AGRONOMY SCIENCE
wcześniej – formerly
Annales UMCS sectio E Agricultura

VOL. LXXVII (3) 2022

http://doi.org/10.24326/as.2022.3.4

[1] Department of Agronomy, Bydgoszcz University of Science and Technology, Prof. S. Kaliskiego 7, Bydgoszcz, Poland
[2] Department of Biogeochemistry and Soil Science, Bydgoszcz University of Science and Technology, Prof. S. Kaliskiego 7, Bydgoszcz, Poland
*e-mail: borowska@pbs.edu.pl

JANUSZ PRUSIŃSKI[1], MAGDALENA BOROWSKA[1]*, EDWARD MAJCHERCZAK[2]

The effect of the soil tillage methods for forecrop and N-mineral fertilization on the yield of winter triticale (× *Triticosecale* sp. Wittmack ex A. Camus 1927)

Wpływ uprawy roli pod przedplon i nawożenia N mineralnym na plonowanie pszenżyta ozimego (× *Triticosecale* sp. Wittmack ex A. Camus 1927)

Summary. The aim of the research was to evaluate the effect of three different methods of soil cultivation for the forecrop on the yield and protein content in winter triticale grain depending on the amount of mineral nitrogen used. The yield of winter triticale grain depended the most on the distribution and sum of rainfall and on the doses of mineral N. A significant impact of the increasing total amount of rain and the distribution of precipitation in the years and months of the research on most of the studied features of triticale was found. The average triticale grain yield and protein content were significantly higher when soybean forecrop was grown using the reduced and strip-till method than after traditional plow cultivation. N doses from 60 to 180 kg ha^{-1} had the highest, but, on average, insignificantly differentiated impact on the yielding of triticale in the years of the study. N fertilization did not differentiate the number of spike-bearing stalks or the weight of 1000 grains. The triticale yield and protein content increased significantly up to the dose of 120 kg N ha^{-1}.

Key words: soil tillage methods, N dose, triticale yield and its components, grain fractions

INTRODUCTION

The growing population and the resulting demand for food burden agriculture around the world, especially in countries with predominance of small farms and the widespread presence of biotic and abiotic stresses, especially drought [Ahluwalia et al. 2021]. Diversification of crops with the use of legumes has a positive effect on the behavior of water in the soil, increases the availability of N and increases the productivity of successive crops

[Buraczyńska and Ceglarek 2009, Skuodienė and Nekrošienė 2009, Płaza and Soszyński 2010, Małecka-Jankowiak et al. 2018]. As a result, there are large amounts of nitrogen in the remainder of legumes, which significantly increases the yield of successive plants by up to 15%, and 100 kg of biological bound N corresponds to as much as 200 kg of mineral N. Similarly, in the studies by Buraczyńska and Ceglarek [2009] an increase in the share of pea in mixtures with spring triticale grown as a forecrop resulted in a significant increase in the grain yield and the content of total protein winter triticale.

Triticale is characterized by high plasticity and a better use of climatic and soil conditions than other cereals [Dumbravă et al. 2016]. It is also a species with a high yielding potential and with favorable nutritional properties of the grain [Biberdžić et al. 2012]. However, significant variability of winter triticale yielding is observed depending on water availability and rainfall distribution during the growing season [Wójcik-Gront and Studnicki 2021].

According to Oral [2018], the greatest impact on the yield of winter triticale, on top of the cultivar, has the nitrogen dose, as cereals show positive reaction to intensive mineral fertilization, in particular nitrogen fertilization. Hence, many authors found a significant difference in the yielding of triticale depending on the doses of mineral N [Biberdžić et al. 2012, Lalević and Biberdžić 2015, Madić et al. 2015, Terzic et al. 2018]. According to Wojtkowiak and Domska [2009], the optimal nitrogen dose for triticale in Poland is 80–120 kg ha^{-1}. However, for example, Gibson et al. [2007] found that in the USA, high yields of triticale grain can be harvested already after the application of 33 kg N ha^{-1}, but the maximum N content in the dry matter of grain is obtained only after fertilization with a dose of 99 kg N ha^{-1}. According to Mut et al. [2005], the intensification of nitrogen fertilization in Turkey not only increases the grain yield, but also the number of ears and the weight of 1000 grains, and the optimal dose of N should be between 120–180 kg ha^{-1}. In turn, Wojtkowiak [2004] found that in Poland, the application of a very high dose, 200 kg N ha^{-1}, not only does not increase the yield of winter triticale, but may cause side effects such as soil degradation and negative environmental impact.

