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RESPONSE OF SOME SPRING WHEAT CULTIVARS TO DIVERSE MINERAL NPK FERTILIZATION

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Abstract. Mineral fertilization is one of the most important components of proper cultivation technology of spring wheat. It actually determines the quantity and quality of grain yield. In 2011-2013 a strict field experiment was carried out which aimed to determine the response of chosen spring wheat cultivars to two NPK fertilization levels. In the research hypothesis it was assumed that varied rates of NPK fertilization will modify the canopy structure, the state of plant nutrition and the quantity and quality of spring wheat grain yield. Two fertilization levels were used: 80 N; 43.6 P and 83 K kg·ha^{-1} (level I) and 120 N; 65.4 P and 124.5 K kg·ha^{-1} (level II). The tested cultivars were: Hewilla, Monsun, Nawra, Ostka Smolicka, Waluta, Zadra, Żura. The higher rate of mineral fertilization in comparison with the lower one resulted in a significant increase in SPAD and LAI indices values, whereas it did not modify MTA index. The number of ears per 1 m^2 was higher on treatment with the higher fertilization level as compared with the lower. The obtained difference was significant and on average it amounted to 26 no.·m^2. The number of grains per ear and TGW were not modified by the fertilization factor. Spring wheat gave the highest yields in 2012 and the lowest in 2013. After the use of the higher fertilization level, the mean grain yield amounted to 5.83 Mg·ha^{-1} and was significantly higher than on the treatment with the lower fertilization level (4.89 Mg·ha^{-1}). Plants of the cultivar Ostka Smolicka were characterized by a significantly higher LAI index in relations to the cultivar Monsun, whereas MTA index was significantly higher in plants of the cultivar Waluta in comparison with the cultivar Żura. The highest value of SPAD index was recorded in plants of the cultivars Hewilla and Ostka Smolicka, and significantly lower in the cultivar Żura. Moreover, a significant difference was indicated in SPAD between the cultivars Nawra and Ostka Smolicka. Plants of the cultivar Waluta lodged significantly heavier than those of the cultivar Nawra. More plump grains were formed by Nawra as compared with Zadra. Ostka Smolnicka was characterized by the highest yield, and Monsun, Nawra and Waluta by significantly lower yields. Also it was

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proved that Hewilla has a significantly higher grain yield than Nawra. Experimental factors did not have a significant effect on total protein content in grain.

Key words: LAI index, mineral fertilization, MTA index, SPAD index, spring wheat, yield

INTRODUCTION

Mineral fertilization has a considerable impact on the yield-forming effect of wheat and improvement of most qualitative discriminants of grain. It is vital to perform proper and sustained wheat fertilization with essential nutrients, including mostly nitrogen, phosphorus and potassium. Balanced fertilization, taking into consideration nutritional needs of wheat plants, enables obtaining high grain yield with the quality corresponding to the standards adopted on the market [Kocoń 2005].

The effect of nitrogen fertilization on the quantity and quality of spring wheat yield have been widely discussed in the scientific literature [Gąsiorowska and Makarewicz 2004, Kocoń and Sułek 2004, Biskupski *et al*. 2007, Cacak-Pietrzak and Sułek 2007, Sułek and Podolska 2008, Jarecki and Bobrecka-Jamro 2012], whereas fewer publications refer to wheat fertilization with phosphorus and potassium, as well as other macroelements, applied into the soil [Martyniak 2009, Kęsik *et al*. 2010, Kopiński and Tujaka 2010, Martyniak *et al*. 2010, Treder and Wanic 2011]. Gondek and Gondek [2010] notice that properly selected rates of fertilizers, both mineral and organic, besides the effect on the quantity and quality of yield, have an essential influence on the natural environment, including the soil and water purity.

The aim of this study was to determine the response of seven spring wheat cultivars to two NPK fertilization levels. In the research hypothesis it was assumed that varied rates of NPK fertilizers will modify canopy structure (LAI and MTA indices), state of plant nutrition (SPAD index) and the quantity and quality of spring wheat grain yield.

