sciendo Agriculture (Poľnohospodárstvo), 67, 2021 (4): 191 – 205

Original article

DOI: 10.2478/agri-2021-0017

INFLUENCE OF FERTILISATION AND CROP ROTATION ON GRAIN YIELD AND QUALITY OF WINTER WHEAT (*TRITICUM AESTIVUM* L.)

MÁRIA BABULICOVÁ, SOŇA GAVURNÍKOVÁ

National Agricultural and Food Centre – Research Institute of Plant Production, Piešťany, Slovak Republic

Babulicová, M. and Gavurníková, S. (2021). Influence of fertilisation and crop rotation on grain yield and quality of winter wheat (*Triticum aestivum* L.). *Agriculture (Poľnohospodárstvo)*, *67*(4), 191 – 205.

At the present time, crop rotations are constantly adapted to economic conditions and one or two main crops are grown in agricultural farms. This has a negative impact on the environment. The optimization of grain yield and quality of winter wheat are dependent not only on the appropriate crop rotation but also on the nitrogen fertilisation. The aim of this study was to examine the effect of crop rotations, fertilisation and preceding crop on grain yield and quality of winter wheat during the years 2015/2016 – 2017/2018. The grain yield of winter wheat after preceding crop pea in crop rotation with 40% proportion of cereals was statistically higher (5.91 t/ha) than in crop rotation with 80% share of cereals (5.55 t/ha). In the treatment with mineral fertilisation and organic manure Veget® incorporation, the grain yield was statistically higher (6.00 t/ha) than in the treatment with mineral fertilisation (5.50 t/ha). According the standard STN 46 1100-2:2018 based on the wet gluten content, the winter wheat grain was classified into the class E by mineral fertilisation + organic manure Veget® in all monitored years. In 2017 the winter wheat grain was categorized into the class P based on wet gluten content in crop rotations with 80% proportion of cereals in the treatment with fertilisers only after preceding crop winter barley.

Key words: crop rotation, fertilisation, preceding crop, winter wheat, grain yield, grain quality

Crop rotations are constantly adapted to economic and political intentions. Agricultural farms are aimed at growing one or two main crops. Companies specialize in a high proportion of cereals and the area of root crops is declining. With an increased proportion of cereals or by an increased proportion of a cereal species, a certain reduction in yield is expected. The damage by fungus diseases, strong pressure of weed infestation the deterioration of soil structure, and negative impact on soil, water, and air regime are reasons of grain yield depression in free crop rotation. Despite this negative trend, crop rotation, adaptive fertilised systems, plant protection, conservation of soil tillage, adaptable varieties remain the main factors in achieving more environmentally friendly technologies (Bokmukhametov *et al.* 2020). Prushchik and Khlupina (2021) consider crop rotation to be one of the most efficient and cost-effective means of increasing the profitability of a cropping system. The generally accepted definition of crop rotation involves scientifically reasonable crop rotation in space and time. The different biology of changing crops and growing technology will improve the phytosanitary state and consequently, to increase productivity. Wheat grain is intended mainly for human nutrition. Therefore, not only high yield is important, but also the favourable quality parameters of the grain. Selecting an appropriate position in the crop rotation and suitable agronomical management contribute to achieving this

Mária Babulicová (*Corresponding author), National Agricultural and Food Centre – Research Institute of Plant Production, Piešťany, Slovak Republic. E-mail: maria.babulicoval@nppc.sk

© 2021 Authors. This is an open access article licensed under the Creative Commons Attribution-NonComercial-NoDerivs License (http://creativecommons.org/licenses/by-nc-nd/4.0/).

purpose (Gaweda & Haliniarz 2021). The optimization of the yield and quality of winter wheat grain depends not only on a suitable crop rotation but also on nitrogen fertilisation, which affects the biomass, accumulation, and distribution of nitrogen into the particular parts of the plants (Zhou *et al.* 2013). Excessive or improper nitrogen application rates negatively affect crop production and are a threat to the environment. More than half of applied N and P are lost in the environment (Cordell *et al.* 2009; Lassaletta *et al.* 2014; Picoli *et al*. 2021). For these reasons, the N application should meet the requirements of the crop, but at the same time be in line with the principles of environmental sustainability. Hlisnikovský *et al.* (2020) point to a reduction in doses of applied mineral phosphorus and potassium due to high purchase prices. According to Duncan *et al.* (2018), the co-application of P, K, and sulphur fertilisers increases the N efficiency and contributes to the enhancement of the grain yield and the protein content. Nitrogen fertilisation increases the global quality of the proteins in the flour and results in an increase in gliadins and glutenins. No differences in grain yields were found when wheat fertilisation with NH_4^+N or NO_3^-N was used. The nitrogen form NO_3^-N is suitable for use in the growth phase BBCH 37 (Fuertes-Mendizabal *et al.* 2013). The genotype × nitrogen interaction significantly influenced the grain yield, protein content, the concentration of nitrogen in the straw, and the efficiency of nitrogen utilisation (Cormier *et al.* 2013). The composition of the protein determines the nutritional value and baking properties of the wheat grain. Changes in protein composition are mainly influenced by genotype, environment, and the interaction between genotype, environment, and fertilisation (Stepień & Wojtkowiak 2019). Qualitative parameters of protein content and sedimentation index were influenced by genotype, whether samples from soft or durum wheat were analysed (Surma *et al.* 2012). To test the sustainability of cropping systems are often not sufficient the short-term cropping experiments. Some cropping practices need a longer time horizon to balance and demonstrate their potentialities. Long-term experiments are therefore suitable for recognizing the sustainability of different cropping systems (Picoli *et al.* 2021). Equally, long-term experiments serve as a monitoring system in the solving of problems related to crop yield decreasing.

The aim of our work was to find out how the different proportion of cereals in crop rotations, preceding crop, fertilisation, and weather conditions of the growing year affect the grain yield and grain quality of winter wheat.

MATERIAL AND METHODS

Field location

The research was realized in the years 2015/2016 – 2017/2018 on the long-term field trial. The field experiment was established in 1974 in Experimental Workstation Borovce which belongs to the Research Institute of Plant Production in Piešťany. The field experiment is situated on Luvic Chernozem (Loamic), pH 5.5 – 7.2, the humus content 1.8 – 2.0%. The area has a continental pattern of climate with a long-term average sum of the annual rainfall of 593 mm and 358 mm rainfall during the vegetation period. The long-term average of annual temperature is 9.2°C, in the vegetation period is 15.5°C (Table 1).