Gerdzhikova [2014] found that fertilization of winter triticale with N positively influences, above all, the weight of the stalks and the weight of grains per spike, and to a lesser extent determines the number of grains per spike and does not significantly differentiate the weight of 1000 grains. According to Abdelaal et al. [2019], fertilization of triticale with mineral N causes a significant increase in the grain yield, and only a slight increase in the weight of 1000 grains.

In a multivariate experiment by Burdujan et al. [2014], the forecrops, including pea, had the greatest impact on the yield of winter triticale, in addition to the sowing date. The benefits in yielding of successive cereal crops are greatest in the conditions of limited fertilization with mineral N [Preisel et al. 2015]. In the study by Brzozowska and Brzozowski [2013], the winter triticale grain and total protein yields when grown after forecrop mixtures of spring triticale and pea, was significantly higher than that of triticale grown after pure cereal cultures. Gibson et al. [2007] report that winter triticale may use N residues from previous crops which reduces nitrogen leaching, especially important in early spring, when some N is or may be leached into the soil profile due to significant rainfall. In their research, triticale plants absorbed 44–93 kg N ha^{-1} from the fields where no fertilization with mineral N was applied, and as much as 164 kg N ha^{-1} after the application of 99 kg N ha^{-1}. In turn, Gerdzhikova et al. [2017] reported that winter triticale grown after legumes can use N in 35.4%, which may significantly increase the protein content in the grain. The higher yield of winter triticale grain grown after legumes is mainly the result of the greater number of ears per 1 m^2 and grains per spike. The fertilization of triticale with mineral N had a positive effect also on the number of spike-bearing stalks, the number of grains per spike and the weight of 1000 grains. According to Buraczyńska and Ceglarek [2009], the grain and protein yield of winter triticale grown after mixtures of spring triticale with peas was significantly higher than that of triticale grown after cereals, resulting in the greater number of ears per 1 m^2 and grains per ear. On the other hand, Skuodienė and Nekrošienė [2009] found that plowing white clover as a forecrop increased the triticale grain yield by as much as 0.94 t ha^{-1}. Moreover, using white clover plowed with green fertilizer as forecrop allowed for the harvesting of as much as 3.88 t ha^{-1} of triticale grain without mineral N fertilization, and had a positive effect on plant height, ear length and number of grains per spike, similarly to the research by Płaza and Soszyński [2010]. According to Faligowska et al. [2019], legumes as forecrops increase the triticale grain yield similarly to the N dose up to 160 kg ha^{-1}, which means that it is not necessary to use such high doses in the cultivation of winter triticale. According to Małecka-Jankowiak et al. [2018], legume forecrops may increase the grain yield of succeeding cereal crops by up to 30%. The hypothesis of the research assumes that the methods of soybean cultivation used as a forecrop for winter triticale, as well as fertilization of winter triticale with mineral N, may significantly affect its grain and protein yield, and the structural components of grain yield. The aim of the research was to assess the effect of the soybean forecrop grown using three different cultivation methods on the yield of winter triticale fertilized with various doses of mineral N.

MATERIALS AND METHODS

A strict two-factor field experiment was carried out in 2016–2020 at the Research Station in Mochełek (53°18'33"N and 18°06'67"E) in a split-plot arrangement in 4 replicates and in soil conditions favorable for winter triticale cultivation. The soil type, classified according to the WRB as Haploic Luvisoils (Cutanic), was a typical lessive soil formed by light loamy sand, deposited in a shallow layer on light loam [FAO 2015]. The phosphorus content was very high (90 mg kg^{-1} of soil), potassium was high (134 g kg^{-1} of soil), and magnesium was low (28.7 mg kg^{-1}). The content of assimilable potassium and phosphorus forms was determined using the Enger-Rhiem DL method, and of magnesium – with the Schachtschabel method. The concentration of nitrate and ammonium ions was assayed colometrically with Behelot and Griess-Ilosvay reactions. Soil pH was measured potentiometrically in 1 mol L^{-1} KCl. In all research years, the soil pH was appropriate for the cultivation of triticale (Tab. 1).