MATERIAL AND METHODS

The strict field experiment was carried out in 2011-2013. It was located at the Faculty Experimental Station of Rzeszów Universtiy in Krasne (50°03′ N; 22°06′ E) near Rzeszów. This was a two-factorial experiment in the split-plot design. The first studied factor was levels of NPK fertilizers, which were applied at rates: 80 N; 43.6 P and 83 K kg·ha^{-1} (level I) and 120 N; 65.4 P and 124.5 K kg·ha^{-1} (level II). The second studied factor was spring wheat cultivars: Hewilla, Monsun, Nawra, Ostka Smolicka, Waluta, Zadra, Żura. Fertilization with phosphorus (granulated triple superphosphate) and potassium (potassium salt) was applied in the autumn under winter ploughing. Nitrogen fertilization on level I was divided into two rates: presowing (50 kg N·ha^{-1}) and at the shooting stage – BBCH 32 (30 kg N·ha^{-1}) and on level II into three rates: presowing (60 kg N·ha^{-1}), at the shooting stage – BBCH 32 (40 kg N·ha^{-1}) and at the earing stage – BBCH 52 (20 kg N·ha^{-1}). Herbicide Chwastox Exstra 300 SL (3.5 dm^3·ha^{-1}), insecticide Sumi – Alpha 050 EC (0.25 dm^3·ha^{-1}), fungicide – Juwel TT 483 SE (1.5 dm^3·ha^{-1}) and growth regulator – Cerone 480 SL (0.75 dm^3·ha^{-1}) were applied to protect wheat plant. Preparations were used according to the producer's instructions.

The field experiment was established in brown soil formed of lessive soil, classified as quality class IIIa, the good wheat complex. Soil reaction was slightly acid and the content of available phosphorus and potassium was moderate.

Sowing of dressed seeds was performed on 4 April in 2011 and 2012 and on 16 April in 2013. The seeding rate was 450 seeds·m^{-2}. Cultivation practices were carried out according to the recommendations for spring wheat cultivation. The weather conditions were given according to the data of the Meteorological Station of the Podkarpacie Centre of Agricultural Counselling in Boguchwała. The area of a plot for harvest was 10 m^2. The scope of the study included the assessment of canopy structure (LAI – Leaf Area Index and MTA – Mean Tip Angle), state of plant nutrition (SPAD index on the scale from 0 to 100), yield structure and the quantity and quality of grain yield (the protein content). Measurements with chlorophyll meter SPAD – 502P were made at the shooting stage (BBCH 59) on 30 flag leaves, whereas the LAI - 2000 gauge by LI-COR (USA) was used at the same developmental stage in the morning. The total protein content was determined on the apparatus SPEKTROMETR FT; NIR MPA made by Bruker. The obtained results were subjected to statistical analysis using the analysis of variance, determining the significance of differences with Tukey's test ($p = 0.05$).

RESULTS AND DISCUSSION

The course of spring wheat growth was modified by the weather conditions. In the years of the study, the total precipitation and its distribution was varied in the first place, and to the lesser extent, the mean temperature (Table 1). The lowest precipitation, from March to August, was recorded in 2012, whereas the highest in 2011. Considerably higher precipitation than the long-term mean occurred in July 2011 and in June 2013. July 2012 in turn was characterized by a high air temperature. In March 2013 high precipitation was recorded (including snowfall) at monthly mean temperatures below zero. In consequences, spring wheat sowing was delayed until the period from 10th to 20th April. Earlier studies [Woźniak and Staniszewski 2007, Gąsiorowska *et al*. 2011, Sułek and Podolska 2012] indicate that the weather conditions have a considerable effect on the course of spring wheat growth and on its yield.

Table 1. Course of the weather conditions in 2011-2013
Tabela 1. Przebieg warunków pogodowych w latach 2011-2013

Month Miesiąc	Precipitation – Opady, mm				Temperature – Temperatura, ºC			
	2011	2012	2013	many years' average wielolecie	2011	2012	2013	many years' average wielolecie
March – Marzec	20.0	28.5	77.2	33.73	2.8	4.19	-1.25	2.57
April – Kwiecień	50.0	26.1	33.9	48.28	10.3	9.73	9.39	8.88
May – Maj	49.2	56.0	87.5	78.04	13.9	14.79	9.84	13.72
June – Czerwiec	88.5	83.6	143.4	85.86	18.1	18.39	18.48	17.22
July – Lipiec	233.7	53.5	19.2	90.52	18.6	21.34	19.33	19.13
August – Sierpień	28.6	56.3	11.0	62.66	19.0	19.04	19.58	18.37

