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The after-effect of chosen Fabaceae forecrops on the yield of grain and protein in winter triticale (*Triticosecale* sp. Wittmack ex A. Camus 1927) fertilized with mineral nitrogen

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ABSTRACT

Two-way field experiment was carried out in a split-plot design in 4 growing seasons at the Experimental Station of the Bydgoszcz University of Science and Technology in Mochełek (Poland). The forecrops for winter triticale cv. Tulus were lupins: yellow, blue and white, field pea and spring barley. Nitrogen (N) fertilization in triticale after harvesting forecrops was: 0-60-120-180 kg N per ha. Average long-term yields of grain and protein in triticale after leguminous forecrops were statistically similar, by 0.84 t/ha and 86 kg/ha higher than after spring barley. On plots without mineral N fertilization, by over 1.5 t/ha more grain was obtained after leguminous forecrops, and by 142 kg/ha more protein than on the plot after spring barley. However, the rate of 180 kg N/ha guaranteed obtaining a significantly highest mean protein yield in triticale. The applied mineral N fertilization at rates from 60 to 180 kg N/ha did not significantly vary the average yield of winter triticale. Mineral nitrogen (N_{min}) content in the layer 0–60 cm after harvesting the leguminous forecrop without mineral N fertilization was by 25.5% higher than after harvesting spring barley fertilized with a rate of 60 kg N per ha.

Keywords: legume forecrops; macronutrient; weather conditions; cereals

The Fabaceae are considered as a perfect forecrop in cereal monocultures. Their main advantage is fixing nitrogen (N) in the soil and not depleting its resources for successively grown plants, as well as interrupting the life cycle of agents of many diseases, especially in cereals, owing to a wide ratio of carbon (C) to N of organic matter from the post-harvest residues left after harvest. Fabaceae plants root deeply, contributing to the cycle of nutrients and better use of water by successively grown plants (Evans et al. 2001, Siddique et al. 2012, Espinoza et al. 2015, Gan et al. 2015), and decreasing their dependence of yielding on inorganic N (Williams et al. 2014), especially under conditions of reduced mineral N fertilization (Reckling et al. 2014, Preissel et al. 2015). Most of N fixed by leguminous plants is removed with yield (Hauggaard-Nielsen et al. 2009, Kalembasa et al. 2014), however the remaining part becomes available for the successively grown plants (Armstrong et al. 1997, Evans et al. 2001, Wysokinski et al. 2014), owing to which protein yield in grain of successively grown cereal plants may also be significantly higher (Gan et al. 2015).

The aim of the conducted research was to determine the effect of selected leguminous forecrops on the grain and protein yield of winter triticale under nitrogen mineral fertilization.

MATERIAL AND METHODS

Study site and experimental design. The 2-way field experiment was carried out in a split-plot design in 4 growing seasons (2011/2012–2014/2015) at the Experimental Station of the University of Science and Technology in Mochelek (53°13'N, 17°51'E) on lessive soil of a very good and good

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rye complex, of a slightly acidic reaction, and of an average to high content of phosphorus (P) and potassium (K) and a very low to low content of manganese (Mg).

The first factor were forecrops for winter triticale: conventional lupin cultivars: yellow Mister, blue Zeus and white Butan, as well as pea Tarchalska and spring barley Stratus from the Polish register of cultivars. Each time, the forecrop for their cultivation were cereals, after which Roundup 360 SL was used each year in autumn at a rate of 2 L/ha. Mineral fertilization at rates of 60 kg P and 80 kg K was applied in spring before preparing the seedbed. A rate of 60 kg N/ha was applied once in spring only before sowing spring barley; no nitrogen was applied under leguminous plants. After harvesting forecrops and carrying out necessary post-harvest and pre-sowing tillage treatments, two-way field experiments were set up with a successively grown plant – winter triticale cv. Tulus sown in the years 2011–2014. The area of plot was 24 m^2. The second factor, fertilization rates of nitrogen (50% $N\text{-}NO_3^-\text{-}N$ and $N\text{-}NH_4^+\text{-}N$ in ammonium saltpetre) for triticale were as follows: 0 kg N (control); 60 kg N/ha (at 28 BBHC); 120 kg N/ha (second rate of 60 kg at 31 BBCH), and 180 kg N/ha (the third rate of 60 kg at 51 BBCH). Row spacing was 12.5 cm, sowing depth 2–3 cm, and the assumed plant density after emergence was 450 plants. Legato Plus 600 SC (1.5 L/ha) was applied on mono- and dicotyledonous weeds, which generally worked very well and there was no need to use any additional cultivation measures in spring, except 2012, when also Huzar Activ 376 OD (0.85 L/ha) was applied.