Table 1. Chemical properties of the soil before sowing of triticale in the years 2016–2019

Years	mg kg^{-1} of soil			mg kg^{-1} of soil		pH in KCl
	P_2O_5	K_2O	Mg	N-NO_3	N-NH_4	
2016	109.0	127	30.0	9.53	5.73	6.3
2017	92.0	149	31.0	5.90	7.96	6.3
2018	82.0	112	27.0	6.12	6.97	6.8
2019	77.0	149	27.0	8.69	2.27	6.5

The soybean forecrop was grown in 2017, 2018 and 2019 by plowing (Conventional Tillage – CT), reduced method (Reduced Tillage – RT – a mixture consisting of blue phacelia – 8 kg ha^{-1} and white mustard – 12 kg ha^{-1}) and left for the winter to mulch catch crops and in a strip-till (ST) – the field was left until spring in a stubble of about 15 cm height without any agrotechnical treatments. In the spring of each year, soybeans were fertilized with doses of 30 kg N, 80 kg P and 70 kg K per ha and the seed was inoculated with Nitragina (IUNG-PIB, PL).

After harvesting soybeans in the subsequent years of research, the entire area of three experimental fields was plowed and sown with winter triticale of the Tulus variety (Nordsaat Saatzucht GmbH) on 24.X, 2.X, and 25.X, respectively. The area of each of the three fields was 1,440 m^2. In the spring of 2018, 2019 and 2020, each field was divided into 4 plots (4 n) where the following total doses of N in the ammonium nitrate form were applied: 0, 60 (in BBCH 20), 120 (50% in BBCH 20 and 50% in BBCH 30) and 180 kg N ha^{-1} (50% in BBCH 20, 30% in BBCH 30 and 20% in BBCH 45). After the beginning of triticale spring vegetation, Huzar Active 387 OD at 1 dm^3 ha^{-1} was applied to dicot weeds. In the following years of research, triticale plants were harvested at full maturity on 26.VII, 24.VII and 12.VIII, respectively, from randomly selected areas of 48.75 m^2 in 4 replicates from each of the 3 forecrop fields (48 plots). Triticale plant density per 1 m^2 before entering the wintering season was 239, 431 and 437, respectively, and the average vegetation season was 274, 268 and 289 days long in the following seasons.

Conditions for growth and development of triticale plants were generally favorable. Only 2018, in February and March negative air temperature was observed, which however did not damage wintering plants.

Table 2. Average air temperature (°C) and rainfall totals (mm) in research years

Month	Temperature (°C)				Rainfall totals (mm)			
	2017/2018	2018/2019	2019/2020	Mean	2017/2018	2018/2019	2019/2020	Mean
October	10.1	9.8	9.8	9.9	106.8	34.0	35.9	58.9
November	4.5	3.4	5.5	4.47	30.5	41.3	69.6	47.1
December	2.0	1.7	2.7	2.13	38.8	42.7	21.1	34.2
January	2.5	–0.7	2.6	1.47	46.3	32.6	37.7	38.8
February	–2.2	2.6	3.6	1.33	5.8	18.1	36	19.9
March	–3.5	5.4	3.9	1.93	16.6	28.8	26.1	23.8
April	9.2	9.3	8.2	8.9	40.4	1.5	0.7	14.2
May	14.8	12.1	10.9	12.6	14.2	89.2	34.6	46.0
June	19.8	21.9	17.9	19.8	26.4	17.7	153.9	66.0
July	18.7	18.6	18.0	18.4	86.0	22.4	85.1	64.5
August	18.8	19.6	19.2	19.2	23.7	37.7	90	50.4
Mean/Sum	8.61	9.43	8.44	9.10	435.5	366	590.7	464.1

In May, June and July – the phase of intensive growth and development of triticale plants, the lowest average air temperature in subsequent seasons was recorded in 2020 (Tab. 2). It is worth noting that from 25 February until 4 March 2018, there was a continuous 8-day period with the temperature below –10°C, and the absolute minimum of –16°C, however, it did not affect the subsequent growth and development of triticale. In turn, the water conditions for triticale in the research years were, except for the 2019/2020 season, unfavorable. In July 2018 and May 2019, almost 90 mm of rainfall was recorded, but in the remaining months of these years, the total rainfall from April to July was only 40 mm on average.