Experimental design and treatments

The experimental design consisted of split plots in a randomized complete block design, with four replications. The experimental field consisted of treatments of 6 m × 8 m plot size. Conventional ploughing to a depth of 22 – 25 cm, sowing, fertilisation, and plant treatments were performed according to the recommendations in the given area (the term of sowing: at least 10th of October; sowing rate: 450 seeds/1 m^2). The pesticides were used according to the actual occurrence of diseases, pests, and weeds. In the field experiment, there were crop rotations with 40, 60, and 80% proportion of cereals. In crop rotations with 80% proportion of cereals, the preceding crop of winter wheat was pea or winter barley. Crops in different crop rotations are presented in Table 2. In crop rotations, two different fertilisation of winter wheat were used: H_1 – mineral fertilisation + organic manure Veget®; H_2 – only fertiliser amendment. The fertilisation by phosphorus and potassium was carried out by balance methodology (Bizík *et al.* 1998). The doses of phosphorus and potassium were calculated on the winter wheat grain yield of 6 tons per hectare. Nitrogen fertilisation

T a b l e 1

Weather conditions in 2016 – 2018 at the Borovce

Month	n[a] (1951 – 1980)		2016		2017		2018	
	xtd [b] [°C]	∑ p [c] [mm]	xtd [°C]	∑ p [mm]	xtd [°C]	∑ p [mm]	xtd [°C]	∑ p [mm]
I.	−1.8	32	3.38	51.4	−8.55	19.8	0.27	30.0
II.	0.2	33	2.62	69.0	−0.50	16.0	−3.67	20.8
III.	4.2	32	3.19	16.4	5.53	20.1	0.40	32.0
IV.	9.4	43	8.78	37.5	7.51	42.8	13.57	17.5
V.	14.1	54	13.91	84.0	14.81	30.4	17.75	27.2
VI.	17.7	80	18.94	23.0	20.37	23.9	19.58	67.3
VII.	18.9	76	19.94	145.2	20.34	28.6	21.07	22.0
VIII.	18.4	68	17.59	52.0	20.94	38.9	22.16	31.8
IX.	14.5	38	15.63	35.0	12.48	75.9	14.88	126.5
X.	9.6	42	6.63	58.3	8.06	55.0	10.02	18.0
XI.	4.6	51	1.90	44.5	2.30	53.8	4.18	17.6
XII.	0.3	46	−3.24	24.2	−0.99	52.6	−1.48	64.5
xtd [°C]	9.2	–	8.54	–	8.52	–	9.89	–
∑ p [mm]	–	595	–	641	–	458	–	475

[a] n – long-term average (1951 – 1980); [b] xtd [°C] – average daily temperature of air in months I. – XII.; [c] ∑p [mm] – sum of precipitation in months I. – XII.

was calculated by methodology by Ložek (1998) based on nitrogen (NO_3^-N, NH_4^+N) in soil (soil samples were taken from 0.0 – 0.3 m of soil profile). In the treatment, organic manure Veget® in a dose of 5 tons/ha/year was used. The composition of organic manure Veget® was as follows: dry matter content minimum, 85% (includes combustible matter content 75%); total N content, 2.5 – 3.0%; total P_2O_5 content, 0.5 – 2.0%; K_2O content, 1.5%; C:N ratio, 13:1; and pH (in water), 8.5. The organic manure Veget® is made from waste products after the production of antibiotics. It is grey-brown up-to-black homogenous substance with granular up-to cloddy structure. The fundamental crude material is composed of the sludge from threonine, penicillin, and amino acids production + the concentrated sludge from The Cleaning of Waste Water after anaerobic processing. Crushed straw and dry sawdust are added to sludge than the tossing substance. The content of nitrogen, phosphorus and potassium in the soil is recorded in Table 3A and Table 3B. Total N rates applied to winter wheat were split to basic fertilisation – in the autumn before sowing, regenerative fertilising – very soon in spring, and production fertilising in the growth stage BBCH 37. Doses of nutrients in years 2015/2016, 2016/2017, and 2017/2018 are introduced in Table 4A and Table 4B. The variety of winter wheat Bertold was used in crop rotations. The Bertold variety was crossbred at the breeding

T a b l e 2

Crop rotations with 40%, 60% and 80% proportion of cereal

Crop rotations		
40% proportion of cereals	60% proportion of cereals	80% proportion of cereals
1. pea	1. pea	1. winter wheat
2. winter wheat	2. winter wheat	2. spring barley
3. silage maize	3. winter barley	3. pea
4. spring barley	4. silage maize	4. winter wheat
5. grain maize	5. spring barley	5. winter barley

enterprise HORDEUM, Sládkovičovo. It has been registered in Slovakia since 2010. The variety has good to very good wintering resistance, it is tolerant of drier conditions. The variety has a high content of nitrogenous substances as well as a high content of quality gluten. The Bertold variety is classified as elite wheat in baking quality. The results from years 2016–2018 were processed by the statistical method: analysis of variance. By the statistical processing was utilized by the statistical program STATISTICA 6. 1 (StatSoft Inc., Tulsa, USA).

Chemical analysis

In samples of winter wheat following qualitative parameters were determined:

- Wet gluten content and Gluten index according to ICC Standard No. 155 (Glutomatic 2200 a Centrifuge 2015, Perten, Sweden) (ICC Stan-

T a b l e 3A

The content of nitrogen, phosphorus and potassium in the soil on the stand of winter wheat in autumn in years 2015 and 2016

PCCR [%]	PC	F	Year 2015				Year 2016			
			[mg/kg]							
			NO_3^-N	NH_4^+N	P	K	NO_3^-N	NH_4^+N	P	K
40	pea	H_1	7.49	3.63	167.8	355	6.30	2.76	157.2	331
		H_2	3.62	2.82	78.4	236	13.96	3.06	172.6	358
60	pea	H_1	10.47	3.50	159.6	335	32.16	2.61	198.8	396
		H_2	5.90	2.85	151.3	338	17.24	2.18	144.4	349
80	pea	H_1	10.91	2.77	153.5	294	16.33	2.06	132.3	303
		H_2	7.80	2.10	74.4	292	15.20	1.68	80.7	269
80	WB	H_1	2.94	2.35	118.0	263	3.91	1.80	130.2	308
		H_2	4.13	1.92	66.2	227	7.69	2.31	99.0	298

PCCR – proportion of cereals in crop rotation; PC – preceding crop; F – fertilisation; WB – winter barley; H_1 – mineral fertilisation + organic manure Veget® incorporation; H_2 – mineral fertilisation.

T a b l e 3B

The content of nitrogen, phosphorus and potassium in the soil on the stand of winter wheat in autumn in year 2017

PCCR [%]	PC	F	Year 2017 [mg/kg]			
			NO_3^-N	NH_4^+N	P	K
40	pea	H_1	14.70	3.67	139.1	319
		H_2	7.76	2.66	107.1	247
60	pea	H_1	29.62	4.76	181.9	289
		H_2	16.30	3.44	123.6	339
80	pea	H_1	18.43	3.46	134.9	266
		H_2	14.28	2.46	72.6	294
80	WB	H_1	9.35	2.94	128.9	322
		H_2	6.77	2.58	87.9	282

All abbreviations are explained under Table 3A.