The use of a higher level of NPK fertilization, as compared with the lower rate, significantly affected an increase in the LAI index value (Table 2). The obtained

difference was 1.17 $m^2 \cdot m^{-2}$. The effect of mineral NPK fertilizers on an increase in the LAI index of wheat was also confirmed by Rehman *et al*. [2010]. Olsen and Weiner [2007] report that the LAI index can be modified by cultivation practices, which affects the wheat grain yield. Biskupski *et al*. [2006], however, report that too high values of LAI results in worsening of the light conditions and supply in CO_2. The plant susceptibility to lodging is also increased, as well as the occurrence of diseases and pests.

Table 2. Field measurements of the stand (mean of the years)
Tabela 2. Pomiary polowe łanu (średnia z lat)

Parameter – Parametr	Cultivar – Odmiana (B)	Fertilization level Poziom nawożenia (A)		Mean for B Średnio dla B
		I	II	
Leaf index Indeks liściowy $m^2 \cdot m^{-2}$	Hewilla	2.00	3.31	2.66
	Monsun	1.43	2.68	2.06
	Nawra	1.90	2.92	2.41
	Ostka Smolicka	2.07	3.32	2.70
	Waluta	1.94	2.96	2.45
	Zadra	1.90	3.20	2.55
	Żura	2.02	3.00	2.51
	Mean for A Średnio dla A	1.89	3.06	2.48
	LSD – NIR for – dla:	A 0.75	B 0.63	A × B ns – ni
Mean angle of leaf slope Średni kąt nachylenia liści degrees – stopnie	Hewilla	56	51	53.5
	Monsun	52	59	55.5
	Nawra	51	51	51.0
	Ostka Smolicka	53	56	54.5
	Waluta	53	61	57.0
	Zadra	48	52	50.0
	Żura	46	51	48.5
	Mean for A Średnio dla A	51.3	54.4	52.9
	LSD – NIR for – dla:	A ns – ni	B 7.4	A × B ns – ni
Leef greenness index Wskaźnik zieloności liścia SPAD	Hewilla	53.8	48.2	51.0
	Monsun	45.7	53.4	49.6
	Nawra	41.8	48.1	45.0
	Ostka Smolicka	48.6	54.4	51.5
	Waluta	45.6	50.3	48.0
	Zadra	46.6	45.1	45.9
	Żura	39.8	48.8	44.3
	Mean for A Średnio dla A	46.0	49.8	47.9
	LSD – NIR for – dla:	A 2.9	B 6.3	A × B ns – ni
Lodging degree Stopień wylegania	Hewilla	7.73	8.07	7.90
	Monsun	8.03	8.03	8.03
	Nawra	8.20	8.17	8.19
	Ostka Smolicka	7.73	7.97	7.85
	Waluta	7.07	7.27	7.17
	Zadra	7.93	8.03	7.98
	Żura	7.73	7.27	7.50
	Mean for A Średnio dla A	7.77	7.83	7.80
	LSD – NIR for – dla:	A ns – ni	B 0.96	A × B ns – ni

ns – ni – non-significant differences – różnice nieistotne

Plants of the cultivar Ostka Smolicka were characterized by a significantly higher LAI index as compared with Monsun. In the study by Biskupski *et al*. [2004, 2006, 2007] the LAI index was increased by nitrogen fertilization and modified with the varietal factor. Kołodziejczyk and Szmigiel [2010] confirmed varietal diversity of the LAI index, but only at the milk stage. Woźniak [2008] obtained the highest value of the LAI index at the earing stage of spring wheat and a lower value at the flowering and milk maturity.

NPK fertilization did not have a significant effect on the MTA index, which on average amounted to 52.9 (Table 2). Only plants of the cultivar Waluta were characterized by a significantly higher MTA index in relations to the cultivar Żura. The study by Biskupski *et al*. [2004, 2006] did not show an effect of fertilization with nitrogen on the MTA index, whereas it confirmed the varietal diversity of this index.

