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Spring triticale yield formation and nitrogen use efficiency as affected by nitrogen rate and its splitting

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Abstract

Little information exists on the pattern of nitrogen (N) uptake, remobilization and N use efficacy in spring triticale. The study was aimed to determine the effect of N rates and application regimes on the yield, yield components, as well as to ascertain optimal N fertilization regime for spring triticale. The study was based on the experiment carried out at the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry in Central Lithuania on an *Endocalcari-Endohypogleyic Cambisol* (*CMg-n-w-can*) during the period 2008–2011. The data were analysed using *ANOVA* method. Nitrogen was applied as basic fertilization (N_{60-180}) shortly before sowing, and N_{90}, N_{150} rates were split in two or three applications. Grain yield, yield components (ears m^{-2}, grains ear^{-1}, productivity g ear^{-1}, and thousand grain weight), grain protein content and nitrogen use efficiency (NUE) were investigated.

The analysis of variance of the data averaged over the four experimental years showed that experimental year significantly ($P \leq 0.01$, $P \leq 0.05$) influenced all the tested parameters on both basic fertilization backgrounds and N splitting treatments. The influence of N rate on the investigated parameters was significant ($P \leq 0.01$, $P \leq 0.05$) on basic fertilization backgrounds almost in all the cases; however, the influence of N splitting regime on the yield and yield components was insignificant. N splitting significantly ($P \leq 0.01$) influenced protein content and all indices of NUE. Fertilization increased the grain yield by 35.7%, compared with the unfertilized control treatment. The N_{90-120} rate was found to be economically and ecologically optimal for spring triticale. It resulted in the highest (4.81–4.92 Mg ha^{-1}) grain yield.

Key words: fertilization, grain yield, nitrogen regime, spring triticale, yield components.

Introduction

Triticale (× *Triticosecale* Wittm.) is the first man-made crop. It was designed in order to obtain a cereal, which combines good quality grain yield from wheat parent with tolerance to abiotic and biotic stress (Villegas et al., 2010). Triticale is often reported to be an interesting crop for unfavourable conditions where productivity of common crops is more or less limited (Ugarte et al., 2007; Estrada-Campuzano et al., 2008). Modern triticale cultivars show higher yields and superior adaptation to soil quality and environments than wheat (Erekul, Köhn, 2006; Ugarte et al., 2007; Estrada-Campuzano et al., 2012). One of the most important crop management techniques for spring triticale production is N fertilization (Gülmezoglu, Kinaci, 2004; Janušauskaitė, 2009; Knapowski et al., 2009; Zečevic et al., 2010). Many authors have reported positive effect of N fertilization on grain yield (Gibson et al., 2007; Lestingi et al., 2010). Grain yield can be analyzed in terms of three primary yield components – number of productive ears per unit of land area, grains ear^{-1} and thousand grain weight (TGW). Nitrogen is the most important yield-boosting nutrient. It affects final grain yield through the influence on the formation of yield components during the whole growing season. Both N rates and application time are important to the development of yield components (Weber et al., 2008; Pecio, 2010). The optimal timing of N application increased grain yield and protein content (Kara, Uysal, 2009; Lestingi et al., 2010). However, Gibson et al. (2007) found that N application at a rate higher than 33 kg ha^{-1} reduced triticale grain yield. The impact of N fertilizers on cereal yield, yield components and grain quality depends not only on the fertilization strategy but also on the weather conditions (Janušauskaitė, Šidlauskas, 2004; Gibson et al., 2007; Pecio, 2010).

The crops were found to utilize the split rates differently depending on the time of additional fertilization. The uptake of N derived from the first N rate applied at the beginning of spring growth was poorer than that from the second splitting rate applied at stem elongation or third splitting rate applied at ear emergence (Sieling, Beims, 2007). In contrast, N applied later in the growing season was taken up more quickly, resulting in higher fertilizer NUE. Growing environments (i.e. soil available N, soil moisture and temperature), genotypes and agronomic management all influence how efficiently fertilizer N is utilized by the crops. There has been extensive research on the timing and rates of N application in spring triticale (Pecio, 2010; Aranjuelo et al., 2012). Predominantly N fertilizer is applied to spring triticale prior to sowing (Mut et al., 2005; Zečevic et al., 2010). Nitrogen stress at critical growth stages may lead to irreversible yield loss (Ewert, Honermeier, 1999; Estrada-Campuzano et al., 2008).