T a b l e 4A

Doses of nutrients: nitrogen, phosphorus and potasium in years 2017/2018 calculated by balance methodology (Bizík *et al.* 1998; Ložek 1998)

PCCR [%]	PC	F	Years 2015/2016					Years 2015/2016				
			Autumn			Spring		Autumn			Spring	
			Before sowing			Early in spring	BBCH 37	Before sowing			Early in spring	BBCH 37
			N	P	K	N	N	N	P	K	N	N
			[kg/ha]									
40	pea	H_1	15	0	0	30	20	30	0	0	45	30
		H_2	30	25	100	45	30	0	0	0	0	0
60	pea	H_1	0	0	90	15	30	0	0	0	0	0
		H_2	30	0	0	45	30	0	0	0	0	0
80	pea	H_1	0	0	90	15	30	0	0	0	0	0
		H_2	15	0	100	30	20	0	30	120	0	0
80	WB	H_1	30	0	90	45	30	30	0	0	45	45
		H_2	30	35	100	45	30	15	30	120	30	20

BBCH – growth stage; Another abbreviations are explained under Table 3A.

T a b l e 4B

Doses of nutrients: nitrogen, phosphorus and potasium in years 2017/2018 calculated by balance methodology (Bizík *et al.* 1998; Ložek 1998)

PCCR [%]	PC	F	Years 2017/2018				
			Autumn			Spring	
			Before sowing			Early in spring	BBCH 37
			N	P	K	N	N
			[kg/ha]				
40	pea	H_1	0	0	0	0	20
		H_2	15	0	120	30	20
60	pea	H_1	0	0	70	0	0
		H_2	0	0	0	0	20
80	pea	H_1	0	0	70	0	20
		H_2	0	0	120	15	30
80	WB	H_1	15	25	0	30	20
		H_2	15	35	120	30	20

BBCH – see Table 4A; Another abbreviations are explained under Table 3A.

dard No. 155) [ICC – International Association for Cereal Science and Technology].
- Falling number according to STN EN ISO 3093 (Falling Number 1800, Perten, Sweden) (STN EN ISO 3093).
- Sedimentation index, Zeleny test according to STN EN ISO 5529 (shaker Brabender, Duisburg, Germany) (STN EN ISO 5529) .

The results were evaluated according to STN 461100-2: Cereals for human consumption. Part 2: Grain of wheat for human consumption (2018) (STN 461100-2). In this standard, winter wheat based on qualitative parameters is divided into 4 classes: E – elite, A – standard, B – basic, P – biscuits.

RESULTS AND DISCUSSION

Weather conditions

The precipitation was distributed very irregularly in the individual months (Table 1). In 2016, the precipitation deficit of 57.0 mm was observed in June. In 2017, the precipitation deficit of 11.9 mm was recorded in March, 23.6 mm in May, and 56.1 mm in June. In 2018, the average monthly temperature in April exceeded the long-term average by 4.17°C, in May by 3.65°C, and in June by 1.88°C. The precipitation deficit reached 25.5 mm in April, 26.8 mm in May, and 17.7 mm in June. The grain yield and baking quality depend on the development of the weather during the growing season. Our results correlate with those reported by Burešová & Palík (2009) who were observed the negative impact of unfavourable weather in the period of full maturity. Garrido-Lestache *et al.* (2004) also reported that a close correlation was observed between the precipitation in the period September – May and the grain yield and the protein content in the grain. The optimal values of both parameters were observed at precipitation in the range of 500 – 550 mm. And on the other hand, excessive rainfall during the vegetative stage can leach nitrogen and other nutrients from the soil root zone reducing their availability for uptake into the plant and formation of phytochemicals, such as protein (Moayedi *et al*. 2021). In the year 2016 sum of participation during the vegetative stage (I. – IV. Month), was the highest. Wheat plants had enough moisture and warmth, which positively influenced the growth and development of wheat plants. Increased rainfall greatly influenced the process of grain formation having a positive effect on grain yield, but a negative effect on the quality of grain. In the year 2016, the yield was the highest (6.85 t/ha), but the wet gluten content was the lowest (29.5%). Most studies have reported a negative correlation between yield and grain protein concentration and thus also with wet gluten content (Barneix 2007; Serrago *et al*. 2013; Vazquez *et al.* 2019). The reported negative correlation between yield and grain proteins concentration is mostly due to a high trans-

T a b l e 5

Average values of grain yield, wet gluten, gluten index, falling number and Zeleny sedimentation index in years 2016 – 2018 (analysis of variance)

Years [A]	GY [t/ha]	WGC [%]	GI	FN [s]	ZSI [ml]
2016	6.96[a]	29.3[a]	86[b]	400[b]	51.1[a]
2017	5.12[b]	32.8[b]	90[a]	426[a]	48.2[a]
2018	5.27[b]	35.1[c]	81[c]	404[b]	48.8[a]
Average	5.78	32.4	86	410	49.4
$LSD_{0.05}$	0.185	1.30	2.53	12.46	3.41

GY – grain yield; WGC – wet gluten content; GI – gluten index; FN – falling number; ZSI – Zeleny sedimentation index; $LSD_{0.05}$ – least significant difference in the level of signification $P = 0.05$. The different characters or different group of characters mean that there are statistically significant differences. If there are identical characters in the group of characters with singly located character (e.g. a, ab or b, bc), there are no statistically significant differences.

port of starch to the wheat grains, not complemented with an equally high transport of N to the grains (Zhang *et al*. 2012; Kong *et al.* 2016; Vazquez *et al.* 2019). López-Bellindo *et al.* (2001) stated that the protein content of the grain increased in May up to a sum of 80 mm of precipitation. The protein content in the grain was highest at temperatures 26 – 27°C. The influence of weather conditions (factor years) on grain yield, wet gluten, gluten index, and the falling number was statistically significant. According to our results, the sedimentation index is the qualitative parameter, which was not statistically significantly influenced by weather conditions (Table 5). Our results are in agreement with Vida *et al.* (2022) who reported, that in their experiment with durum wheat, the effect of weather in particular years, the genotype, and their interaction on gluten index was statistically significant. Yong *et al.* (2004) state that major quality parameters such as grain hardness, flour yield, sedimentation value, mixograph parameters, and starch viscosity are influenced more by genotype than by environment. However, Rozbicki *et al.* (2015) reported, that in addition to the grain yield, protein content, wet gluten, falling number, and sedimentation value were more influenced by the environment.

The grain yield of winter wheat

In 2016 – 2018 the grain yield of winter wheat was influenced in statistically significant measure by fertilisation, the proportion of cereals, weather in particular years, and the interactions between fertilisation with the proportion of cereals, fertilisation with the weather in particular years, and the proportion of cereals with the weather in particular years (Table 5 – 8). The results are in agreement with Káš *et al.* (2019), who reported that

T a b l e 6

Average values of grain yield, wet gluten, gluten index, falling number and Zeleny sedimentation index in crop rotation with 40%, 60% and 80% proportion of cereals (analysis of variance)

PCCR [%]	GY [t/ha]	WGC [%]	GI	FN [s]	ZSI [ml]
40	5.91^{a}	33.5^{a}	85^{b}	411^{a}	52.3^{a}
60	5.88^{a}	32.4^{ab}	84^{b}	413^{a}	48.3^{b}
80	5.56^{b}	31.4^{b}	89^{a}	406^{a}	47.6^{b}
Average	5.78	32.4	86	410	49.4
$LSD_{0.05}$	0.185	1.30	2.53	12.46	3.41

PCCR – proportion of cereals in crop rotation. Another abbreviations are explained under Table 5.

