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GRAIN YIELD AND MORPHOLOGICAL CHARACTERISTICS OF SPRING TRITICALE PLANTS AS AFFECTED BY CULTIVAR AS WELL AS MULTI-NUTRIENT FERTILISER TYPE AND RATE

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Abstract. A field experiment was conducted in Borki-Wyrki, Zbuczyn Gmina (commune), from 2017 to 2019. The objective was to assess yield performance and morphological characteristics of two spring triticale cultivars as affected by multi-nutrient fertiliser type and rate, the fertilisers being Polifoska 6 and Polifoska Krzem. Three experimental factors were tested: spring triticale cultivar – Milewo and Dublet, mineral fertiliser type – Polifoska 6 and Polifoska Krzem, and mineral fertiliser rate –0 $kg \cdot ha^{-1}$, 140 $kg \cdot ha^{-1}$, 280 $kg \cdot ha^{-1}$, 420 $kg \cdot ha^{-1}$. Spring triticale plant development and yield performance were significant affected by experimental factors, that is cultivar, fertiliser type and rate, were shown to influence these characteristics. Superior yields were produced by cv. Dublet compared with cv. Milewo. Cultivars fertilised with Polifoska Krzem produced higher grain yields than Polifoska 6. An increase in fertiliser rate was followed by higher grain yields. Spring triticale cultivar as well as multi-nutrient fertiliser type and rate significantly affected ear length. Significantly longer ears were developed by cv. Milewo. Longer ears were developed by cereal plants fertilised with Polifoska 6. Similarly, higher fertiliser rates had a beneficial effect on ear length. Fertiliser rate contributed to a significant increase in plant height compared with unamended control. Cv. Milewo plants were significantly higher than cv. Dublet plants.

Key words: *xTriticosecaleWittm. ex A. Camus*, grain yield, cultivar, multi-nutrient fertiliser, morphological characteristics of plants.

INTRODUCTION

Proper and rational fertilisation beneficially affects plant yield quantity and biological value (Kwiatkowski et al. 2006; García-Molina and Barro 2017; Wojtkowiak et al. 2018). According to Wacławowicz et al. (2017), growers need to apply mineral fertilisers if they want their crop plants to produce optimum yields. Winiarski (2004) claims that fertilisation is the main yield-forming factor. The extent of fertiliser influence on yield increases dependent upon rate and ranges from 50 to 70%. The most frequent form of nutrient application to crop plants is fertilisation with

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solid fertilisers. Polifoska 6, containing 6% nitrogen, 20% phosphorus, 30% potassium and 7% sulphur, is an example of such fertiliser (Wojtkowiak 2014). Economic benefits resulting from an application of multi-nutrient mineral fertilisers clearly indicate that a wider range of such fertilisers should be available (Stępień and Mercik 2001) although growers, interested in such products, already have a wide variety of fertilisers to choose from. Polifoska Krzem is one of such products. It contains 6% nitrogen, 12% phosphorus, 34% potassium, 10% sulphur and 1% silicon. Multi-nutrient fertilisers are popular due to their uncomplicated application, solubility and complex elemental composition. They compete with mono-nutrient products because a single application of such products supplies the soil with several nutrients (Nogalska et al. 2012). Malakouti (2008), Wojtkowiak and Domska (2009) as well as Knapowski et al. (2010) claim that an increase in yields may be obtained due to a combined application of mineral fertilisers and micro-element fertilisers. A regular application of fertilisers increases their effectiveness and profitability as reflected in the plant yields (Jadczyszyn 2004). The objective of the study was to assess yield performance and morphological characteristics of two spring triticale cultivars as affected by mineral fertiliser regime (type and rate).