The experiment was a 2-factorial fitted into completely randomized block system design with four replicates. Data were processed by ANOVA using STATISTICA version 10 (StatSoft Tulsa. OK. USA). The $p < 0.05$ and $p < 0.01$ were set as significance level. The HDS test a $p < 0.05$ was used for the difference between parameter means. Pearson correlation coefficients were used for the relationship between obtained parameters. The means in tables and charts provided with the same letters did not differ significantly.

RESULTS

The average 3-year yield of winter triticale grain was 4.28 t ha^{-1} (Tab. 3). The increasingly better humidity conditions in the subsequent years of research were accompanied by a significant, growing yield of triticale grain. Only in the 2017/2018 season, the yield of triticale grain grown after soybean forecrop in CT was significantly higher than after the RT. On average, for the period of 3 years of research, a significantly higher yield of triticale was obtained after its cultivation after soybean using a reduced method and in strip-till than after plowing. In the season 2017/18 and 2019/20 there was no significant effect of the applied N doses on the yielding of triticale, which was significantly higher than in the control object without N (0). However, in the season 2018/19 significantly higher was obtained at the dose

Table 3. The effect of tillage methods for forecrop on the yielding of winter triticale fertilized with mineral N

Specification		Year			Mean
		2018	2019	2020	
Tillage methods (T)	CT	2.56^{a}	4.18^{b}	5.16^{c}	3.97^{b}
	RT	2.08^{b}	4.65^{ab}	6.72^{a}	4.48^{a}
	ST	2.34^{ab}	4.78^{a}	6.03^{b}	4.38^{a}
N dose (N)	0	1.83^{b}	3.82^{c}	4.46^{b}	3.37^{b}
	60	2.36^{a}	4.95^{ab}	6.18^{a}	4.50^{a}
	120	2.50^{a}	5.02^{a}	6.53^{a}	4.74^{a}
	180	2.61^{a}	4.36^{bc}	6.70^{a}	4.50^{a}
Mean		2.33^{C}	4.54^{B}	5.97^{A}	4.28
T		*	*	**	**
N		**	**	**	**
T × N		ns	**	*	**

Values of a parameter followed by the same letter did not differ significantly between tillage methods and N dose (ANOVA followed by Tuckey's HDS test. $p < 0.05$). ANOVA results: ** $p < 0.01$; * $p < 0.05$; ns – not significant.

of 60 and 120 kg of N. It is worth emphasizing the significant dependence of the grain yield on the soybean forecrop cultivation method and the applied doses of N. It was observed that the sum of rainfall in May 2019 (89.2 mm) significantly influenced the increase in grain yield, while a similar sum of rainfall in July 2018 (86.0 mm), did not produce such an effect.

The yield of triticale grain was significantly influenced by the number of grains per spike, and to a lesser extent by the number of stalks, the weight of 1000 grains and N dose (Tab. 4). In turn, the weight of grains per spike depended to the greatest extent on the number of grains per spike and slightly less on the dose of N. The correlation of other characteristics was significantly lower.

Table 4**.** Correlation matrix [Pearson] between parameters studied [n = 48]

Specification	N dose	Number of stalks	Number of grains per spike	Weight of 1000 grains	Grain yield
Number of stalks	–0.068^{ns}	–	–	–	–
Number of grains per spike	0.195*	0.016^{ns}	–	–	–
Weight of 1000 grains	–0.175*	0.233*	0.178*	–	–
Grain yield	0.230*	0.374**	0.686**	0.314**	–
Weight of the grains per spike	0.207*	–0.341**	0.747**	0.076^{ns}	0.368**