T a b l e 7

Average values of grain yield, wet gluten, gluten index, falling number and Zeleny sedimentation index in the treatments H_1 and H_2 (analysis of variance)

Years [A]	GY [t/ha]	WGC [%]	GI	FN [s]	ZSI [ml]
H_1	5.99^{a}	35.6^{a}	82^{b}	423^{a}	50.6^{a}
H_2	5.58^{b}	29.3^{b}	89^{a}	397^{b}	48.2^{a}
Average	5.79	32.5	86	412	49.4
$LSD_{0.05}$	0.151	1.06	2.07	10.18	2.78

H_1 – mineral fertilisation + organic manure Veget® incorporation; H_2 – mineral fertilisation. Another abbreviations are explained under Table 5.

a significant positive effect of used fertilisers was noted from dose 80 kg N/ha, the best yields were generally obtained at 120 kg N/ha and 160 kg N/ha. Rajičić *et al.* (2019) stated that nitrogen had the most significant impact on the yield of wheat. The average highest yield was achieved in the treatment N 120 kg/ha, P 100 kg/ha, K 60 kg/ha (5.528 t/ha). In accord with our results, Dai *et al.* (2019) point out the importance of appropriate doses and suitable form of nitrogen in nitrogen fertilisers. The biomass yields and wheat grain quality parameters increased (except for gliadin) with increasing nitrogen doses. Buczek *et al.* (2020) argue that a reduction in grain yield and an increase in wheat grain quality parameters (with the exception of ω gliadins) are associated with low overall precipitation during the grain formation and ripening.

By the fertilisers placement with organic manure Veget® into the soil (Table 7, 8) the grain yield after pea was statistically significantly higher (5.99 t/ha) than by fertilisers only (5.58 t/ha). Holík *et al.* (2018) also reported that the combination of fertilisers with manure is the best way to achieve a high grain yield of good quality. Gopinath *et al.* (2008) conducted a winter wheat field experiment during the transition to organic production. The effect of three organic amendments [farmyard manure (FYMC), vermicompost, and lantana (*Lantada spp*. L.) compost] were compared with the mineral fertiliser treatment. The grain yield of wheat in all the treatments with the organic amendments was significantly lower than with the mineral treatment in the first and the second year during the transition. Wozniak & Gos (2014) stated that winter wheat grain yield increased at a nitrogen rate of 150 kg/ha compared to a 90 kg/ha dose. Hejcman & Kunzová (2010) assessed the effect of different doses on grain yield. They found out that application of nitrogen doses from 46 to 121 kg per hectare, the yield increased by 7.1 to 72.8 kg per hectare. Rekowski *et al.* (2019) emphasize that adequate doses of nitrogen are important to improve the baking quality of winter wheat. The experiment with both winter wheat cultivars pointed out that though the grain yield and protein content increased in both cultivars by two levels of late N fertiliser, the improved baking quality in the cultivar Discus was achieved at a lower N level. Ma *et al.* (2019) found out that by higher doses of N fertilisers the

T a b l e 8

Grain yield of winter wheat in crop rotation [t/ha]

PCCR [a]	Fertilisation	Preceding crop	Grain yield [t/ha]			
			2016	2017	2018	Average
40% Average	H_1	pea	7.46	5.03	5.59	6.02
	H_2		6.80	5.28	5.35	5.81
			7.13	5.15	5.47	5.91
60% Average	H_1	pea	7.53	5.29	5.38	6.07
	H_2		6.93	4.92	5.22	5.69
			7.23	5.10	5.30	5.88
80% Average	H_1	pea	7.02	5.37	5.26	5.88
	H_2		6.02	4.87	4.86	5.25
			6.52	5.12	5.06	5.56
80% Average	H_1	winter barley	7.03	5.27	4.99	5.76
	H_2		6.00	4.51	4.41	4.97
			6.51	4.89	4.70	5.37
Total average			6.85	5.07	5.13	5.68

All abbreviations are explained under Table 3A.

leaching of soil nitrate into deeper soil layers (>100 cm) increased.

In our experiment, in crop rotations with 80% proportion of cereals statistically, significant lower grain yield was recorded (5.56 t/ha) than in crop rotation with 40% proportion (5.91 t/ha) and in crop rotation with 60% proportion (5.88 t/ha) – Table 6, Table 8. Borgi *et al.* (1995) reported that in wheat – maize rotation the maximum grain yield was achieved at the highest dose of fertilisers, even if no manure was used. In crop rotation in which the alfalfa was included, the maximum yield was achieved with a lower dose of fertilisers. Like *et al.* (2018) evaluated the effect of factors (1) crop rotation (wheat/wheat and oilseed rape/wheat), (2) soil tillage, (3) nitrogen fertiliser rate. The results indicate that winter wheat has been significantly affected by soil tillage, nitrogen fertiliser rate ($p<0.001$), and forecrop ($p<0.05$).

The statistically significantly higher grain yield was achieved in 2016 (6.96 t/ha) than in 2018 (5.27 t/ha) and 2017 (5.12 t/ha) – Table 5, Table 8).

In 2017, as a result of current climate changes and the instability of the weather the decrease of winter wheat grain yield was 1.84 t/ha, and in 2018 1.69 t/ha in comparison with grain yield in 2016. Our results confirmed the possibility of increasing the grain yield at 7.3% (0.41 t/ha) in crop rotations with the different shares of cereals in the treatment with fertilisers and the organic manure Veget® incorporation. The effect of fertilisers and manure Veget® increased the winter wheat grain yield markedly in a crop rotation with a higher share of cereals (above 60%). In crop rotation with an 80% share of cereals increasing of grain yield was 14.3% (0.73 t/ha). Efforts to produce a new organic fertiliser made from waste products of the industrial and agricultural production may direct farmers to cope with crop declines due to climate changes.