MATERIALS AND METHODS

In order to achieve the assumed experimental objectives, a field experiment with spring triticale was carried out in 2017–2019. The trial was set up in Borki-Wyrki, Zbuczyn Gmina, Siedlce Poviat. The experimental soil was a podzol type whose granulometric composition was that of medium loam (BN-78/9180-11). According to the WRB FAO classification system, the soil represents Albic Podzols (Ochric), and converted to the international USDA classification, its granulometric composition was that of sandy clay loam. The soil was characterized by a high abundance of phosphorus, an average abundance of potassium and an average abundance of magnesium. The experiment was a split-split-plot arrangement with three replicates. The gross and harvested size of a plot was, respectively, 18 and 15 m^2. Three experimental factors were investigated: factor 1 – spring triticale cultivar: Milewo and Dublet, factor 2 – mineral fertiliser type: Polifoska 6 and Polifoska Krzem, and factor 3 – mineral fertiliser rate: 0 $kg \cdot ha^{-1}$, 140 $kg \cdot ha^{-1}$, 280 $kg \cdot ha^{-1}$, 420 $kg \cdot ha^{-1}$. Spring triticale was preceded by oats in each study year. In the spring, phosphorus-potassium fertilisers were applied as assumed in the methodology. Nitrogen fertilisation was supplemented by a preplant application of the first rate of 40 $kg \cdot ha^{-1}$ and a post-plant application of 40 $kg \cdot ha^{-1}$ of ammonium nitrate (34%), at the stage of first node (BBCH 31). Cultivation practices included an application of herbicide and insecticide. T control dicotyledonous weeds, Chwastox Trio 540 SL (active ingredients: MCPA + dicamba + mecoprop) was used at the rate of 1.5 $l \cdot ha^{-1}$ at the stage of 4–5 leaves (BBCH 14–15) of spring triticale plants. In each plot, 20 plants were selected randomly to determine the following plant morphological characteristics: plant height and ear length. Triticale was harvested at the stage of full grain maturity (BBCH 98) on 7th August, 5th August and 29th July in 2017, 2018 and 2019, respectively. Grain yield was determined during harvest and converted to 1 hectare basis. The study results were statistically analysed using variance analysis suitable for the split-split-plot design, both for each study year and as a three-year synthesis. Tukey test was applied to calculate confidence half-intervals to be used for means comparison purposes at the significance level of 0.05. Analysis of variance with regression was conducted for grain yield in successive study years. Significance of sources of variation was checked by means of F Fisher–Snedecor test and presented as charts of 2nd order polynomial curves. Maximum value of the function was also calculated, it reflecting the fertilisation level at which the highest yield is obtained, by equating the first derivative of the 2nd degree polynomial with zero. To obtain equations, multiple regression analysis was performed for the yields of cultivars, with the dependent variable (y) of grain yield and independent variables of ear number (X1), number of grains per ear (X2) and 1000 grain weight (X3). The wise-step analysis of multiple regression was performed by including consecutive variables in the equation. Significance of R coefficient was checked with F Fisher–Snedecor test, and significance of coefficients of partial regression, by means of t-Student test. Calculations were performed using Statistica 12.0 software (Trętowski and Wójcik 1991).

RESULTS

Variance analysis of the obtained results for each study year demonstrated a significant effect of fertiliser type and rate on spring triticale grain yield (Table 1). A higher grain yield was produced by spring triticale fertilised with Polifoska Krzem rather than Polifoska 6. Fertiliser rate had a significant influence on spring triticale grain yield. The poorest performance was found for the unfertilised control. Increasing fertiliser rates, that is 140, 280 and 420 kg·ha^{-1}, contributed to a significant increase in grain yield compared with control. However, yields associated with these fertiliser rates remained at a similar level.