** $p < 0.01$; * $p < 0.05$; ns – non-significant.

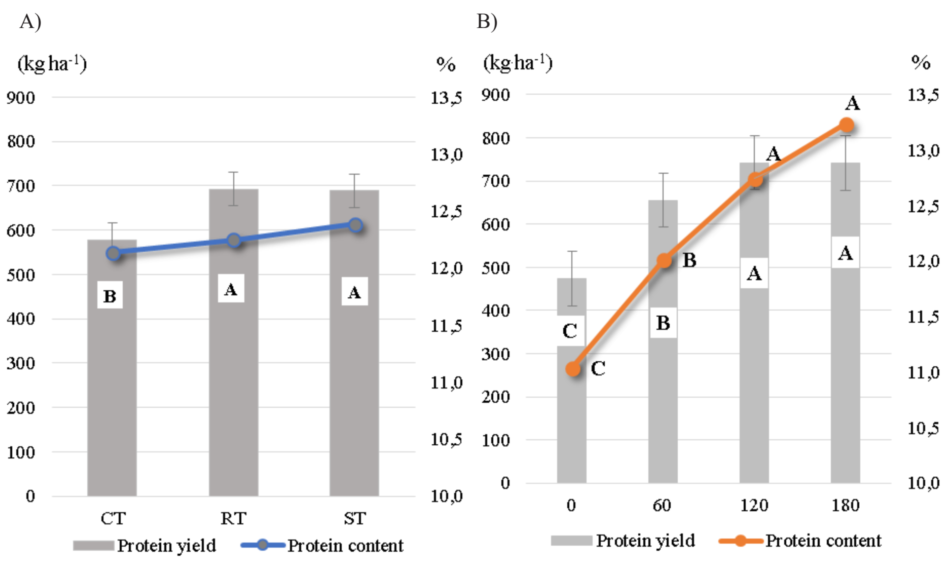
Table 5. The effect of tillage methods for forecrop on the yield components of the winter triticale fertilized with mineral N

Factor		Number of stalks per 1 m^2	Number of grains per spike	Weight of grains per spike (g)	Weight of 1000 grains (g)
Year (Y)	2018	292^b	27.6^c	0.957^c	34.6^b
	2019	254^c	48.4^a	1.711^a	35.5^b
	2020	367^a	44.4^b	1.176^b	39.3^a
Tillage methods (T)	CT	298	38.9	1.27^{ab}	36.1
	RT	305	40.8	1.35^a	37.0
	ST	310	40.5	1.22^b	36.3
N dose (N)	0	312	35.0^b	1.11^b	37.7
	60	305	42.2^a	1.31^a	36.4
	120	299	41.5^a	1.34^a	36.1
	180	301	41.7^a	1.36^a	35.6
Mean		304	40.1	1.28	36.5
Y		**	**	**	**
T		ns	ns	**	ns
N		ns	**	**	ns
Y × T		ns	*	**	ns
Y × N		ns	ns	ns	*
T × N		ns	ns	ns	ns
Y × T × N		ns	**	ns	ns

Values of a parameter followed by the same letter did not differ significantly between tillage methods and N dose (ANOVA followed by Tuckey's HDS test $p < 0.05$). ANOVA results: ** $p < 0.01$; * $p < 0.05$; ns – not significant.

The number of spike-bearing stalks was significantly highest in 2020 and lowest in 2019 (Tab. 5). On average, in the multiannual period, there was no significant effect of the cultivaton methods or the applied N doses on the number of triticale stalks per 1 m^2. The average number of triticale grains per spike was 40.1, the highest in 2019 and the lowest in 2018. The methods of forecrop cultivation did not have a significant impact on this feature. Also, the applied doses of mineral N (60–180 kg ha^{-1}) did not significantly differentiate the number of grains per spike, which, however, was significantly higher than in the control object. In 2019, the weight of grains per spike was significantly higher than in 2020, and in 2018 – the lowest. The average weight of grains per spike was 1.28 g and after the application of mineral N fertilization, regardless of the N dose, it was significantly higher than in the control object. In turn, the average weight of 1000 grains was 36.5 g – significantly the highest in 2020, and it did not differ significantly between 2018 and 2019. There was no significant effect of the soil cultivation for forecrop or N fertilization on the weight of 1000 winter triticale grains.

The triticale protein content and yield were significantly differentiated by the soybean forecrop cultivation method and by the doses of mineral N (Fig. 1). Significantly higher protein content was found in the fields cultivated after soybean in RT and ST, and the maximum protein yield was obtained after the application of 120 kg N ha^{-1}.



Values of a parameter followed by the same letter did not differ significantly between row spacing and planting density [ANOVA followed by Tuckey's HDS test. p < 0.05]. ANOVA results: ** p < 0.01; * p < 0.05; ns – not significant.