Wet gluten content

The content of wet gluten was influenced in statistically significant measure by weather in particular years, fertilisation, the proportion of cereals, and interactions between the weather in particular years and fertilisation; the weather in particular years, and the proportion of cereals (Table 5 – 7). The content of wet gluten was statistically significant higher by

T a b l e 9

The wet gluten content of winter wheat in crop rotation [%]

PCCR [a]	Fertilisation	Preceding crop	Wet gluten content [%]			
			2016	2017	2018	Average
40%	H_1	pea	31.1	42.2	37.0	36.8
Average	H_2		25.9	29.7	34.8	30.1
			28.5	36.0	35.9	33.5
60%	H_1	pea	32.4	37.6	36.0	35.3
Average	H_2		29.0	25.5	33.7	29.4
			30.7	31.5	34.8	32.3
80%	H_1	pea	31.6	36.0	36.3	34.6
Average	H_2		25.7	26.0	33.1	28.2
			28.6	31.0	34.7	31.4
80%	H_1	winter barley	33.4	33.8	36.3	34.5
Average	H_2		26.6	20.0	32.0	26.2
			30.0	26.9	34.1	30.3
Total average			29.5	31.3	34.9	31.9

All abbreviations are explained under Table 3A.

the fertilisation with fertilisers and manure Veget® incorporation after pea (35.6%) than by the fertilisation with fertilisers only (29.3%) (Table 7, 9). Similar results were reported by Tanác *et al.* (2010). They found that increasing doses of industrial fertilisers tend to increase the value of wet gluten and backing values. Rieux *et al.* (2013) came to the conclusion that the protein and wet gluten content of the grain are higher when fertilisers containing nitrogen, phosphorus, and potassium were used in comparison with the fertilisation with manure only. The content of wet gluten is affected by the level of inputs. According to Sip *et al.* (2013), the wet gluten content increased at 5% by conventional soil tillage and high level of inputs. In crop rotation with a 40% proportion of cereals, the content of wet gluten was statistically significantly higher (33.5%) than in crop rotation with 80% proportion of cereals after pea (31.4%) (Table 6). The higher average content of wet gluten was reached after preceding crop pea (31.4%) than after winter barley (30.3%) (Table 9). The results are in agreement with Wanic *et al.* (2019) who reported that the protein content and wet gluten content of wheat following wheat were lower than after pea and winter rape. In 2018 statistically significantly higher content of wet gluten was found (35.1%) than in 2016 (29.3%) and in 2017 (32.8%), whereby in 2017 was a statistically significantly higher content of wet gluten than in 2016 – Table 5, Table 9. According to STN 461100-2 based on wet gluten content, the grain from treatments with fertilisers and manure Veget® incorporation was classified into class E. The minimum value of wet gluten for class E is 28%, for class A is a minimum of 26%, for class B is a minimum of 23% and for class P is the maximum value of wet gluten 23%. In 2016, the winter wheat grain was classed into class B from crop rotations with 40% and 80% proportion of cereals after pea and from the treatment with fertilisers only. The winter wheat grain from crop rotation with 80% proportion of cereals after winter barley and from the treatment with fertilisers only was classed into class A. In 2017 the winter wheat grain from crop rotations with a 60% proportion of cereals by the treatment with fertilisers was classed into class B. In this year the winter wheat grain from crop rotations with 80% proportion of cereals after preceding crop pea was classed into the class A. The winter

T a b l e 10

Gluten index in grains of winter wheat in crop rotations

PCCR[a]	Fertilisation	Preceding crop	Gluten index			
			2016	2017	2018	Average
40%	H_1	pea	87	83	76	82
Average	H_2		90	95	80	88
			88	89	78	85
60%	H_1	pea	79	88	78	81
Average	H_2		84	97	82	88
			81	92	80	84
80%	H_1	pea	86	88	81	85
Average	H_2		93	95	89	92
			90	91	85	89
80%	H_1	winter barley	73	90	84	83
Average	H_2		91	99	88	93
			82	95	86	88
Total average			85	92	82	86

All abbreviations are explained under Table 3A.

wheat grain from crop rotations with 80% proportion of cereals by the treatment with fertilisers only after preceding crop winter barley was classed into the class P. Based on our results to achieve a high content of wet gluten in wheat, we recommend the application of mineral fertiliser together with the organic manure Veget®. This manure can be applied in crop rotations with 40%, 60%, and 80% proportion of cereals with preceding crops – pea and winter barley. However, it is also important to choose the right wheat variety with good baking quality.

Gluten index

The gluten index of winter wheat was influenced in statistically significant measure by fertilisation, the proportion of cereals, weather in particular years, and the interactions between the proportion of cereals with the weather in particular years (Table 5 – Table 7). In a long-term experiment by the fertilisation with fertilisers only after preceding crop pea the gluten index was significantly higher (89) than in the fertilisation with fertilisers and manure Veget® incorporation (83) – Table 7, Table 10. In crop rotation with 80% proportion of cereals after pea significantly higher gluten index (89) was found than in crop rotation with 40% proportion of cereals (85) and in crop rotation with 60% proportion of cereals (84) – Table 6, Table 10. Sekularac *et al.* 2018 stated that the statistically significant influence on the gluten index has genotype. Gluten quality is characterized by the degree of extensibility and elasticity (Ćurić *et al.* 2001). The Gluten Index is a method of analysing wheat protein that provides simultaneous determination of gluten quality and quantity (ICC Standard No 155). The findings of Eljak *et al.* (2018) demonstrated that the growing environments, fertilisations, and their interaction significantly affected the gluten index. According to Vida *et al.* (2014) the genotype was the most important factor affecting the quality of gluten measured as gluten index. Bouacha *et al.* (2014) also reported that the effect of genotype was larger on gluten index in comparison with the effects of interactions of genotypes, environments, and fertilisers.

In the year 2017 statistically significant higher gluten index (90) was recorded than in 2016 (86)

T a b l e 11

Falling number of winter wheat in crop rotations

PCCR [a]	Fertilisation	Preceding crop	Falling number [s]			
			2016	2017	2018	Average
40% Average	H_1	pea	415	449	405	423
	H_2		379	428	391	399
			397	439	398	411
60% Average	H_1	pea	424	441	422	429
	H_2		394	398	397	397
			409	420	409	413
80% Average	H_1	pea	415	433	407	418
	H_2		373	409	402	394
			394	421	404	406
80% Average	H_1	winter barley	428	427	401	419
	H_2		389	390	395	391
			408	408	398	405
Total average			402	422	402	409

All abbreviations are explained under Table 3A.

and in the year 2018 (81), whereby the gluten index in 2016 was statistically significantly higher than in 2018 – Table 5, Table 10. According to STN 461100-2 based on the gluten index, the grain from all treatments was classified into class E. The minimum value of the gluten index for the class E is 65.

Falling number

The falling number was influenced in statistically significant measure by the fertilisation and weather in particular years (Table 5 – Table 7). In the treatment with fertilisers and manure Veget® incorporation the falling number after pea was statistically significantly higher (423 s) than in the treatment with fertilisers only (397 s) – Table 7, Table 11. In 2017 the winter wheat was liable to drought stress. In crop rotations after preceding crop pea, in 2017 the statistically significant higher falling number was found out (426 s) than in 2016 (400 s) and the year 2018 (404 s) – Table 5, Table 11. These results correlate with those reported by Amiri *et al.* (2018) who argued that the stress due drought resulted in a decreasing grain yield and at the same time an increasing of falling numbers. The results of Eljak *et al.* (2018) indicated, that the falling number of wheat flours was significantly affected by the fertilisation and environmental conditions. Migliorini *et al.* (2016) have found that in the falling number were highly significant differences among wheat varieties, which were planted under organic conditions.