Understanding the fertilization effect has been a continuous endeavour toward improving fertilization technology and strategy to reduce the negative impacts to increase the crop yield. Nevertheless, the effect of N fertilization on spring triticale has not been extensively studied. In particular, insufficient information is available about the effect of applying different levels of N and N partitioning on yield and yield components. The objective of this study is to determine the effect of different N rates and application regimes on yield, yield components, and to identify optimal N fertilization regime for spring triticale.

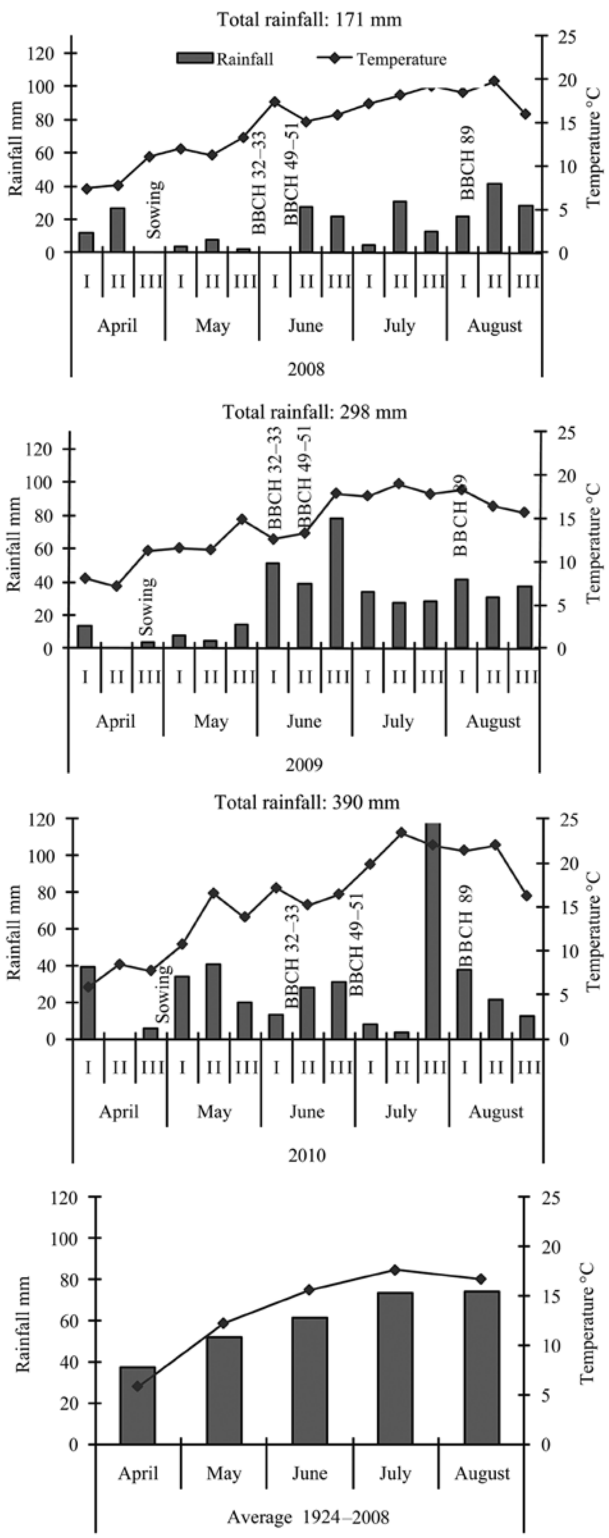
Materials and methods

Site and soil properties. The field experiment was carried out in 2008–2011 at the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry in Central Lithuania (55°23′50″ N, 23°51′40″ E) on an *Endocalcari-Endohypogleyic Cambisol* (*CMg-n-w-can*) (FAO, ISRIC and ISSR, 1998). Chemical soil properties are provided in Table 1.

