutrient levels. As a result, the importance of variety-specific fertilisation in winter wheat production is further emphasised.
6. The N_{opt} + PK doses for each genotype also varied in each crop year. In the 2018 growing season, the fertiliser conversion rate was unfavourable due to the dry weather in spring-summer (N_{60-150} + PK). As a result of the dry autumn and spring weather, the applied fertilisers were significantly less efficient in 2019 (N_{90-150} + PK). However, due to the rainy weather in May-June of the 2020 growing season, optimum fertiliser effects were observed after sweet maize already at a relatively low level (N_{60} + PK), and at the N_{150} + PK nutrient level in the case of unfavourable previous crops. The examined winter wheat genotypes had different quantitative and qualitative optimum levels after each previous crop. After sweet maize, maximum yields could be achieved by applying a significantly lower dose of nutrients (N_{80-110} + PK), while it is necessary to apply an increased amount of fertilisers in order to achieve the maximum quality values (N_{150} + PK). In contrast, after unfavourable previous

crops, the qualitative maximum dose was lower ($N_{120-150}$ + PK) than the quantitative optimal dose ($N_{130-150}$ + PK).

7. Based on the distribution of the variance components, the examined agrotechnical factors had different effects on the yield quality, averaged over the three growing seasons. Protein content was most affected by genotype (50 %), while wet gluten content (77 %), and sedimentation value (82 %) were most influenced by nutrient replenishment. A close positive correlation was found between nutrient supply and protein content [r = 0.669 (**)], wet gluten content [r = 0.651 (**)] and sedimentation [r = 0.688 (**)], averaged over the three examined years. Nutrient replenishment (71 %) had the greatest influence on yield, while previous had a 19 % influence on yield and genotype only had a 10 % influence. These results also show that harmonious nutrient supply tailored to the needs of the plant plays a prominent role in successful winter wheat production.

6. RESULTS THAT CAN BE USED IN PRACTICE

1. The proper choice of previous crop, regardless of crop year and genotype, is especially important for successful winter wheat production. Averaged over the different nutrient levels and genotypes, yields varied between 5471-8169 kg ha^{-1} after sweet maize, 4982-7187 kg ha^{-1} after sunflower, and 4451-6416 kg ha^{-1} after maize.
2. The effect of unfavourable previous crops can be reduced by fertilisation, but it cannot be completely eliminated. Examined as an average of the three years, the maximum yield values were between 6852-8610 kg ha^{-1} (N^{90} + PK) after sweet maize, between 7281-8216 kg ha^{-1} (N_{143} + PK) after sunflower, and between 7140-7883 kg ha^{-1} (N_{150} + PK) after maize.
3. Winter wheat genotypes show genetic advancement. It is advised to look for the newest genotypes in practice. These new genotypes have higher yield potential, better stem rigidity, better disease resistance, and adaptability in both favourable and unfavourable crop years. Averaged over the thee examined years and the various previous crops, the yield of the old variety (GK Öthalom) (7091 kg ha^{-1}) is exceeded by the yields of the newly bred varieties, such as Mv Ispán (8232 kg ha^{-1}), Ingenio (7513 kg ha^{-1}).) and the Hyland wheat hybrid (8039 kg ha^{-1}).
4. Hybrid wheat has better disease resistance compared to varieties. Averaged over the three examined years, the Hyland hybrid was the most tolerant to powdery mildew (1.3-1.9 %), HTR (5.1-15.0 %), and leaf rust infection (0.4-1.6 %).
5. Variety-specific fertilisation is required in winter wheat production. In each case, the fertiliser dose depends on the given genotype. Depending on the previous crop, averaged over the three years in this study, Mv Ispán (N_{90-140} + PK) and the winter wheat hybrid Hyland (N_{80-140} + PK) reached their highest yields even at lower fertiliser levels, while the winter wheat cultivars GK Öthalom ($N_{110-150}$ + PK), and Ingenio ($N_{100-150}$ + PK) reached their maximum yield only with a higher fertiliser dose.
6. Selecting the proper variety is important in terms of quantity, but even more so in terms of quality. The quality characteristics of the examined hybrids did not improve in parallel with their productivity. Based on the results of the three years, the protein content (11.0-12.1 %), wet gluten content (21.1-24.9 %) and

sedimentation values (28.9-32.7 ml) of the Hyland hybrid were weaker than the results of the other varieties in each crop year.

7. Optimal fertiliser doses differ in terms of quantity and quality. In the case of a favourable previous crop, less fertiliser is needed to achieve maximum yield values than to achieve the proper quality. However, after a previous crop that is considered unfavourable, a lower dose of fertilisation is also expedient in order to achieve better content values.
8. Fertilisation is the most important agrotechnical element of winter wheat in terms of quantity and quality. With optimised variety selection and agrotechnics, 8-9 t / ha yield can be reached in different crop years on chernozem soil. Certain plant physiological (LAI) traits can be used in crop forecasting (data measured at the time of earing and flowering).

7. LIST OF PUBLICATIONS RELATED TO THE DISSERTATION

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Registry number: DEENK/187/2021.PL
Subject: PhD Publication List

Candidate: Ágnes Fekete
Doctoral School: Kálmán Kerpely Doctoral School

List of publications related to the dissertation

Hungarian scientific articles in Hungarian journals (1)

1. **Fekete, Á.**, Szabó, É., Pepó, P.: Összefüggés vizsgálatok az őszi búza (Triticum aestivum L.) növényfiziológiai paraméterei és termésmennyisége között. *Növénytermelés. 69* (3), 27-51, 2020. ISSN: 0546-8191.

Foreign language scientific articles in Hungarian journals (2)

2. **Fekete, Á.**, Pepó, P.: Genetic progress in winter wheat quality and quantity parameters. *Agrártud. Közl. 2* (2), 71-75, 2020. ISSN: 1587-1282. DOI: http://dx.doi.org/10.34101/ACTAAGRAR/2/3835

3. **Fekete, Á.**, Pepó, P.: Comparative study of a winter wheat variety and hybrid sown after different pre-crops on chernozem soil. *Agrártud. Közl. 1*, 63-69, 2019. ISSN: 1587-1282. DOI: http://dx.doi.org/10.34101/actaagrar/1/2373

Foreign language conference proceedings (4)

4. **Fekete, Á.**, Pepó, P.: The interaktive effects of quality and quantity parameters on winter wheat variety and hibrid on chernozem soil. *Rev. Agric. Rural Dev. 8* (1-2), 16-22, 2019. ISSN: 2677-0792. DOI: http://dx.doi.org/10.14232/rard.2019.1-2.16-22

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7. **Fekete, Á.**, Pósa, B., Sallai, A., Tarnawa, Á., Klupács, H.: Evaulating the correlation between yield chracteristics and SPAD values of winter wheat (Triticum aestivum L.) treated different N doses.
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List of other publications

Foreign language scientific articles in Hungarian journals (1)

8. **Fekete, Á.**, Pepó, P.: The role of green manure crops in Hungarian plant production.
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9. Pepó, P., **Fekete, Á.**, Vad, A.: How to improve the agronomic efficiency in precision maize production.
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    Agrárunió. 20 (5), 24-26, 2019. ISSN: 1589-6846.

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