Fig. 1. Triticale protein content and yield depending on the tillage methods for forecrop (A) and fertilization with mineral N (B)

The mean contribution of the grain size fractions from 1.6 g to 2.5–2.8 g increased significantly and ranged from 0.41% to 40.2%, whereas it was significantly lower (34.1%) in the fraction above 2.8 mm (Tab. 6). The effect of the soybean cultivation method on the contribution of individual triticale grain size fractions was variable and increased with increasing doses of mineral N. The doses of N determined the variability of the grain contribution in individual fractions only to a small extent. In fractions <1.6 to 2.5–2.8 mm, the effect of the N dose was small, most often higher after the use of doses of 60–120 kg N. In turn, in the >2.8 mm fraction, it increased with the increase of the N dose to 180 kg N ha^{-1}. The accuracy of the grain was not affected by the thermal and humidity conditions in the years of the research. However, significantly higher triticale grain accuracy was observed after the soybean forecrop was cultivated in RT and ST compared to CT. The highest accuracy of triticale grain was achieved only after using 180 kg of N ha^{-1}.

The Wilks lambda coefficient was used to assess the share of winter triticale grain – its lower value means a higher quality of the estimated model. This means that the lower the value of the discussed coefficient, the better the quality of the estimated model turns out to be, which was found in the authors' own research in the case of soil cultivation methods and the applied doses of mineral N under triticale.

Table 6. The effect of tillage methods under forecrop and mineral N dose on winter triticale grain size fraction contribution

Factor		Grain size fraction					Grain accuracy (%)
		<1.6 mm	1.6–2.2 mm	2.2–2.5 mm	2.5–2.8 mm	>2.8 mm	
Year (Y)	2018	0.5^{a}	6.5	19.0^{a}	40.1	33.2^{b}	73.3
	2019	0.4^{b}	6.2	18.5^{a}	39.9	33.8^{b}	73.7
	2020	0.3^{c}	6.0	17.4^{b}	40.7	35.3^{a}	76.0
Tillage methods (T)	CT	0.4^{a}	7.8^{a}	21.4^{a}	41.2^{b}	28.3^{c}	69.5^{b}
	RT	0.4^{a}	5.2^{b}	15.0^{c}	35.2^{c}	43.7^{a}	78.9^{a}
	ST	0.4^{a}	5.7^{b}	18.6^{b}	44.3^{a}	30.2^{b}	74.5^{ab}
N dose (N)	0	0.5^{a}	8.5^{a}	22.1^{a}	39.8^{b}	28.0^{c}	67.8^{b}
	60	0.4^{a}	7.6^{a}	20.1^{a}	41.5^{a}	29.7^{b}	71.2^{b}
	120	0.4^{a}	6.7^{a}	20.2^{a}	41.5^{a}	30.6^{b}	72.1^{b}
	180	0.4^{a}	2.1^{b}	10.8^{b}	38.0^{c}	48.1^{a}	86.1^{a}
Mean		0.41^{E}	6.23^{D}	18.3^{C}	40.2^{A}	34.1^{B}	74.3
Year – lambda Wilksa = 0.25020. F (10.64) = 6.3949. *p* = 0.0000							
Tillage methods – Wilks lambda = 0.01353. F (10. 64) = 48.619. *p* = 0.0000							
Nitrogen fertilization – Wilks lambda = 0.01349. F (15. 88.739) = 22.232. *p* = 0.0000							

DISCUSSION

Changes in the sequence of crops grown on agricultural land may enhance the yield by up to 20% mainly due to improved nitrogen nutrition and the accompanying greater water supply [Kirkegaard et al. 2008]. According to Oral [2018], the triticale grain yield is primarily determined by climatic and soil conditions and production technology [Biberdžić et al. 2012], as well as the cultivar, N dose and their interactions. In the case of legume forecrops, this means an increase in symbiosis activity, preservation of water in the soil and, consequently, an increase in the availability of N and the productivity of cereal succeeding crops [Gan et al. 2015], as well as their economic profitability [Preisel et al. 2015]. In Europe, it is estimated that the cultivation of cereals after legumes saves 21–88 kg N ha^{-1} and increases the grain yield by 17–21% [Reckling et al. 2014]. On the other hand, in Canada, according to Gan et al. [2015] legume forecrops increase the yield of cereal grain by 35.5%, and the yield of protein by 50.9%, with the use of 33% of N.