Sampling and analysis. The N content in grain was determined with the Kjeldahl method with the use of furnace for mineralization and Buchi distiller, and semi-automatic titration with the use of Easy titrator. N_{min} content was determined according to the Polish Agrochemical Soil Analysis (Anonymous 1997).

Meteorological conditions. Conditions of triticale growth and development in autumn in all research years were generally beneficial. While it is true that absolute minima of temperature in successive dormancy seasons were high: –24.1, –18.5, –14.4 and –13.5°C, triticale plants survived winter dormancy well, owing to a several-centimetre layer of snow. Favourable moisture conditions in 2012, 2013 and 2014 (bit less in June and July) spring-summer seasons covered the demand for water of the plants during flowering and pods setting. However extremely dry vegetation season was observed in 2015, which contributed to the lowest triticale seed yield obtained throughout the test cycle.

Statistical analysis. Statistical calculations were made with the use of programme ANALWAR – 5.3 FR (Bydgoszcz, Poland). The obtained results were subjected to 2-way analysis of variance in a split-plot design. Significance of differences was verified with the use of the Tukey's test with P = 95%. Means in tables denoted by the same letters for each factor did not differ significantly.

RESULTS AND DISCUSSION

The results indicate that the weather conditions as well as the applied factors affected significantly the yield of triticale (Table 1). Analysis of Fisher's orthogonal contrasts showed that grain yield of triticale not fertilized with mineral N was in 56.3% determined by the used forecrops, and in 43.7% by weather conditions in the growing season. In case of using mineral N, weather conditions in the spring-summer growing season determined the yield of triticale to even a higher degree – up to 92.4%, and the proportion of forecrops and N rates in its variation was little. On the other hand, protein yield in triticale grain not fertilized with mineral N did not significantly depend on weather conditions in the research years, and was up to 82.6% determined by the applied forecrops. Janusauskaite (2013) found similar correlations

Table 1. The effect of years and applied factors on the yield of seeds and protein in winter triticale

Source of variation	Degrees of freedom	Seed yield	Protein yield
		F-ratio	*F*-ratio
0 kg N/ha			
Harvest year	3	14.3* (43.7%)	1.80^{ns}
Forecrop	4	18.4* (56.3%)	8.52* (82.6%)
60-120-180 kg N/ha			
Harvest year	3	146.2* (92.4%)	45.4* (52.8%)
Forecrop	4	11.01* (6.95%)	4.91* (5.70%)
N fertilization	2	1.08^{ns}	35.6* (41.5%)

*P = 95%; ns – non significant

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Table 2. The yield of winter triticale cv. Tulus depending on the forecrop and nitrogen (N) fertilization (t/ha, mean for 2012–2015)

Forecrop (A)	N dose (kg/ha, B)				Mean
	0	60	60 + 60	60 + 60 + 60	
Yellow lupin cv. Mister	5.81	6.46	6.33	6.22	6.21[A]
Narrow-leaved lupin cv. Zeus	5.71	6.06	6.24	6.36	6.09[A]
White lupin cv. Butan	5.25	6.13	6.43	6.12	5.99[A]
Pea cv. Tarchalska	5.34	6.07	6.01	6.31	5.93[A]
Mean for legumes	5.53	6.18	6.25	6.25	6.05
Spring barley Stratus	3.97	5.58	5.37	5.91	5.21[B]
Mean	5.22[b]	6.06[a]	6.08[a]	6.18[a]	5.88