Table 1. Grain yield [t·ha^{-1}] of test cultivars (C) of spring triticale according to fertiliser type (T) and rate (R)

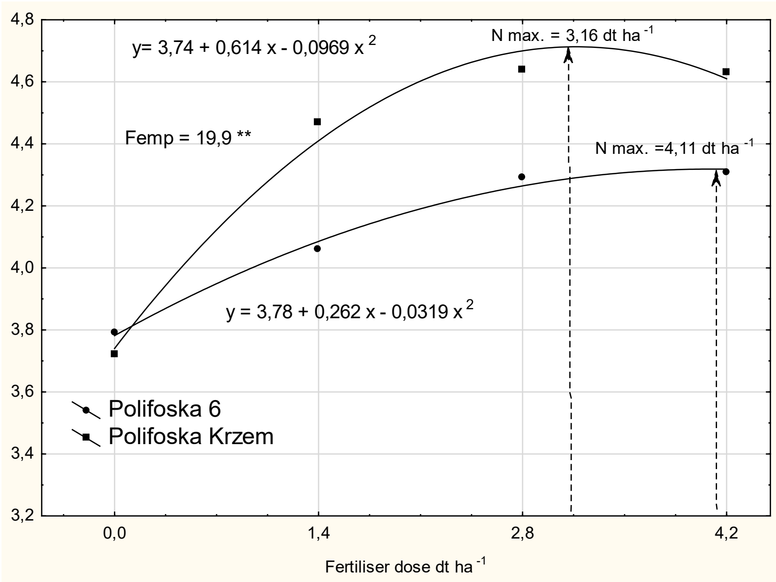
Study years	Cultivar	Fertiliser Type	Fertiliser rate kg·ha^{-1}				Mean
			0	140	280	420	
2017–2019	Milewo	Polifoska 6	3.10	3.42	3.59	3.49	3.40
		Polifoska Krzem	3.32	3.79	3.82	3.91	3.71
		mean	3.21	3.60	3.71	3.70	3.55
	Dublet	Polifoska 6	3.34	3.63	3.54	3.80	3.58
		Polifoska Krzem	3.31	3.80	4.08	3.95	3.78
		mean	3.32	3.71	3.81	3.88	3.68
	mean	Polifoska 6	3.22	3.52	3.57	3.65	3.49
		Polifoska Krzem	3.31	3.79	3.95	3.93	3.75
		mean	3.27	3.66	3.76	3.79	3.62

$LSD_{0.05}$ for: C – non significant (ns.); T – 0.08; R – 0.16; TxC – ns.; RxC – ns.; RxT – ns.

Figure 1 shows second order polynomial regression curves for the association between spring triticale grain yield and fertiliser rate of two fertiliser types in the growing season of 2017. A highly significant effect was confirmed. The regression coefficient value for Polifoska Krzem was higher compared with Polifoska 6. Grain yield increased following the rate of 2.8 and 3.16 dt·ha^{-1} of Polifoska Krzem. Above the latter rate, the parabola is flatter due to a decline in the grain yield of spring triticale amended with the highest fertiliser rate which was 4.2 dt·ha^{-1}. For Polifoska 6, the regression coefficient was lower, which means that spring triticale yield was lower at all the fertiliser rates. The highest fertiliser rate contributed to the yield of 4.11 dt·ha^{-1} which, although lower compared with Polifoska Krzem, was still on the rise.

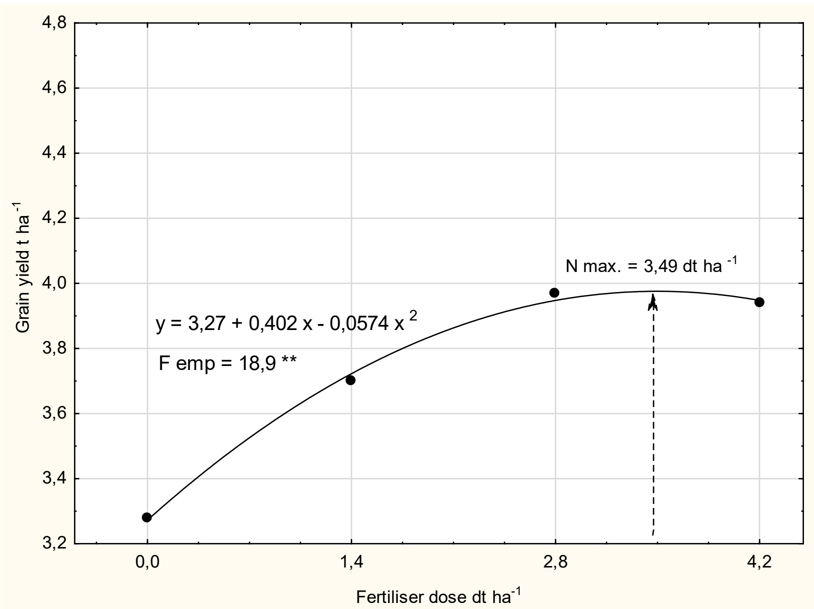
The grain yield of spring triticale harvested in the 2018 season was not significantly differentiated by fertilizer rate, therefore the polynomial curve from this year of research was not included.