In the authors' own research, the average yield of triticale grain was 4.28 t ha^{-1} and it was significantly higher when the soybean forecrop was grown using a reduced method or in strip-till, although a large variability in triticale yield was observed in the subsequent years. First, higher yields of winter triticale were found in the research years accompanied by an increasing amount of rainfall during the growing season. It is well known that drought stress is one of the main factors limiting the use of the yielding potential of arable crops [Ahluwalia et al. 2021], including cereals, which was observed in the 2017/2018 season with a very unfavorable distribution of rainfall. Only in July 2018 a sufficient total rainfall depth of 86 mm was recorded, which, however, did not affect further accumulation of triticale grain, because from the beginning of March to the end of June this year, only 97 mm of rainfall in total was recorded. However, in the following seasons, the total rainfall depth was already higher, and the highest in the 2019/2020 season, even hindering the maturation of plants and their collection. Thus, not only the sum of precipitation, but also their distribution, were of great importance for the yielding potential of modern triticale cultivars, which was also confirmed by Alaru et al. [2004]. The difference in the yielding of triticale in the first and third growing season under such different humidity conditions was as much as 256%, whereas for example in the studies of Płaza and Soszyński [2010] only slightly less, 174%.

Legume forecrops allow to reduce the demand of succeeding crops for N and the costs of nitrogen fertilizers [Diaz-Ambrona and Mingues, 2001]. Their forecrop value is a key component of the economic profitability of cereals and allows to decrease the fertilization with mineral N by 23–31 kg ha^{-1} and simultaneous increase in grain yield by 0.5–1.6 t ha^{-1} compared to cereal forecrops [Preisel et al. 2015]. Małecka-Jankowiak et al. [2018] achieved a 30% increase in the grain yield of successive cereal crops grown after legume forecrop. Also Prusiński et al. [2016] recorded higher grain and protein yield (by 0.84 t ha^{-1} and 86 kg ha^{-1}, respectively) of winter triticale Tulus cultivated after legumes. However, there are reports in which the legume forecrop (pea) did not significantly affect the yield of winter triticale [Wysokinski et al. 2021], which probably indicates the necessity of checking the abundance and availability of N derived from post-harvest residues of the forecrop, as well as the need to design intercrops as a way to increase the amount, and especially the stability of triticale yield [Weih et al. 2021]. Hence, it is not recommended to use high doses of N in the cultivation of triticale grown after legumes, which may significantly reduce the costs of mineral fertilizers [Faligowska et al. 2019].

Many authors reported a significant effect of the doses of mineral N on the yielding of triticale [Biberdžić et al. 2012, Lalević and Biberdžić 2015, Faligowska et al. 2019, Madić et al. 2015, Terzic et al. 2018]. Abdelaal et al. [2019] found that all doses of N fertilization, from 30 to 150 kg N ha^{-1}, caused a significant increase in the yield of triticale grain compared to the control. In Poland, optimal doses of N for triticale range from 80–120 kg N ha^{-1} [Wojtkowiak 2004, Wojtkowiak and Domska 2009] to 100–150 N ha^{-1}, and e.g. in Asia, according to Mut et al. [2005], as much as 120–180 kg of N ha^{-1}. The doses of mineral N used in our research – 60–120–180 kg ha^{-1} did not significantly differentiate the triticale grain yield, which on average amounted to 4.58 t ha^{-1}, but was significantly lower, by as much as 26.4%, on the control site without N fertilization. Lalević and Biberdžić [2015] found a significant effect of subsequent doses of mineral N in cereal cultivation, but only up to 120 kg N ha^{-1}, which led to the maximum increase in grain yields compared to the control. However, in the authors' own research, the difference between the lowest and the highest grain yield after the application of 60, 120 and 180 kg ha^{-1} of N was not statistically significant and amounted to only 5.3%. Also in earlier authors' own research [Prusiński et al. 2016] the yield of winter triticale cv. Tulus cultivated after legumes and fertilized with doses from 60 to 180 kg N ha^{-1} did not differ significantly, but was always significantly lower when spring barley was used as a forecrop. It is worth emphasizing that the content of mineral N in the 0-60 cm soil layer after harvesting the forecrop of 4 legume species without mineral N fertilization was 25.5% higher than after harvesting spring barley fertilized with 60 kg N ha^{-1}.