Table 1. Chemical soil properties

Year	Properties			
	pH_{KCl}	P_2O_5 mg kg^{-1}	K_2O mg kg^{-1}	N_{min} kg ha^{-1}
2008	6.1	150	142	43
2009	6.5	102	142	55
2010	5.5	98	148	33
2011	6.7	168	133	58

Weather conditions. Figure shows rainfall and mean air temperature at the experimental site (Dotnuva weather station located about 500 m from the experimental field) over the 4-year study. Rainfall varied considerably between years. The growth period in 2008 was dry; the total amount of rainfall from beginning of April to harvest was 170 mm, or 68% of the long-term mean. 2009 and 2011 were wetter and the total amount of rainfall amounted to 298 mm and 262 mm, respectively, or was by 19% and 4% higher than the long-term mean. 2010 was the wettest year, the amount of rainfall from the beginning of April to harvest totalled 390 mm, or was by 56% higher, compared to the long-term mean. The differences in temperature between the four experimental years were relatively modest (Fig.). The mean air temperature in 2008 and 2009 was similar to the long-term mean. However, in 2010 and 2011 the mean temperature during the growing season was 0.7–1.4, 0.6–2.4, 3.0–4.0 and 0.6–3.1 °C above the long-term mean in May, June, July and August, respectively.



N timing – at sowing, stem elongation (BBCH 32–33), end of booting – beginning of heading (BBCH 49–51) and triticale harvesting time (BBCH 89)

Figure. Rainfall and temperature distribution during the growing season

Treatments and agronomic management. A pre-crop was spring barley in all experimental years. The spring triticale 'Nilex' was sown to a depth of 4–5 cm, with 13 cm between the rows and a density of 4 million viable seeds per hectare. The harvested area per plot amounted to 20.4 m^{-2}. According to the nutrient status in the soil, $P_{66}K_{130}$ fertilization was applied for all treatments shortly before triticale sowing. Phosphorus and potassium were applied in the form of granulated superphosphate (20% P_2O_5) and potassium chloride (60% K_2O), respectively. All fertilizers applied before sowing were incorporated into the soil. The N fertilizer as ammonium nitrate (34% N) was applied shortly before sowing in five treatments as basic fertilization (N1): 60 (N_{60}), 90 (N_{90}), 120 (N_{120}), 150 (N_{150}) and 180 (N_{180}) kg ha^{-1} and a control plot receiving zero N (N_0); the rates of N_{90} and N_{150} were also split (N2) in the amounts $N_{60} + N_{30}$ and $N_{90} + N_{30} + N_{30}$, respectively, and applied before sowing + at stem elongation (BBCH 32–33) and before sowing + at stem elongation (BBCH 32–33) + at the end of booting – beginning of heading (BBCH 49–51), respectively.

The experiment was designed as a randomized complete block with four replications. Fertilizer application dates and pesticides applied during the growing season are indicated in Table 2. The growth stages of spring triticale were recorded following Meier (2001). The number of ears per m^2 was determined on plant samples collected from 100-cm-long sections of two rows (0.52 m^2) from each plot at physiological maturity. The number of grains per ear and productivity per ear (g) were established on 10 main stems. Each year, the plots were harvested within the first ten-day period of August at complete maturity (BBCH 89) with a plot harvester "Wintersteiger Delta" (Germany). The harvested area of triticale plots was 20 m^2. Grain yield as t ha^{-1} was calculated at 15% moisture content. Thousand grain weight (TGW) was calculated with a seed counter "Contador" (Germany) from the samples selected after harvesting. Grain protein content from each plot was measured using the grain analyser Infratec 1241 (Denmark).

Table 2. Dates of additional nitrogen fertilization and pesticide application

	2008	2009	2010	2011
Sowing	21 April	16 April	27 April	20 April
Emergence	30 April	24 April	7 May	27 April
Stem elongation (BBCH 32–33) (1st additional fertilization)	30 May	1 June	7 June	6 June
End of booting – beginning of heading (BBCH 49–51) (2nd additional fertilization)	10 June	11 June	29 June	8 June
Maturity (BBCH 89)	10 August	10 August	8 August	5 August
Herbicide	MCPA + Grodyl 75 WG (a.i. MCPA 500 g l^{-1} + amidosulfuron 750 g kg^{-1}) 1.3 l ha^{-1} + 0.030 kg ha^{-1}			
Fungicide	Archer Top 400 EC (a.i. propiconazole 125 g l^{-1} + fenpropidin 275 g l^{-1}), 1.0 l ha^{-1} Falcon 460 EC (a.i. tebuconazole 167 g l^{-1} + triadimenol 43 g l^{-1} + spiroxamin 250 g l^{-1}), 0.6 l ha^{-1}	Falcon 460 EC (a.i. tebuconazole 167 g l^{-1} + triadimenol 43 g l^{-1} + spiroxamin 250 g l^{-1}), 0.6 l ha^{-1}		Input 460 EC (a.i. protioconazole 160 g l^{-1} + spiroxamin 300 g l^{-1}), 1 l ha^{-1}
Insecticide	Karate Zeon 5 CS (a.i. lambda-cihalotrin), 0.20 l ha^{-1}	–	Fastac 50 (a.i. alfa-cipermetrin 50 g l^{-1}), 0.2 l ha^{-1}	–