Figure 2 demonstrates a second order polynomial curve for the association between spring triticale grain yield and fertiliser rate in 2019. Spring triticale grain yield increase was observed for the rate 2.8 dt·ha^{-1} of Polifoska Krzem and Polifoska 6. which slowly continued for the rate of 3.49 dt·ha^{-1} but it was followed by a decline in grain yield for the highest rate, that is 4.2 dt·ha^{-1}.



** Highly significant effect.

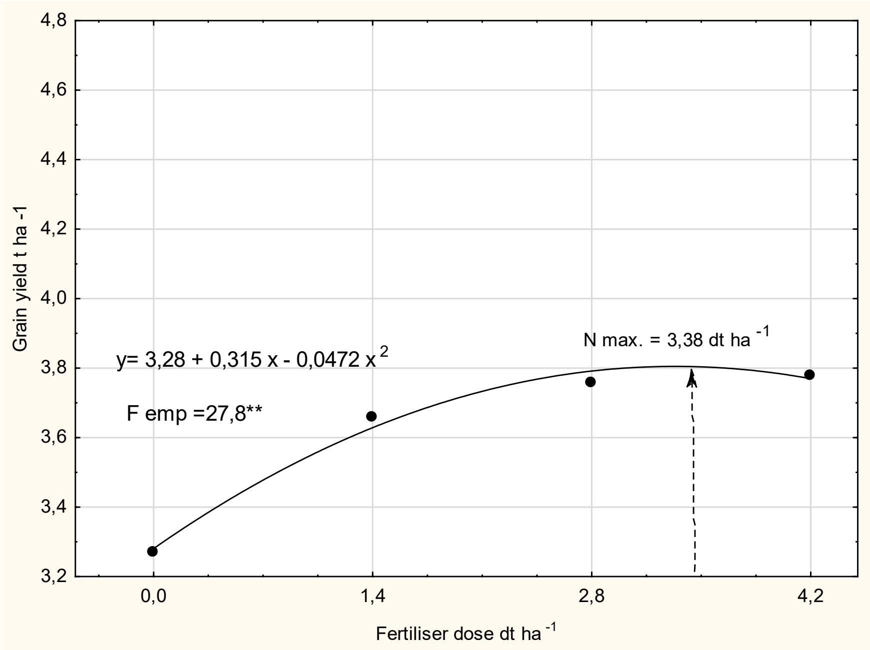
Fig. 1. Second order polynomial curves for the association between triticale grain yield (y) [dt·ha^{-1}] and fertiliser rate (x) of two products (2017)



** Highly significant effect.

Fig. 2. Second order polynomial curve for the association between triticale grain yield (y) [dt·ha^{-1}] and fertiliser rate (x) (2019)

Figure 3 presents a second order polynomial curve for the association between spring triticale grain yield and fertiliser rate based or results averaged across the study years 2017–2019. There was confirmed a substantial increase in spring triticale grain yield from the control rate to the rate of 2.8 dt·ha^{-1} of Polifoska 6 and Polifoska Krzem. A slight increase in grain yield was observed up to the rate 3.38 dt·ha^{-1}, which was followed by a decline although the yield was the highest for the highest rate of Polifoska 6 and Polifoska Krzem, that is 4.2 dt·ha^{-1}.