According to STN 461100-2 based on the falling number, the grain from all treatments was classified into class E. For classes E, A, and B is the minimum value of falling number 220 s, and therefore our measured values of this qualitative parameter were not problematic. All applications fertilisers, crop rotations with all proportions of cereals, and all preceding crops are suitable for achieving of good falling number when is planted high-quality wheat variety.

Zeleny sedimentation index

The Zeleny sedimentation index was influenced in statistically significant measure by the proportion of cereals in crop rotation (Table 5 – Table 7). In crop rotation with 40% proportion of cereals statistically significantly higher Zeleny sedimentation

T a b l e 12

Zeleny sedimentation index of winter wheat in crop rotations

PCCR [a]	Fertilisation	Preceding crop	Zeleny sedimentation index [ml]			
			2016	2017	2018	Average
40% Average	H_1	pea	52	58	47	52
	H_2		50	50	58	52
			51	54	52	52
60% Average	H_1	pea	54	44	48	48
	H_2		49	47	48	48
			52	45	48	48
80% Average	H_1	pea	54	50	50	51
	H_2		48	42	43	44
			51	46	46	48
80% Average	H_1	winter barley	56	49	51	52
	H_2		50	33	42	42
			53	41	46	47
Total average			52	46	48	49

All abbreviations are explained under Table 3A.

index was found than in crop rotation with 60% proportion of cereals and in crop rotation with 80% proportion of cereals (Table 6, Table 12). Wozniak *et al.* (2018) reported that the content of protein and wet gluten in grain and the value of sedimentation index are more influenced by the growing method than by the progress of weather conditions in the monitored years. On the other hand, Jaskulska *et al.* (2018) declare that the content of protein and wet gluten in grain, the sedimentation index, the volume, and the weight of bread varies depending on conditions in individual growing years. Lin *et al.* (2015) illustrated the improvement of qualitative parameters by long-term and continuous fertilisation, while the effect of optimal doses of fertilisers is greater than the effect of organic manure.

According to STN 461100-2 based on the sedimentation index the grain from all treatments was classified into the class E (minimum value for the class E is 40 ml), but in 2017 winter wheat grain in crop rotation with 80% proportion of cereals and in the treatment with fertilisers only after preceding crop winter barley was classified into the class A (minimum value for the class A is 30 ml).

CONCLUSIONS

In 2016 – 2018, the achieved results showed that the highest yield and quality of winter wheat was achieved in crop rotation with 40% proportion of cereals in the treatment with fertilisers and organic manure Veget®. The grain from the treatment with fertilisers and organic manure Veget® in all monitored years based on wet gluten content was classified into class E. In 2016, the winter wheat grain was classified based on wet gluten content into the class B in crop rotations with 40% and 80% proportion of cereals in the treatment with fertilisers only after preceding crop pea. Likewise, in 2017 the winter wheat grain was classified based on wet gluten content into the class B in crop rotations with 60% in the treatment with fertilisers only after preceding crop pea. During this year, the winter wheat grain in crop rotation with 80% proportion of cereals in the treatment with fertilisers only after preceding crop winter barley was classified into the class P.

According to STN 461100-2 based on the Zeleny sedimentation index the grain from all treatments was classified into the class E, but in 2017 winter wheat grain in crop rotation with 80% proportion of cereals and in the treatment with fertilisers only after preceding crop winter barley was classified into the class A.

To achieve a high yield and good baking quality of wheat we recommend the application of mineral fertiliser and organic manure Veget® in crop rotation with 40% or 60% proportion of cereals and with preceding crop – pea. However, it is also important to choose the right wheat variety with good baking quality.

The reduction of animal production resulted in a lack of farmyard manure and livestock manure. For this reason, some farms process the poultry manure or sheep manure into high-quality organic fertilisers. The utilisation of many by-products of plant or animal production to processing into suitable organic fertilisers is a reliable method of increasing the yield and quality of agricultural products. The use of organic fertilisers produced in this way, together with synthetic fertilisers, not only increases agricultural production, but reduces environmental risks and leads to sustainable farming.

Funding: This work was supported by the Ministry of Agriculture and Rural Development Slovak Republic (resort project of research and development: „Growing systems of field crops friendly to environment“) and by the Operational Programme Integrated Infrastructure within the project: Support for research, development, and innovation of international NPPC projects approved in the H2020 program no. 313011W956, co-financed by the European Regional Development Fund.

Conflicts of interest: The authors declare no conflict of interest.

REFERENCES

Amiri, R., Sasani, S., Jalali-Honarmand, S., Rasae, A., Seifolahpour, B., and Bahraminejad, S. (2018). Genetic diversity of breadwheat genotypes in Iran for some nutritional value and baking quality traits. *Physiology and Molecular Biology of Plants*, *24,* 147 – 157. DOI:10.1007/s12298-017-0481-4.

Barneix, J.A. (2007). Physiology and biochemistry of source-regulated protein accumulation in the wheat grain. *Journal of Plant Physiology, 164,* 581 – 590. DOI:10.1016/j.