Higher NPK fertilization resulted in a significant increase in the value of SPAD index by 3.8 units as compared with the lower fertilizer rate. The lowest value of the SPAD index was recorded in plants of the cultivar Żura (44,3), and significantly higher in Hewilla (51.0) and Ostka Smolicka (51.5). Additionally, there were shown differences in the SPAD index (by 6.5 units) between the cultivars Nawra and Ostka Smolicka (Table 2). Kulig *et al*. [2009] confirmed usefulness of the SPAD test in determination of the pogłównej rate of nitrogen fertilization in spring wheat. This referred to both the grain yield quantity and quality. Also Majchrzak and Skrzypczak [2010] proved the usefulness of SPAD measurements for assessment of spring wheat yield in different cropping systems. They obtained higher SPAD values at the 3-4 node stage than after wheat earing. Kulig *et al*. [2010] showed intervarietal differences in the state of nutrition of spring wheat plants. They confirmed obtained results each year by measurements.

The applied NPK fertilization had a considerably less effect on the degree of lodging of spring wheat plants than the varietal differences (Table 2). It was confirmed statistically that plants of the cultivar Waluta lodged more heavily than the cultivar Nawra. Borkowska *et al*. [1999] notice that too intensive fertilization of wheat with nitrogen may lead to heavy lodging of plants and increased incidence of diseases caused by fungi, and consequently, to a decrease in the grain yield.

The number of ears per $1m^2$ was significantly higher by 26 no.$\cdot m^2$, on the treatment with the higher level of mineral NPK fertilization as compared with the lower level (Table 3). The tested cultivars did not differ significantly in the number of ears per area unit, and the ear density did not exceed 500 no.$\cdot m^2$ only in the cultivars Nawra and Monsun. On average in the conducted experiment, the number of ears per 1 m^2 was 505.6 no.$\cdot m^2$. Sułek and Podolska [2012] showed diversification in the ear density between the cultivars; this, however, was changing in the years.

The number of grains per ear was not modified by the fertilization and varietal factors (Table 3). In the study by Gondek [2012], organic fertilization had a more favourable effect on the seed plumpness as compared with mineral NPK. Sułek and Podolska [2012], in turn, showed a varietal diversity in the number of grains per ear, which was dependent on the years of the study.

However, the varietal diversity of TGW was confirmed. Plants of the cultivar Nawra formed more plump grain than Zadra. Biskupski *et al*. [2006] also proved a high TGW (43.3g) in the cultivar Nawra. However, Borkowska *et al*. [2003] did not find the diversity of TGW between the tested cultivars.

Total protein content was on average 12.6% (Table 3). The experimental factors used did not have a significant effect on the concentration of this component in the grain. Gondek [2012] in turn found an increase in the total protein content in spring wheat grain as affected by fertilization (mostly mineral NPK) as compared with the control treatment.

Table 3. Yield components and protein content in grain, %
Tabela 3. Elementy plonowania i zawartość białka w ziarnie, %

Parameter – Parametr	Cultivar – Odmiana (B)	Fertilization level Poziom nawożenia (A)		Mean for B Średnio dla B
		I	II	
Number of ears Liczba kłosów 1 m^2	Hewilla	500	548	524.0
	Monsun	490	501	495.5
	Nawra	480	490	485.0
	Ostka Smolicka	500	533	516.5
	Waluta	489	530	509.5
	Zadra	496	515	505.5
	Żura	493	513	503.0
	Mean for A Średnio dla A	493	519	505.6
	LSD – NIR for – dla: A 25.2 B ns – ni A × B ns – ni			
Number of grains per ear Liczba ziaren w kłosie	Hewilla	29	30	29.5
	Monsun	27	29	28.0
	Nawra	26	28	27.0
	Ostka Smolicka	29	31	30.0
	Waluta	26	28	27.0
	Zadra	28	31	29.5
	Żura	27	31	29.0
	Mean for A Średnio dla A	27,4	29,7	28.6
	LSD – NIR for – dla: A ns – ni B ns – ni A × B ns – ni			
Thousand grain weight Masa tysiąca ziaren g	Hewilla	37.6	38.7	38.15
	Monsun	36.4	40.2	38.30
	Nawra	38.8	40.7	39.75
	Ostka Smolicka	37.6	38.9	38.25
	Waluta	38.8	39.0	38.90
	Zadra	34.9	36.4	35.65
	Żura	36.2	37.8	37.00
	Mean for A Średnio dla A	37.2	38.8	38.00
	LSD – NIR for – dla: A ns – ni B 3.95 A × B ns – ni			
Protein content Zawartość białka %	Hewilla	12.0	12.4	12.20
	Monsun	12.5	12.9	12.70
	Nawra	12.8	13.1	12.95
	Ostka Smolicka	12.2	12.5	12.35
	Waluta	12.6	12.8	12.70
	Zadra	12.4	12.7	12.55
	Żura	12.8	13.0	12.90
	Mean for A Średnio dla A	12.47	12.77	12.62
	LSD – NIR for – dla: A ns – ni B ns – ni A × B ns – ni			