** Highly significant effect.

Fig. 3. Second order polynomial curve for the association between triticale grain yield (y) [dt·ha^{-1}] and fertiliser rate (x) (averaged across 2017–2019)

Changes in spring triticale yields were affected by basic yield components such as ear number per 1 m^2, grain number per ear and 1000 grain weight (Table 2). Changes in cv.Milewo yield were to a greater extent affected by variation in grain number per ear (X_2) and 1000 grain weight (X_3). In turn, cv. Dublet had a higher value of regression coefficient for ear number. Changes in yield following an application of two different fertilisers were also affected by ear number, grain number per ear and 1000 grain weight. Compared with Polifoska Krzem, changes in yield due to an application of Polifoska 6 were to a greater extent caused by variation in grain number per ear and 1000 grain weight. The effect of individual components of grain yield under no-fertiliser conditions was associated with changes in grain number per ear and 1000 grain weight. When the fertiliser rate ranged from 140 to 420 kg·ha^{-1}, changes in yield were connected with grain number per ear. Coefficients of linear regression were similar and ranged from 0.0610 to 0.0705.

Table 2. Assessment of associations between grain yield (Y), ear number (X_1), grain number per ear (X_2) and 1000 grain weight (X_3) for spring triticale cultivars, fertiliser type and rate

Factor	Factor variant	Regression equation	R
Cultivar	Milewo	$Y = -6.88 + 0.0192 X_1 + 0.0862 X_2 + 0.0700 X_3$	$R^2 = 0.93$
	Dublet	$Y = -6.50 + 0.0305 X_1 + 0.0679 X_2 + 0.0355 X_3$	$R^2 = 0.98$
Fertiliser type	Polifoska 6	$Y = -6.43 + 0.0162 X_1 + 0.0894 X_2 + 0.0689 X_3$	$R^2 = 0.96$
	Polifoska Krzem	$Y = -6.47 + 0.0251 X_1 + 0.0764 X_2 + 0.0617 X_3$	$R^2 = 0.96$
Fertiliser rate kg·ha^{-1}	0	$Y = -5.61 + 0.0973 X_2 + 0.0111 X_3$	$R^2 = 0.92$
	140	$Y = 0.999 + 0.0710 X_2$	$R^2 = 0.50$
	280	$Y = 1.619 + 0.0610 X_2$	$R^2 = 0.27$
	420	$Y = 1.22 + 0.0705 X_2$	$R^2 = 0.32$

Variance analysis of results averaged across study years demonstrated that test cultivars and fertiliser rates had a significant influence on plant height (Table 3). Cv.Milewo plants were higher compared with cv. Dublet. It was also found that, in plots amended with the highest fertiliser rate, that is 420 kg·ha^{-1}, plants were significantly higher compared with unamended control plants. Lower fertiliser rates had no effect on plant height.

An assessment of means calculated across the study years using variance analysis demonstrated a significant effect of experimental factors on spring triticale ear length (Table 4). There was also confirmed an interaction between fertiliser type and cultivars as well as fertiliser rate and cultivars, Significantly longer ears were developed by cv. Milewo, and following an application of Polifoska 6. Significant differences in the length of spring triticale ears were determined between control plants or plants harvested in plots fertilised with 140 kg·ha^{-1} and plants from units amended with either 280 or 420 kg·ha^{-1}. Interactions of fertiliser type with cultivar, and fertiliser rate with cultivar demonstrated a divergent response of cultivars amended with the experimental fertilisers and rates. Longer ears were developed by cereal plants fertilised with Polifoska 6. Similarly, higher fertiliser rates had a beneficial effect on ear length.