jplph.2006.03.009.
Bikmukhametov, Z., Shakirov, R., and Sabirova, R. (2020). Adaptive technologies for intensification of winter wheat grain production in biologized crop rotation. *BIO Web of Conferences, 17,* 00067. DOI:10.1051/bioconf/20201700067.
Bizík, J., Fecenko, J., Kotvas, F., and Ložek, O. (1998). *Metodika hnojenia a výživy rastlín* [*Methodology of plant fertilization and nutrition*]. Nitra: Slovak Agricultural University, 112 p. ISBN 80-967812-1-9.
Borgi, B., Giordani, G., Corbellini, M., Vaccino, P., Guermandi, M., and Toderi, G. (1995). Influence of crop rotation, manure and fertilizers on bread making quality of wheat (*Triticum aestivum L.). European Journal of Agronomy, 4,* 37 – 45. DOI:10.1016/S1161-0301(14)80015-4.
Bouacha, O.D., Nouaigui, S., and Rezgui, S. (2014). Effects of N and K fertilizers on durum wheat quality in different environments. *Journal of Cereal Science*, *59,* 9 – 14.
Buczek, L., Jarecki, W., Janczak-Pieniazek, M., and Borecka-Jamro, D. (2020). Hybrid wheat yield and quality to cultivation intensity and weather condition. *Journal of Elementology, 25*(1), 71 – 83. DOI:10.5601/jelem.2019.24.2.1825.
Burešová, I. and Palík, S. (2009). Počasí jako faktor pekárenské kvality pšeničného zrna [Weather as a factor of winter wheat backing quality]. *Obilnářské listy*, *17,* 11 – 14.
Cordell, D., Drangert, J.O., and White, S. (2009). The story of phosphorus: Global food security and food for thought. *Global Environmental Chang*e, *19,* 292 – 305. DOI: 10.1016/j.gloenvch.2008.10.009.
Cormier, F., Faure, S., Dubreuil, P., Heumez, E., Beauchene, K., Lafarge, S., Praud, S., and Legouis, J. (2013). A multi-environmental study of recent breeding progress on nitrogen use efficiency in wheat (*Triticum aestivum*, L.). *Theoretical and Applied genetics*, *126,* 3035 – 3048.
Ćurić, D., Karlović, D., Tušak, D., Petrović, B., and Đugum, J. (2001). Gluten as a standard of wheat flour quality. *Food Technology and Biotechnol*ogy, *39,* 353 – 361.
Dai, X-j., Yang, Z-p., Lu, M., Li, H., Fan, P., Song, J-m., and Gao, Z-q. (2019). Effects of nitrogen forms and amounts on nitrogen translocation, yield and quality of strong-gluten wheat. *Journal of Plant Nutrition and Fertilizers Science,* 5, 710 – 720.
Duncan, E.G., O'Sullivan, C.A., Roper, M.M., Biggs, J.S., and Peoples, M.B. (2018). Influence of co-application of nitrogen with phosphorus, potassium and Sulphur on the apparent efficiency of nitrogen fertilizer use, grain yield and protein content of wheat: Review. *Field Crop Research, 226,* 56 – 65. DOI:10.1016/j.fcr.2018.07.010.
Eljak, S.A., Hassan, H.A., Gorafi, Y.S.A., Ahmed, I.A.M., and Ali, M.Z.A. (2018). Effect of fertilizers application and growing environment on physicochemical properties and bread making quality of Sudanese wheat cultivar. *Journal of Saudi Society of Agricultural Sciences, 17*(4), 376 – 384. DOI:10.1016/j.jssas.2016.09.002.
Fuertes-Mendizabal, T., Gonzalez-Torralba, J., Arregui, L.M., Gonzales-Moro, M.B., and Estavill, J.M. (2013). Ammonium as sole N source improves grain quality in wheat. *Journal of Science of Food and Agriculture*, *93*(9), 2162 – 2171. DOI:10.1002/jsfa.6022.
Garrido-Lestache, E., López-Bellido, R.J., and López-Bellido, L. (2004). Effect of N rate, timing and splitting and N type on bread-making quality in hard red spring wheat under rainfall Mediterranean conditions. *Field Crop Research*, *85,* 213 – 236. DOI:10.1016%2FS0378-4290(03)00167-9.
Gopinath, K.A., Saha, Supradip, Mina, B.L., Pande, Harit, Kundu, S., and Gupta, H.S. (2008). Influence of organic amendments on growth, yield and quality of wheat and on soil properties during transition to organic production. *Nutrient Cycling in Agroecosyst*ems, *82,* 51 – 60. DOI:10.1007/s10705-008-9168-0.
Gaweda, D. and Haliniarz, M. (2021). Grain yield and quality of winter wheat depending on previous crop and tillage system. *Agriculture*, *11*(2), 133. DOI:10.3390/agriculture11020133.
Hejcman, M. and Kunzová, E. (2010). Sustainability of winter wheat production on sandy –loamy Cambisol in the Czech Republic: Results from a long-term fertilizer and crop rotation experiment. *Field Crop Research*, *115*(2), 191 – 199. DOI:10.1016/J.FCR.2009.11.004.
Hlisnikovský, L., Menšík, L., and Kunzová, E. (2020). The development of winter wheat yield and quality under different fertilizer regimes and soil-climatic conditions in the Czech Republic. *Agronomy, 10(8),* 1160. DOI:10.3390/agronomy10081160.
Holík, L., Hlisnikovský, L., and Kunzová, E. (2018). The effect of mineral fertilizer and farmyard of winter wheat grain yield and grain quality. *Plant, Soil and Environment*, *64*(10), 491 – 497. DOI:10.17221/342/2018-PSE.
ICC Standard No. 155: Determination of Wet Gluten Quantity and Quality (Gluten Index ac. to Perten) of Whole Wheat Meal and Wheat Flour (*Triticum aestivum*) (1994).
Jaskulska, D., Jaskulski, D., Galezewski, L., Knapowski, T., Kozeva, W., and Waclawowicz, R. (2018). Mineral composition and baking value of the winter wheat grain under varied environmental and agronomic conditions. *Food Biofortification*, *2018,* Article ID 5013825. DOI: 10.1155/2018/5013825.
Káš, M., Műhlbachova, G., and Kusá, H. (2019). Winter wheat yields under different soil-climatic conditions in a long-term field trial. *Plant, Soil and Environment*, 65, 27 – 34. DOI:10.17221/606/2018-PSE.
Kong, L., Xie, Y., Hu, L., Feng, B., Li, S. (2016). Remobilization of vegetative nitrogen to developing grain in wheat (*Triticum aestivum* L.). *Field Crop Research, 196,* 134 – 144. DOI:10.1016/j.fcr.2016.06.015.
Lassaletta, L., Billen, G., Grizzetti, B., Anglade, J., and Garnier, J. (2014). 50 year trends in nitrogen use efficiency of world cropping systems: The relationship between yield and nitrogen input to cropland. *Environmental Research Letters, 9*(10), 105011. DOI:10.1088/1748-9326/9/10/105011.
Like, L., Gaile, Z., and Ruža, A. (2018). Effect of nitrogen fertilization on winter wheat yield and yield quality. *Agronomy Research*, *16*(2). DOI:10.15159/AR.18.064.
Lin, Z., Chang, X., Wang, D., Zhao, G., and Zhao, B. (2015). Long-term fertilization effects on processing quality of wheat grain in the North China Plain. *Field Crop Research, 174,* 55 – 60. DOI:10.1016/j.fcr. 2015.01.008.
López-Bellindo, L., López-Bellido, R.J., Castillo, J.E., and López-Bellido, F.J. (2001). Effects of long-term tillage, crop rotation and nitrogen fertilization on bread-making quality of hard red spring wheat. *Field Crop Research*, *72*(3), 197 – 210. DOI:10.1016/S0378-4290(01)00177-0.
Ložek, O. (1998). *Optimalizácia výživy ozimnej pšenice* [*Optimization of nutrition of winter wheat*]. Nitra: Slovak Agricultural University, 57 p. ISBN 80-7137-555-1.
Ma, G., Liu, W., Li, S., Zhang, P., Wang, Ch., Lu, H., Wang, L., Xie, Y., Ma, D., and Kang, G. (2019). Determining the optimal N input to improve grain yield and quality in winter wheat with reduced apparent N loss in the North China lain. *Frontiers in Plant Science,* 10, 181, DOI:10.3389/fpls.2019.00181.
Migliorini, P., Spagnolo, S, Torri, L., Arnoulet, M., Lazzerini, G., and Ceccarelli, S. (2016). Agronomic and quality characteristics of old, modern and mixture wheat varieties and landraces for organic bread chain in diverse environ-

ments of northern Italy. *European Journal of Agronomy*, *79,* 131 – 141. DOI:10.1016/j.eja.2016.05.011.