Means denoted by the same letters for each factor did not differ significantly. *LSD* for interaction B/A = 0. 625; A/B = 0.704

in spring triticale fertilized with four N rates – however, weather conditions determined the grain yield to a slightly lesser degree (45.1%) than N doses (54.9%).

The average long-term grain yield of winter triticale cv. Tulus was 5.88 t/ha (Table 2), similarly as in the field experiments of other authors in various European countries (Alaru et al. 2004, Buraczyńska and Ceglarek 2009, Lalević and Biberdžić 2015), or e.g. in Asia (Mut et al. 2005, Saglam and Ustunalp 2014). The applied forecrops did not significantly vary the grain yield of winter triticale, which – irrespective of the N rates – was 6.05 t/ha, i.e. significantly by 840 kg/ha higher (16.1%) than after spring barley (5.21 t/ha). A significant increase in the grain yield in cereals cultivated after leguminous forecrops was also observed by Gan et al. (2015) by 0.80 t/ha, Buraczyńska and Ceglarek (2009) by 1.1 t/ha and Preissel et al. (2015) by 1.5–1.6 t/ha. It should be emphasized that along with deterioration in humidity conditions in the growing seasons, especially 2015, this difference at level 0 N was up to 1.88–1.93 t/ha (by 43.5% and 54.9%), which confirms a better use of water by successively grown plants after leguminous forecrops, than after cereals (Evans et al. 2001, Siddique et al. 2012, Espinoza et al. 2015, Gan et al. 2015).

The most beneficial effect of leguminous forecrops on the yield of triticale was observed on the plot with no mineral N fertilization (by 1.55 t/ha), and the lowest when a rate of 180 kg N/ha was applied (by 0.34 t/ha) (Figure 1). Reckling et al. (2014) think that higher yield of successively grown plants after leguminous forecrops is obtained under conditions of reduced N fertilization. After these forecrops, an increase in the grain yield of triticale along with applying increasing N rates was on average 700 kg/ha (12.6%).

To obtain the highest triticale grain yields, rates from 90 kg N/ha (Alaru et al. 2004) to 120 kg N/ha (Saglam and Ustunalp 2014) or even to 180 kg N/ha (Mut et al. 2005) should be applied. Lalević and Biberdžić (2015) found an increase in the grain yield in triticale cultivated after other cereal plants along with an increase in the N rate from 0 to 120 N/ha by 1646 kg/ha. In our experiment, an increase in the N rate under triticale cultivated after spring barley enabled obtaining a grain yield higher on average by 41.5% compared with the

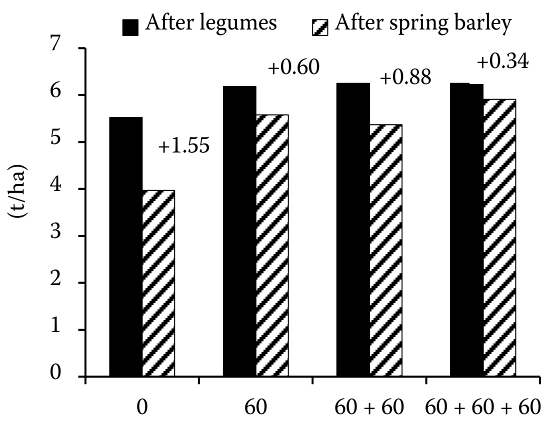

Figure 1. Differences in the grain yield of triticale cultivated after leguminous forecrops and spring barley depending on the nitrogen (N) rate under triticale, $P = 95\%$