Table 3. Plant height [cm] of test cultivars (C) of spring triticale as affected by fertiliser type (T) and rate (R)

Study years	Cultivar	Fertiliser type	Fertiliser rate kg·ha^{-1}				Mean
			0	140	280	420	
2017–2019	Milewo	Polifoska 6	108.9	114.1	114.2	114.5	112.0
		Polifoska Krzem	109.2	114.2	114.5	114.8	113.2
		mean	109.1	114.2	114.3	114.6	113.1
	Dublet	Polifoska 6	104.4	109.3	109.5	110.0	108.3
		Polifoska Krzem	104.6	109.2	109.8	109.8	108.4
		mean	104.5	109.3	109.6	109.9	108.3
	mean	Polifoska 6	106.6	111.7	111.8	112.3	110.6
		Polifoska Krzem	106.9	111.7	112.1	112.3	110.8
		mean	106.7	111.7	112.0	112.3	110.7

$LSD_{0.05}$ for: C – 0.13; T – ns.; R – 0.28; TxC – ns.; RxC – ns.; RxT – ns.

Table 4. Ear length [cm] of test cultivars (C) of spring triticale as affected by fertiliser type (T) and rate (R)

Study years	Cultivar	Fertilisertype	Fertiliser rate in kg·ha^{-1}				Mean
			0	140	280	420	
2017–2019	Milewo	Polifoska 6	8.7	9.4	9.8	10.1	9.5
		Polifoska Krzem	8.7	9.2	10.0	9.9	9.4
		mean	8.7	9.3	9.9	10.0	9.5
	Dublet	Polifoska 6	8.5	8.9	8.9	9.1	8.9
		Polifoska Krzem	8.0	8.4	8.7	8.8	8.5
		mean	8.3	8.7	8.8	8.9	8.7
	mean	Polifoska 6	8.6	9.2	9.3	9.6	9.2
		Polifoska Krzem	8.3	8.8	9.3	9.3	9.0
		mean	8.5	9.0	9.3	9.5	9.1

$LSD_{0.05}$ for: C – 0.15; T – 0.09; R – 0.22; TxC – 0.12; RxC – 0.28; RxT – ns.

DISCUSSION

The grain yield of test spring triticale cultivars was affected by fertiliser type and rate. In the present study, spring triticale yields were influenced by fertiliser type, significantly higher yields being associated with an application of Polifoska Krzem vs. Polifoska 6. According to many authors, mineral fertilisation is considered an essential yield-forming factor (Winiarski 2004; Wacławowicz et al. 2017). Malakouti (2008), Wojtkowiak and Domska (2009) as well as Knapowski et al. (2010) claim that an application of mineral fertilisers alongside micro-element products results in yield increase. In the current study, spring triticale fertilised with Polifoska Krzem developed a greater number of productive ears compared with Polifoska 6, which was reflected in grain yield levels. Research by Yu and Gao (2012) has confirmed that silicon can enhance spring triticale yields due to an increased ear number and grain number per ear. In the experiment reported here, in 2017–2018, fertiliser rate was another factor which significantly affected spring triticale yields. According to Winiarski (2004), the share of fertilisers in yield increase depends on fertiliser rate and ranges from 50 to 70%. Many works (Czuba 1996; Grześkiewicz and Trawczyński 1998; Jabłoński 1998; Mazur et al. 2001) have confirmed that fertiliser rate has a positive impact on yield quantity and, when doubled for multi-nutrient fertiliser, it results in yield increase. Plant height was significantly affected by cultivar and fertiliser rate. Cv. Milewo plants were by 4.9 cm higher than cv. Dublet. Also research by COBORU (Research Centre for Cultivar Testing) demonstrated significant differences in plant height between test plants (www.coboru.gov.pl). The highest plants were produced in plots amended with the highest fertiliser rate, which concurs with findings reported by Katyal and Datta (2004).