Soil analyses. Soil samples were collected prior to spring triticale sowing, to a depth of 0–25 cm for pH_{KCl}, P_2O_5, K_2O content and to a depth of 0–40 for mineral nitrogen (N_{min}) content. Soil pH_{KCl} was established in KCl 1 M, w/v 1:2.5, available P_2O_5 and K_2O were measured by ammonium lactate extraction (A-L method) (Egner et al., 1960). N_{min} ($N\text{-}NO_3 + N\text{-}NH_4$) was determined: $N\text{-}NO_3$ – ionometrically, $N\text{-}NH_4$ – spectrophotometrically.

Different nitrogen use efficiency (NUE, kg kg^{-1} N) was calculated for each treatment:

$NUE_{yield} = (Yield_N - Yield_{N0}) / N_x$, where $Yield_N$ is grain yield (kg ha^{-1}) from nitrogen (N) fertilized treatments, $Yield_{N0}$ – grain yield in unfertilized treatment, and N_x – nitrogen input (N_{60}, N_{90}, N_{120}, N_{150}, N_{180}, kg ha^{-1} N);

NUE_{prot} (mg in 100 g DM^{-1} kg N) was calculated according to the formula:

$NUE_{prot} = (PROT_N - PROT_{N0}) / N_x$, where $PROT_N$ is grain protein content (%) in N fertilized treatments, $PROT_{N0}$ – grain protein content in unfertilized treatment, N_x – nitrogen input (N_{60}, N_{90}, N_{120}, N_{150}, N_{180}, kg ha^{-1} N). Grain protein content in dry matter was calculated by multiplying the total nitrogen (after Kjeldahl) by a coefficient 5.7.

$NUE_{prot\ yield}$ (kg kg^{-1} N) was calculated according to the formula:

$NUE_{prot\ yield} = (PROT\ YIELD_N - PROT\ YIELD_{N0}) / N_x$, where $PROT\ YIELD_N$ is grain protein yield (kg kg^{-1} N) in N fertilized treatments, $PROT\ YIELD_{N0}$ – grain protein yield in control treatment, N_x – N rate (N_{60}, N_{90}, N_{120}, N_{150}, N_{180}, kg ha^{-1}).

Statistical analysis. Analysis of variance was performed using the *ANOVA* statistical package with two-way factors, N regime and year, to establish the treatment effects. Treatment means were compared using Fisher's protected least significant difference (LSD) test at $P \leq 0.05$. Contrasts were used to determine the effect of fertilization rates on yield, yield components, grain protein and nitrogen use efficiency. The Fisher's LSD ($P \leq 0.05$, $P \leq 0.01$) test was used to estimate significant treatment effects.

Results and discussion

Impact of basic fertilization on yield, yield components and protein content. Grain yield. The analyses of variance showed that basic fertilization rates were the main factor determining the differences between treatments (54.9%) and the influence of N rate was significant for yield at $P \leq 0.01$ (Table 3). Year significantly ($P \leq 0.01$) influenced grain yield, but explained 9.6% of the total variability of yield on basic fertilization backgrounds. Effect of year × N rate interaction was significant at $P \leq 0.01$ and explained 13.0% of the total variability of yield. The highest grain yield was obtained in 2011 (8.5% higher than the trial mean) (Table 4), when the total amount of rainfall was close to the long-term mean and was more-or-less evenly distributed throughout the growing season (Fig.). The lowest productivity of triticale (4.0% lower than the trial mean) was noted in 2010. Basic fertilization and N splitting significantly increased grain yield. Fertilization resulted in 35.7% higher yield compared with the control treatment. The mean effect of all fertilization rates on the yield was significant. Grain yield increased in line with N rate increasing up to N_{120}. However, the grain yield differences between N_{90} and N_{120} were not significant (0.11 Mg ha^{-1}).