The correlation coefficients of most of the studied triticale characteristics did not differ significantly. Stoyanov [2019], similarly to authors' own research, found the largest and the most significant relationships expressed by the positive Pearson correlation coefficient between the number and the grain weight per spike. However, the high correlation between the weight of 1000 grains and the grain weight per spike was not confirmed. It should be emphasized that the number, in addition to the grain weight per spike, determines the yield of triticale grain to the greatest extent, which indicates their primary importance in shaping the spike productivity. It should also be emphasized that the values of the triticale structural yielding components were varied in successive seasons. The number of spike-bearing stalks and the weight of 1000 grains were significantly the highest in the wettest season of 2019/2020, whereas the number and weight of grains per spike in the slightly less humid season of 2018/2019. In the studies by Buraczyńska and Ceglarek [2009], the higher yield of triticale grain cultivated after the mixture of spring triticale and pea was due to the higher number of grains per spike. Also, Brzozowska and Brzozowski [2013] found a beneficial effect of N fertilization on the components of triticale yield, including the number of spike-bearing stalks, the number of grains per spike and the weight of 1000 grains. Authors' own research confirms the results of Płaza and Soszyński [2010], who also found a statistically similar number of grains per spike, regardless of the doses of N 60–180 kg ha^{-1}. In turn, Abdelaal et al. [2019] report that the weight of 1000 grains increases slightly with an increase in the N dose from 30 to even 150 kg N ha^{-1}, which has not been confirmed in authors' own studies. According to Skuodienė and Nekrošienė [2009], the weight of grains per spike does not significantly depend on the dose of N. However, in the studies by Lalević and Biberdžić [2015] it was significantly the highest for the dose of 120 kg N ha^{-1}, and in the studies by Gerdzhikova et al. [2017], higher by 22%. Oral [2018] also found a significant effect of increasing N doses on increasing the weight of grains per spike. According to Madić et al. [2015], N fertilization had the greatest impact on the grain weight per spike. Regardless of the environmental conditions, the correlations between the number of grains per spike, the grain weight per spike and the grain yield remain high. This indicates that the number of grains per spike is essential for shaping the spike productivity and is a key component of the triticale grain yield [Stoyanov 2019].

The protein yield depends on the obtained grain yield and its protein content [Wojtkowiak 2004]. According to Abdelaal et al. [2019], increasing doses of mineral N from 30 to 150 kg N ha^{-1} had a significant impact on the content and yield of triticale protein. In the authors' own research, a sufficient dose of N to achieve the significantly highest of both values was 120 kg ha^{-1}. However, in previous authors' own research, the significantly highest protein yield was guaranteed by the dose of 180 kg N ha^{-1} [Prusiński et al. 2016]. In turn, Cimrin et al. [2004] found that the triticale protein yield does not increase significantly anymore after application of 80 kg N ha^{-1}, which may indicate the significant role of thermal and humidity conditions, their distribution and the region of triticale cultivation on the protein yield.

Triticale grain shows a high variability of physical, chemical and milling characteristics caused mainly by weather conditions in the years and places of cultivation [Gil 2001], and in authors' own research also by the soybean forecrop and the method of its cultivation. The division of triticale grain weight into fractions resulted from significantly different amounts of rainfall and the soybean forecrop cultivation method. On the other hand, the accuracy of triticale grain did not differ significantly in the research years and was again significantly the highest after soybean grown using the reduced tillage and in strip-till method. However, only the application of 180 kg N ha^{-1} guaranteed the significantly highest thickness and accuracy of triticale grain, which was also indicated by Janowska-Miąsik [2015].

CONCLUSIONS

Growing soybean as a forecrop and the method of its cultivation had a significant impact on the yield of winter triticale grown as a successor crop, while its grain yield was mainly determined by the sum and distribution of atmospheric precipitation. The soybean forecrop cultivated in reduced tillage and in strip-till had a positive effect on the yield of triticale, as well as on the content and yield of protein. No significant differences in the yielding of winter triticale fertilized with doses from 60 to 180 kg N ha^{-1} probably resulted from different sums and rainfall dates in subsequent years and growing seasons.

The evaluated samples of triticale were characterized by high variability of the physical and milling characteristics of the grain. Due to very different water and thermal conditions in the research years, also the values of the triticale yield structural components were very diverse, and additionally significantly different from those obtained in other countries and continents.

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The source of funding: This study was made possible by a grant of the Polish Ministry of Agriculture and Rural Development. Project No. HOR 3.6.2.2016–2020. Development of soybean cultivation technology taking into account the regional conditions of the country.

Received: 09.05.2022
Accepted: 30.08.2022