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Table 3. The total protein yield in winter triticale cv. Tulus cultivated after 5 forecrops (kg/ha, mean for 2012–2015)

Forecrop (A)	N dose (kg/ha, B)				Mean
	0	60	60 + 60	60 + 60 + 60	
Yellow lupin cv. Mister	476	571	596	660	576^{A}
Narrow-leaved lupin cv. Zeus	487	547	631	658	581^{A}
White lupin cv. Butan	441	534	576	661	553^{A}
Pea cv. Tarchalska	457	541	623	701	581^{A}
Mean for legumes	465	548	606	670	573
Spring barley Stratus	323^{c}	477^{b}	495^{b}	652^{a}	487^{B}
Mean	437^{c}	534^{b}	584^{b}	666^{a}	555

Means denoted by the same letters for each factor did not differ significantly. *LSD* for interaction B/A = ns; A/B = ns

plot 0 N, similarly (by 35.7%) as in the studies of Janusauskaite (2013).

The total protein content in the grain of triticale cv. Tulus was on average 10.6%. Mineral N rate, similarly as in the studies of Cimrin et al. (2004), did not significantly vary the content of N in grain, although more protein in cereal grain under increasing N rates was observed by many authors (Alaru et al. 2004, Cimrin et al. 2004, Mut et al. 2005). According to Armstrong et al. (1997) in the grain of wheat cultivated after white and blue lupin, the content of N was even by 20% higher than when the forecrop was spring barley. The average protein yield in triticale grain was 555 kg/ha (Table 3), and after spring barley it was significantly the lowest (487 kg/ha), whereas after leguminous forecrops it was on average 573 kg/ha. An increase in the protein yield by 127.5 kg/ha in the grain of cereals cultivated after leguminous forecrops was also observed by Gan et al. (2015). The most beneficial effect of leguminous forecrops on the protein yield in triticale was observed on the plot with no mineral N fertilization (an increase by 142.5 kg/ha), and the lowest, when 180 kg N/ha was applied (by 18 kg/ha) (Figure 2).

Every year after harvesting forecrops and winter triticale, mineral N content was determined in the soil profile 0–60 cm (Table 4). The average content of N_{min} in the layer 0–60 cm after harvesting leguminous forecrops not fertilized with mineral N amounted to 84.1 kg N/ha, and was by 25.5% higher than after spring barley (67 kg N/ha), in spite of the fact that each time before sowing it, a rate of 60 kg N/ha was applied. Most N_{min} in the studied profile was found after harvesting yellow lupin cv. Mister (91.7 kg N/ha) and field pea cv.

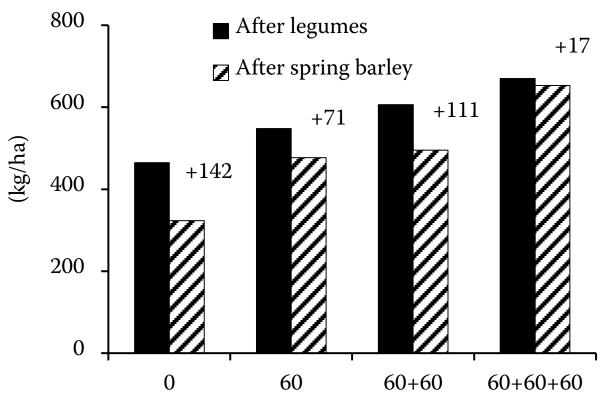

Figure 2. Difference in the protein yield in the grain of triticale cultivated after leguminous forecrops and spring barley depending on the nitrogen (N) rate under triticale, *P* = 95%