Table 3. Mean squares (percentage of the sum of squares in parenthesis) and significant effects of year, N rates and N splitting on grain yield, ears m^{-2}, grains ear^{-1}, productivity g ear^{-1}, thousand grain weight (TGW) in spring triticale crop over four years

Source	DF	Grain yield Mg ha^{-1}	Ears m^{-2}	Grains ear^{-1}	Productivity g ear^{-1}	TGW g
Year (Y)	3	1.40** (9.6)	59009** (21.9)	1203** (31.7)	0.395** (17.4)	165.56** (81.0)
N rate (N1)	5	4.79** (54.9)	31577** (19.6)	146** (6.4)	0.060 ns (4.4)	2.14* (1.7)
Y × N1	15	0.38** (13.0)	10019** (22.3)	106** (14.1)	0.081 ns (17.9)	2.89** (7.1)
Year (Y)	3	1.98** (39.8)	38517** (25.6)	414** (19.5)	0.230 ** (19.3)	112.3 ** (89.2)
N splitting (N2)	3	0.12 ns (2.5)	7810 ns (5.2)	49 ns (2.3)	0.042 ns (3.5)	1.64* (1.3)
Y × N2	9	0.14 ns (8.4)	7421 ns (14.8)	66 ns (9.3)	0.086 ns (21.8)	1.08 ns (2.6)

DF – degrees of freedom; *, ** – significant at the $P \leq 0.05$ and $P \leq 0.01$ probability level, respectively; ns – not significant

The differences in triticale grain yield between the experimental years resulted from the weather conditions. This finding was confirmed by the studies of other researchers (Gülmezoglu, Kinaci, 2004; Marton, 2008; Janušauskaitė, 2009; Pecio, 2010). Alaru et al. (2009) showed that the greatest influence on grain yield formation was exerted by the trial year ($P < 0.001$) followed by N regimes ($P < 0.01$). Significant difference in triticale grain yield was also indicated by Kinaci and Gülmezoglu (2007). High variation of weather conditions reflected in grain yield of spring triticale and in effects of N fertilization was established by Koziara et al. (2007). In the present study, we also found significant influence of year on grain yield ($P \leq 0.01$). The highest grain yield was possible due to favourable moisture conditions during the whole growing period and smaller productivity of triticale resulted from worse moisture conditions (Pecio, 2010). In the present study, the highest grain yield (5.11 Mg ha^{-1}) was obtained in the year with rainfall content close to the long-term mean (262 mm) and even distribution of rainfall during the growing season. In contrast to the data of Pecio (2010), the lowest grain yield (4.52 and 4.54 Mg ha^{-1}) was obtained in the wet experimental years (390 and 298 mm during the growing season, respectively), when rainfall distributed unevenly and the largest part of it fell as torrential rains in July and June, respectively.

The yield-augmentation effect of N was found in the studies of many authors (Sekeroglu, Yilmaz, 2001; Koziara et al., 2007; Ghobadi et al., 2010, Estrada-Campuzano et al., 2012). In the study of Pecio (2010), it was found that grain yield of spring triticale increased with increasing N rates up to $N_{90\text{-}120}$. Knapowski et al. (2009) also indicated that the highest grain yield was achieved by N_{120} application. Mut et al. (2005) concluded that N rates should be between N_{120}–N_{180}. Ghobadi et al. (2010) indicated that in semiarid regions the upper limit of nitrogen is N_{175}. In our study, the peak values of the yield and the essential differences between treatments were obtained when fertilization rates reached N_{90}. However, in order to increase grain protein, especially if triticale is grown for feed, N_{120} is a more suitable rate.