In the study discussed here, spring triticale ear length was affected by experimental factors, i.e. cultivar, fertiliser type and fertiliser rate. Longer ears were developed by cv. Milewo compared with cv. Dublet, hence an interference that spring triticale ear length is influenced by the genotype of individual cultivars. Fertiliser type had an effect on ear length as longer ears were determined for plants fertilised with Polifoska 6. It can be inferred that it was due to higher phosphorus content in Polifoska 6 compared with Polifoska Krzem. According to Piwowar (2013), phosphorus contributes to longer ears, and increases the amount of other components. In the present study, fertiliser rate affected spring triticale ear length as well. Ears were significantly higher in fertilised units compared with unamended control, which was also confirmed in research by Jadczyszyn (2004) who concluded that an application of mineral fertilisers contributes to increased cereal cultivation effectiveness.

CONCLUSIONS

1. Spring triticale grain yield was predominantly affected by experimental factors, i.e. cultivar, fertiliser type and rate.
2. Cv. Dublet produced superior grain yields compared with cv. Milewo. Spring triticale harvested in plots amended with Polifoska Krzem outperformed crops fertilised with Polifoska 6 in terms of grain yield. An increase in multi-nutrient fertiliser rate was followed by increasing spring triticale grain yields.
3. Fertiliser rate contributed to an increase in plant height compared with unamended control. Cv. Milewo plants were higher than cv. Dublet plants.
4. Spring triticale cultivar, as well multi-nutrient fertiliser type and rate significantly affected ear length. Significantly longer ears were developed by cv. Milewo. Longer ears were developed by cereal plants fertilised with Polifoska 6. Similarly, higher fertiliser rates had a beneficial effect on ear length.
5. The difference between studied varieties was not significant.

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PLON ZIARNA I CECHY MORFOLOGICZNE ROŚLIN PSZENŻYTA JAREGO W ZALEŻNOŚCI OD ODMIANY, RODZAJU I DAWKI NAWOZU WIELOSKŁADNIKOWEGO

Streszczenie. Doświadczenie polowe zostało przeprowadzone w latach 2017–2019 w miejscowości Borki-Wyrki na terenie gminy Zbuczyn. Celem przeprowadzonych badań była ocena wielkości plonu i cech morfologicznych dwóch odmian pszenżyta jarego w zależności od rodzaju nawozu mineralnego wieloskładnikowego i dawek. Zastosowano nawóz w postaci Polifoski 6 i Polifoski Krzem. W doświadczeniu uwzględniono trzy czynniki badawcze. Pierwszym czynnikiem była odmiana pszenżyta jarego: Milewo, Dublet; drugim czynnikiem był rodzaj nawozu mineralnego: Polifoska 6, Polifoska Krzem; trzecim czynnikiem były dawki nawozu mineralnego: 0 $kg \cdot ha^{-1}$, 140 $kg \cdot ha^{-1}$, 280 $kg \cdot ha^{-1}$, 420 $kg \cdot ha^{-1}$. Na rozwój roślin i plonowanie pszenżyta jarego decydujący wpływ miały czynniki doświadczenia, tj. odmiana, rodzaj nawozu i dawki. Większym plonem ziarna charakteryzowała się odmiana Dublet niż odmiana Milewo. Odmiany nawożone nawozem Polifoską Krzem dały większy plon ziarna niż Polifoską 6. Wraz ze wzrostem dawki nawożenia wzrastał plon ziarna. Odmiana pszenżyta jarego, a także rodzaj i dawka nawozu wieloskładnikowego istotnie różnicowały długość kłosa. Istotnie dłuższe kłosy wykształciła odmiana Milewo. Dłuższe kłosy uzyskano, nawożąc zboże Polifoską 6. Jednocześnie na ich długość korzystny wpływ miały wyższe dawki. Dawka nawozu powodowała zwiększenie wysokości roślin w porównaniu z obiektem kontrolnym, bez nawożenia. Odmiana Milewo charakteryzowała się istotnie wyższymi roślinami w porównaniu z odmianą Dublet.

Słowa kluczowe: *xTriticosecaleWittm. ex A. Camus*, plon ziarna, odmiana, nawóz wieloskładnikowy, cechy morfologiczne roślin.