ns – ni – non-significant differences – różnice nieistotne

Spring wheat gave the highest yields in 2012 (on average 5.74 Mg·ha^{-1}), whereas the lowest in 2013 (on average 5.01 Mg·ha^{-1}). Varied mineral NPK fertilization had a significant effect on the grain yield each year (Table 4). After the application of a higher fertilization level, the mean grain yield amounted to 5.83 Mg·ha^{-1}, and on the treatment with the lower fertilization level, 4.89 Mg·ha^{-1}. Sułek and Podolska [2012] also indicated that the spring wheat grain yield is dependent on the weather conditions and cultivation intensity. Gondek and Gondek [2010] and Gondek [2012], while conducting experiments concerning spring wheat fertilization, confirmed a high yield-forming effect of mineral NPK fertilizers. Rehman *et al*. [2010] show that besides mineral NPK fertilizers, also fertilization with farmyard manure has a favourable effect on wheat yield.

Table 4. Spring wheat yield depending on fertilization level, Mg·ha^{-1}
Tabela 4. Plonowanie pszenicy jarej w zależności od poziomu nawożenia, Mg·ha^{-1}

Year Rok	Cultivar – Odmiana (B)	Fertilization level Poziom nawożenia (A)		Mean for B Średnio dla B
		I	II	
1	2	3	4	5
2011	Hewilla	5.0	6.1	5.55
	Monsun	4.7	5.6	5.15
	Nawra	4.8	5.7	5.25
	Ostka Smolicka	4.9	6.1	5.50
	Waluta	4.6	5.5	5.05
	Zadra	4.8	5.8	5.30
	Żura	4.9	5.8	5.35
	Mean for A Średnio dla A	4.81	5.80	5.31
	LSD – NIR for – dla: A 0.75 B 0.52; A × B ns – ni			
2012	Hewilla	5.6	6.6	6.10
	Monsun	5.3	6.0	5.65
	Nawra	5.0	5.4	5.20
	Ostka Smolicka	5.8	6.6	6.20
	Waluta	5.1	6.0	5.55
	Zadra	5.4	6.1	5.75
	Żura	5.2	6.3	5.75
	Mean for A Średnio dla A	5.34	6.14	5.74
	LSD – NIR for – dla: A 0.65 B 0.85 A × B ns – ni			
2013	Hewilla	4.8	5.8	5.30
	Monsun	4.2	5.2	4.70
	Nawra	4.2	5.3	4.75
	Ostka Smolicka	5.0	6.2	5.60
	Waluta	4.4	5.3	4.85
	Zadra	4.4	5.3	4.85
	Żura	4.5	5.6	5.05
	Mean for A Średnio dla A	4.50	5.53	5.01
	LSD – NIR for – dla: A 0.84 B 0.75 A × B ns – ni			

Table 4 continue – cd. tabeli 4

1	2	3	4	5
Mean in the years Średnio w latach	Hewilla	5.1	6.2	5.65
	Monsun	4.7	5.6	5.15
	Nawra	4.7	5.5	5.10
	Ostka Smolicka	5.2	6.3	5.75
	Waluta	4.7	5.6	5.15
	Zadra	4.9	5.7	5.30
	Żura	4.9	5.9	5.40
	Mean for A Średnio dla A	4.89	5.83	5.36
LSD – NIR for – dla: A 0.73 B 0.53 A × B ns – ni				

ns – ni – non-significant differences – różnice nieistotne

Of the tested cultivars, Ostka Smolnicka gave a higher yield, whereas Monsun, Nawra and Waluta gave significantly lower yields. It was also proved that the cultivar Hewilla give higher grain yields than Nawra. On average in the experiment the grain yield of the tested cultivars of spring wheat amounted to 5.36 $Mg \cdot ha^{-1}$. The studies by many authors [Kołodziejczyk *et al*. 2007, Sułek and Podolska 2012] also showed significant intervarietal differences in spring wheat grain yield.