Yield components. The ears m^{-2} was significantly ($P \leq 0.01$) influenced by year, N rate and year × N rate interaction (Table 3). The impact of all factors on the ears m^{-2} was almost identical; year, N rate and their interaction explained 21.9, 19.6 and 22.3 % of ear m^{-2} total variability, respectively. Stand density depended on the weather conditions of the experimental year. The highest values of ears m^{-2} (433) was recorded in 2011 (10.2% higher than the trial mean) and the lowest (315) ears m^{-2} was recorded in 2010 (19.8% lower than the trial mean) (Table 4). Fertilization resulted in 31.1% higher

Table 4. Grain yield and yield components of spring triticale as affected by year and N fertilization

Source	Grain yield Mg ha^{-1}	Ears m^{-2}	Grains ear^{-1}	Productivity g ear^{-1}	Thousand grain weight g
Year[a]					
2008	4.69 b	420 a	49 a	1.16 c	41.2 a
2009	4.54 c	403 b	45 c	1.44 a	38.1 c
2010	4.52 c	315 c	54 a	1.37 b	35.0 c
2011	5.11 a	433 a	42 c	1.24 b	39.5 a
Trial mean	4.71	393	48	1.30	38.5
N fertilization[b]					
N_0	3.59 b	309 b	44 b	1.20 b	39.2 b
N_{60}	4.53 a	369 a	46 b	1.36 b	38.2 c
N_{90}	4.81 a	396 a	49 a	1.32 b	38.5 c
N_{120}	4.92 a	425 a	50 a	1.31 b	38.5 c
N_{150}	4.93 a	377 a	46 b	1.37 a	38.3 c
N_{180}	5.09 a	431 a	49 a	1.34 b	38.8 b
$N_{60} + N_{30}^{c}$	4.84 a	405 a	48 a	1.25 b	38.4 c
$N_{90} + N_{30}^{c} + N_{30}^{d}$	5.01 a	430 a	47 b	1.28 b	37.8 c
Mean of fertilized treatments					
	4.87	405	48	1.32	38.4
Contrasts: fertilization ($N_{60} + N_{90} + N_{120} + N_{150} + N_{180}$) *vs* no fertilization (N_0)					
	1.28**	96**	4*	0.12 ns	−0.8*
N_{60} *vs* N_{90}	0.28*	27 ns	3 ns	−0.04 ns	0.3 ns
N_{60} *vs* N_{120}	0.39**	56*	4*	−0.05 ns	0.3 ns
N_{60} *vs* N_{150}	0.40**	8 ns	0	0.01 ns	0.1 ns
N_{60} *vs* N_{180}	0.56**	62*	3 ns	−0.02 ns	0.6 ns
N_{90} *vs* N_{120}	0.11 ns	30 ns	1 ns	−0.01 ns	0 ns
N_{90} *vs* N_{150}	0.12 ns	−19 ns	−3 ns	0.05 ns	−0.2 ns
N_{90} *vs* N_{180}	0.28*	35 ns	0	−0.02 ns	0.3 ns
N_{120} *vs* N_{150}	0.01 ns	−48 ns	−4*	0.06 ns	−0.2 ns
N_{120} *vs* N_{180}	0.17 ns	6 ns	−1 ns	0.03 ns	0.3 ns
N_{150} *vs* N_{180}	0.16 ns	54*	3 ns	−0.03 ns	0.5 ns
Basic fertilization *vs* additional fertilization					
N_{90} *vs* $N_{60} + N_{30}^{c}$	0.03 ns	9 ns	−1 ns	0.07 ns	0.1 ns
N_{150} *vs* $N_{90} + N_{30}^{c} + N_{30}^{d}$	0.08 ns	53*	2 ns	0.09 ns	0.5 ns

Notes. [a] – different letters in column denote a statistically significant difference (at $P \leq 0.05$ according to LSD) between years' mean and trial mean; [b] – different letters in column denote a statistically significant difference (at $P \leq 0.05$ according to LSD) between fertilized treatments and unfertilized treatment; [c] – N splitting at stem elongation growth stage (BBCH 32–33); [d] – N splitting at the end of booting–beginning of heading (BBCH 49–51). *, ** – difference is significant at $P \leq 0.05$ and $P \leq 0.01$, respectively; ns – not significant.

ears m^{-2}, compared with the control treatment. Fertilizers significantly increased stand density in all the tested cases. The ears m^{-2} increased in proportion to N rates in the range N_{60}–N_{120}. The higher N rates did not have any significant effect on this parameter.