Moayedi, S., Elias, E.M., and Manthey, F.A. (2021). Effect of weather on grain quality traits of durum wheat grown in the Northern Plains of USA. *American Journal of Plant Sciences*, *12,* 1894 – 1911. DOI:10.4236/ajps.2021.1212131.

Rajičić, V., Milivijević, J., Popović, S, Durić, N., Perišić, V., and Terzić, D. (2019). Winter wheat yield and quality depending on the level of nitrogen, phosphorus and potassium fertilization. *Agriculture and Forestry*, *65*(2), 79 – 88. DOI: 10.17707/Agricult/Forest.65.2.06.

Picoli, I., Sartori, F., Polese, R, Borin, M., and Berti, A. (2021). Can long-term experiments predict real field N and P balance and system sustainability? Results from maize, winter wheat, and soybean trials using mineral and organic fertilisers. *Agronomy*, *11,* 1472. DOI:10.3390/agronomy11081472.

Prushchik, I. and Khlupina S. (2021). Effectiveness of winter wheat cultivation in adaptive crop rotation on chernozem typical. *BIO Web Conferences, 32*(1), 01007. DOI:10.1051/bioconf/20213201007.

Rajičić, V., Milivijević, J., Popović, S, Durić, N., Perišić, V., and Terzić, D. (2019). Winter wheat yield and quality depending on the level of nitrogen, phosphorus and potassium fertilization. *Agriculture and Forestry*, *65*(2), 79 – 88. DOI: 10.17707/Agricult/Forest.65.2.06.

Rekowski, A., Wimmer, M.A., Henkelman, G. and Zörb, Ch. (2019). Is a change of protein composition after application of nitrogen sufficient to improve the baking quality of winter wheat? *Agriculture, 9*(5), 101. DOI:10.3390/agriculture9050101.

Rieux, C.M., Vanasse, A., Chantigny, M.H., Gelinas, P., Angers, D.A., Rochette, P., and Royer, I. (2013). Yield and bread-making potential of spring wheat under mineral and organic fertilization. *Crop Science, 53*(3), 1139 – 1147. DOI:10.2135/cropsci2012.07.0448.

Rozbicki, J., Ceglinska, A., Gozdowski, D., Jakubczak, M., Cacak-Pietrzak, G., Ma˛dry, W., Golba, J., Piechocinski, M., Sobczynski, G.,Studnicki, M., and Drzazga, T. (2015). Influence of the cultivar, environment and management on the grain yield and bread-making quality in winter wheat. *Journal of Cereal Sci*ence, *61,* 126 – 132. DOI:10.1016/j.jcs.2014.11.001.

Sekularac, A., Torbica, A., Zivancev, D., Tomic, J., Knezevic, D. (2018). The influence of wheat genotype and environmental factors on gluten index and the possibility of its use as bread quality predictor. *Genetica – Belgrade*, *50,* 85 – 93. DOI:10 2298/GENSR1801085S.

Serrago, R.A., Alzueta, I., Savin, R., and Slafer, G.A. (2013). Understanding grain yield responses to source-sink ratios during grain filling in wheat and barley under contrasting environments. *Field Crop Research, 150*, 42 – 51.

Sip, V., Vavera, R., Chrpová, J., Kusá, H., and Růžek, P. (2013). Winter wheat yield and quality related to tillage practice, input level and environmental conditions. *Soil Tillage Res*earch, *132,* 77 – 85.

Stępień, A. and Wojtkowiak, K. (2019). Evaluation of the effect of different levels of nitrogen and manganese fertilizer on the yield, macronutrient content and technological properties of winter wheat. *Journal of Elementology, 24*(2), 661 – 675. DOI:10.5601/jelem.2018.23.4.1706.

STN EN ISO 3093: Wheat, rye and their flours, durum wheat and durum wheat semolina. Determination of the falling number according to Hagberg-Perten (ISO 3093: 2009) (2010).

STN EN ISO 5529: Wheat. Determination of the sedimentation index. Zeleny test (ISO 5529:2007) (2008).

STN 461100-2: Cereals for human consumption. Part 2: Grain of wheat for human consumption (2018).

Surma, M., Adamski, T., Banaszak, Z., Kaszmarek, Z., Kuczynska, A., Majche,r M., Lugowska, B., Obuchowski, W., Samanowicz, B. and Krystkowiak, K. (2012). Effect of genotype, environment and their interaction on quality parameters of wheat breeding lines of diverse grain hardness. *Plant Production Science, 15,* 192 – 203.

Tanács, L., Gregová, E., Bodnár, K., Lantos, F., and Monostori, T. (2010). Effect of fertilizers and fungicides applied in various doses and combinations on baking characteristics of wheat. *Cereal Research Communications, 38,* 579 – 588.

Vazquez, D., Berger, A., Prieto-Linde, M.L., Johansson, E. (2019). Can nitrogen fertilization be used to modulate yield, protein content and bread-making quality in Uruguayan wheat? *Journal of Cereal Science*, *85,* 153 – 161. DOI:10.1016/j.jcs.2018.12.001.

Vida, G., Szunics, L., Veisz, O., Bedo, Z., Lang, L., Arendas, T. et al. (2014). Effect of genotypic, meteorological and agronomic factors on the gluten index of winter durum wheat. *Euphytica*, *197,* 61–71.

Vida, G., Cséplő, M., Rakszegi, M., Bányai, J. (2022). Effect of Multi-Year Environmental and Meteorological Factors on the Quality Traits of Winter Durum Wheat. *Plants*, *11,* 113. DOI:10.3390/plants11010113.

Wanic, M., Denert, M., and Treder, K. (2019). Effect of forecrop on the yield and quality of common wheat and spelt wheat grain. *Journal of Elementology, 24,* 369 – 383. DOI: 10.5601/jelem.2018.23.1.1585.

Wozniak, A. and Gos, M. (2014). Yield and quality of spring wheat and soil properties as affected by tillage system. *Plant, Soil and Environment*, *60,* 141 – 145.

Wozniak, A., Rachon, L. and Stepniowska, A. (2018). Spring wheat grain quality in relation to a cropping system. *Journal of Elementology*, *23,* 1295 – 1306. DOI:10.5601/jelem.2018.23.1.1580.

Yong, Z., Zhonghu, H., Ye, G., Aimin, Z., and Ginkel, M. (2004). Effect of environment and genotype on bread-making quality of spring-sown spring wheat cultivars in China. *Euphytica, 139,* 75 – 83.

Zhang, Y., Zhang, Y., Liu, N., Su, D., Xue, Q., Stewart, B.A., Wang, Z. (2012). Effect of source-sink manipulation on accumulation of micronutrients and protein in wheat grains. *Journal of Plant Nutrition and Soil Science, 175,* 622 – 629.

Zhou, O.P., Biswas, D.K., Ma, B.L. (2013). Comparisons among cultivars of wheat, hulless and hulled oats: Dry matter, N and P accumulation and partitioning as affected by N supply. *Journal of Plant Nutrition and Soil Science*, *176,* 929 – 94

Received: December 12, 2021
Accepted: January 24, 2022