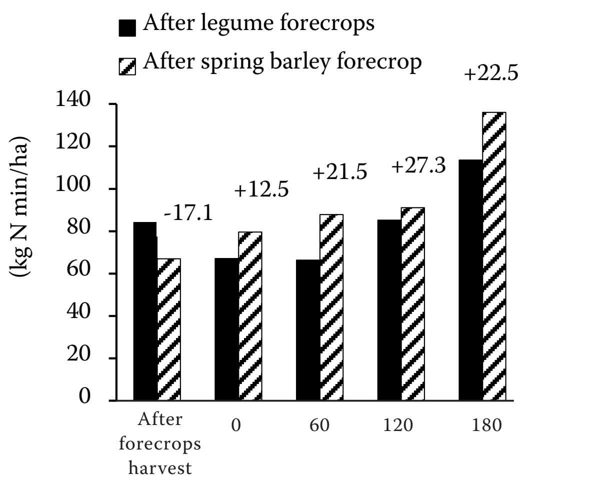

Figure 3. Differences in the content of N_{min} in the layer of 0–60 cm after harvesting forecrops and after winter triticale depending on the nitrogen (N) rate, *P* = 95%

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Table 4. Content of mineral nitrogen (N, kg N/ha) in the layer of 0–60 cm after harvesting forecrops and winter triticale

Forecrop	After forecrop harvest (2011–2014)	N dose after triticale harvest (2012–2015, kg/ha)				Mean
		0	60	120	180	
Yellow lupin cv. Mister	91.7	63.9	69.0	81.4	116	82.5
Narrow-leaved lupin cv. Zeus	71.8	75.4	70.4	109	114	92.2
White lupin cv. Butan	73.3	57.5	58.8	76.8	117	77.5
Pea cv. Tarchalska	99.8	71.8	67.1	73.6	107	79.9
Mean for legumes	84.1	67.1	66.3	85.2	113.5	82.8
Spring barley Stratus	67.0	79.6	87.8	91	136	98.6
Mean	80.7	69.6	70.6	86.4	118	86.1

Tarchalska (99.8 kg N/ha), which practically enabled obtaining similar triticale yields, however with a lower use of mineral N as in the case of other species (Evans et al. 2001, Siddique et al. 2012, Williams et al. 2014, Espinoza et al. 2015, Gan et al. 2015). The difference in the content of N_{min} left after triticale cultivated after spring barley and leguminous forecrops along with an increase in N rates was only 21.5, 5.80 and 22.5 kg N/ha, respectively (Figure 3). Gan et al. (2015) found that the amount of N_{min} in the profile 0.1–1.0 m left after harvesting durum wheat cultivated after cereals fertilized with mineral N was 55.4 kg N/ha, and after field pea 54.6 kg N/ha. Yellow lupin plants use from over 50% N (Kalembasa et al. 2014) to 70–75%, and pea 50–60% N derived from symbiosis (Hauggaard-Nielsen et al. 2009), but from 20.9% of N (Wysokiński et al. 2014) to 20.5–33.0% (Gan et al. 2015) is used by cereals cultivated after leguminous plants.

In conclusion, leguminous forecrops left significantly more N_{min} in the soil profile than spring barley, which was fertilized before sowing with a rate of 60 kg N/ha. The average long-term grain yield of winter triticale cv. Tulus was 5.88 t/ha, and after leguminous forecrops it was similar, on average by 0.84 t/ha higher than after spring barley. This difference at the level 0 of N fertilization together with the deterioration of humidity conditions was up to 1.88–1.93 t/ha (by 43.5% and 54.9%). The applied mineral fertilization with N rates from 60 to 180 kg N/ha did not significantly vary the average grain yield of winter triticale. On plots without mineral N fertilization after leguminous forecrops, by 1.56 t/ha more grain was obtained and by 142.2 kg/ha more protein than on the plot after spring barley. Under conditions of low-intensity farming with no or low rates of the applied N, cereal cultivation after leguminous plants guarantees obtaining at least average yields of winter triticale, whereas applying higher than 60 kg N/ha has no justification. The content of N_{min} in the layer of 0–60 cm after harvesting leguminous forecrops fertilized with mineral N was by 25.5% higher than after harvesting spring barley, under which 60 kg N/ha was applied before sowing.

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