The grains ear^{-1} was significantly ($P \leq 0.01$) influenced by the experimental year and the year explained the largest part (31.7%) of total variability of grains ear^{-1} on basic fertilization backgrounds (Table 3). N rate and year × N rate interaction significantly ($P \leq 0.01$) influenced the grains ear^{-1}. N rate explained small part (6.4%) of the grain ear^{-1} variation and interaction of year × N rate explained 14.1%. The grains ear^{-1} differed between years. The greatest number of grains ear^{-1} (54 grains or 12.5% more than the trial mean) was obtained in wet year 2010. The lowest number of grains ear^{-1} (42 grains or 12.5% less than the trial mean) was established in 2011, in contrast to the highest values of grain yield and ears m^{-2} that year. In general, N fertilization resulted in 9.1% higher grain ear^{-1}, compared with the control treatment. However, significant differences were found only in 42% of the tested cases. Grain ear^{-1} significantly increased under basic application of N_{90}, N_{120} and N_{180}. Productivity g ear^{-1} was significantly ($P \leq 0.01$) influenced only by the year and this factor explained 17.4% of the total variability of productivity g ear^{-1} on basic fertilization backgrounds (Table 3).

The effect of N rate and year × N rate interaction on productivity g ear^{-1} was insignificant. The highest productivity g ear^{-1} (1.44 g) was obtained in 2009, when the total amount of rainfall (298 mm) from the beginning of April to harvesting was close to the long-term mean (Table 4). In dry 2008, when within the mentioned period as little as 170.6 mm rainfall fell, productivity g ear^{-1}

was the lowest (1.16 g or 10.8% less than the long-term mean). Fertilization determined 8.3% increase in productivity g ear^{-1}, but the differences between fertilized and unfertilized treatments were insignificant in almost all the tested cases. TGW was influenced by year and year × N rate interaction at $P \leq 0.01$. The influence of N rate on TGW was significant at $P \leq 0.05$ (Table 3). Year was a major factor responsible for TGW variability (81.0%), whereas year × N rate interaction determined 7.1% and N rate only 1.7% of the total variability. Unlike the productivity g ear^{-1}, the highest TGW (41.2 g) was obtained in 2008, and was 10.7% higher, compared with the trial mean. The values of TGW in fertilized treatment were significantly (by 2.0%) lower (with one exception – under N_{180} fertilization) than in the control treatment.

The problem of the share of yield components in final triticale grain yield is often addressed in scientific literature. Giunta and Motzo (2005) showed that the better performance of triticale was associated with higher number of spikes m^{-2} and grains spike^{-1}, with no clear advantage in average grain weight. The grain yield and yield components such as ears m^{-2} and grains ear^{-1} revealed significant negative differences under deficient moisture conditions, compared to sufficient moisture regime, but the grain weight was not statistically different under different moisture conditions (Villegas et al., 2010). Pecio (2010) indicated the most important role of the ear m^{-2} and the smallest contribution of TGW. However, the number of productive ears per unit area is the most variable yield component and is strongly affected by environmental conditions and N fertilization, while TGW seems to be a very stable yield component. The low contribution of TGW to grain yield is explained by strong competition between these and other yield components. In the present study, the most important yield components proved to be the ears m^{-2} and grain ear^{-1}. Both the mentioned yield components and the yield itself increased with N rate increasing up to N_{120}. TGW was less important in the process of grain yield formation. Similar data were reported in the study of Sekeroglu and Yilmaz (2001), where the highest ear number m^{-2}, grains ear^{-1}, grain weight ear^{-1} and the highest grain yield were observed for N_{120} application. The results of the present study are in conformity with the findings of Kozak et al. (2007) too, who reported that two major yield components are number of ears and number of grains per ear per unit area, and more effort should be put into a good stand shaped by means of agronomic treatments, particularly at tillering and stem elongation growth stages when formation of these yield components takes place.

Protein content. The analysis of variance revealed that grain protein content was significantly influenced ($P \leq 0.01$) by year, basic N fertilization rates and their interaction (Table 5). The year in large part (46.6%) explained the total variability and N rate explained a similar part (41.7%) of grain protein total variability. The year × N rate interaction was significant at $P \leq 0.01$; however, it explained only 5.0% of the total variability.