CONCLUSIONS

1. Higher NPK fertilization level significantly increased the SPAD and LAI indices value, but it did not modify the MTA index. Plants of the cultivar Ostka Smolicka were characterized by the highest LAI and SPAD indices, and the MTA index was the highest in wheat cultivar Waluta.

2. The number of ears per 1 m^2 was significantly dependent on the mineral NPK fertilization level, whereas this factor had no significant effect on the number of grains per ear, TGW and the total protein content in grain. Nevertheless, the lodging level and TGW were significantly determined by cultivar traits.

3. Application of the higher NPK fertilization rate significantly increased the grain yield by 0.94 $Mg \cdot ha^{-1}$ as compared with the lower fertilization level. The cultivar Ostka Smolnicka gave the highest yield, whereas Monsun, Nawra and Waluta had the lowest yields.

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REAKCJA KILKU ODMIAN PSZENICY JAREJ NA ZRÓŻNICOWANE NAWOŻENIE MINERALNE NPK

Streszczenie. Nawożenie mineralne jest jednym z najważniejszych elementów poprawnej agrotechniki pszenicy jarej. Decyduje bowiem o wielkości i jakości plonu ziarna. W latach 2011-2013 przeprowadzono ścisłe doświadczenie polowe, którego celem było określenie reakcji wybranych odmian pszenicy jarej na dwa poziomy nawożenia NPK. W hipotezie badawczej założono, że zmienne dawki nawożenia NPK zmodyfikują architekturę łanu, stan odżywienia roślin oraz wielkość i jakość plonu ziarna pszenicy jarej. Stosowano dwa poziomy nawożenia: 80 N; 43,6 P i 83 K kg·ha^{-1} (poziom I) oraz 120 N; 65,4 P i 124,5 K kg·ha^{-1} (poziom II). Badano odmiany: Hewilla, Monsun, Nawra, Ostka Smolicka, Waluta, Zadra, Żura. Większa dawka nawożenia mineralnego w porównaniu z niższą wpłynęła na istotny wzrost wartości wskaźnika SPAD i LAI, nie modyfikowała natomiast wskaźnika MTA. Liczba kłosów na 1 m^2 była większa na obiekcie z wyższym poziomem nawożenia w porównaniu z niższym. Uzyskana różnica była istotna i wynosiła średnio 26 szt.·m^2. Liczba ziaren w kłosie i MTZ nie zostały zmodyfikowane przez czynnik nawozowy. Najwyższej plonowała pszenica jara w 2012 roku, a najniższej w 2013 roku. Po zastosowaniu wyższego poziomu nawożenia średni plon ziarna wyniósł 5,83 Mg·ha^{-1} i był istotnie wyższy niż na obiekcie z niższym poziomem nawożenia (4,89 Mg·ha^{-1}). Rośliny odmiany Ostka Smolicka charakteryzowały się istotnie wyższym wskaźnikiem LAI w odniesieniu do Monsun, zaś wskaźnik MTA był istotnie wyższy u roślin odmiany Waluta w porównaniu z odmianą Żura. Najwyższą wartość wskaźnika SPAD odnotowano u roślin odmiany Hewilla i Ostka Smolicka, a istotnie niższą u Żura. Wykazano zarazem istotną różnicę wskaźnika SPAD pomiędzy odmianą Nawra a Ostka Smolicka. Rośliny odmiany Waluta wylegały istotnie silniej niż odmiany Nawra. Dorodniejsze nasiona wykształciła odmiana Nawra w porównaniu z odmianą Zadra. Najwyższym plonem charakteryzowała się odmiana

Ostka Smolnickiej, a istotnie niższym Monsun, Nawra i Waluta. Udowodniono również, że odmiana Hewilla plonem ziarna istotnie przewyższa odmianę Nawra. Czynniki doświadczenia nie wywarły istotnego wpływu na zawartość białka ogólnego w ziarnie.

Słowa kluczowe: nawożenie mineralne, plon, pszenica jara, wskaźnik LAI, wskaźnik MTA, wskaźnik SPAD

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