Table 5. Summary of *ANOVA* results (mean square values) (percentage of the sum of squares in parenthesis) for grain protein content, increases of grain yield (NUE_{yield}), of protein content (NUE_{prot}) and of protein yield ($NUE_{prot\ yield}$) of spring triticale

Source	DF	Grain protein content %	NUE_{yield} kg kg^{-1} N	NUE_{prot} mg in 100 g DM^{-1} kg N	$NUE_{prot\ yield}$ kg kg^{-1} N
Year (Y)	3	29.64** (46.6)	121** (8.7)	523** (18.6)	1.96** (7.9)
N rate (N1)	5	15.92** (41.7)	469** (55.9)	515** (30.5)	7.58** (50.9)
Y × N1	15	0.64** (5.0)	16 ns (5.7)	106** (18.8)	0.48 ns (9.7)
Year (Y)	3	16.06** (46.6)	181** (29.8)	590** (31.5)	3.12** (28.2)
N splitting (N2)	3	9.90** (32.6)	111** (18.2)	163* (8.7)	0.84 ns (7.6)
Y × N2	9	0.692** (6.8)	6 ns (3.2)	57 ns (9.1)	0.21 ns (5.8)

DF – degrees of freedom; DM – dry matter; *, **, significant at the $P \leq 0.05$ and $P \leq 0.01$ probability level, respectively; ns – not significant

The highest protein content in grain was obtained in dry 2008 and was by 8.6% higher than the trial mean (Table 6). Basic fertilization significantly increased protein content, which is consistent with the results obtained by other authors. Fertilization resulted in 15.8% higher protein content compared with unfertilized triticale. The mean effect of all fertilization rates on protein content was significant. Protein content increased in proportion to the N rates up to the highest rate N_{180}. Knapowski et al. (2009) have reported that an increase in N fertilization rate from N_{80} to N_{120} resulted in a significant 5.9% increase in protein content in the triticale grain. Sekeroglu and Yilmaz (2001) reported that the highest protein content was obtained for N_{80} application and further rate N_{120} did not increase protein content. The data of Mut et al. (2005) showed that protein content in triticale grain increased with up to $N_{120.}$

Nitrogen use efficiency (NUE). Year and N rates significantly ($P \leq 0.01$) influenced NUE_{yield}. The main factor determining the differences in NUE_{yield} between treatments (55.9%) was N rate (Table 5). The influence of year × N rate interaction on NUE_{yield} was insignificant. The highest NUE_{yield} (12.7 kg kg^{-1} N) was obtained in a sufficiently wet year 2011. As expected, increasing basic N fertilization rate decreased NUE_{yield}. Each N rate increasing by 30 kg decreased NUE_{yield} by 2.0 kg kg^{-1}

Table 6. Grain protein content and increases of grain yield (NUE_{yield}), protein content (NUE_{prot}) and protein yield ($NUE_{prot\ yield}$) of spring triticale as affected by year and nitrogen fertilization

Source	Grain protein content %	NUE_{yield} kg kg^{-1} N	NUE_{prot} mg 100 g DM^{-1} kg N	$NUE_{prot\ yield}$ kg kg^{-1} N
Year[a]				
2008	13.9 a	11.4 a	19.7 a	1.92 a
2009	13.5 a	9.4 b	6.5 c	1.27 c
2010	13.1 a	6.7 c	13.4 b	1.17 c
2011	11.4 c	12.7 a	11.7 b	1.61 b
Trial mean	13.0	10.1	12.8	1.49
N fertilization[b]				
N_0	11.4 b	–	–	–
N_{60}	12.0 a	15.5 a	10.1 b	1.88 a
N_{90}	12.5 a	13.5 a	11.9 b	1.77 a
N_{120}	13.0 a	11.0 b	13.5 b	1.60 b
N_{150}	13.7 a	8.9 b	15.7 b	1.50 b
N_{180}	13.9 a	8.3 b	14.2 b	1.41 b
$N_{60} + N_{30}$[c]	13.0 a	13.9 a	18.2 a	2.06 a
$N_{90} + N_{30}$[c] $+ N_{30}$[d]	14.3 a	9.4 b	19.1 a	1.71 b
Mean of all fertilized treatments				
	13.2	11.5	14.7	1.70
Mean of basic fertilized treatments ($N_{60} + N_{90} + N_{120} + N_{150} + N_{180}$)				
	13.0	11.4	13.1	1.63
Contrasts: fertilization ($N_{60} + N_{90} + N_{120} + N_{150} + N_{180}$) *vs* no fertilization (N_0)				
	1.8**[e]			
N_{60} *vs* N_{90}	0.5**	2.0 ns	1.8 ns	−0.11 ns
N_{60} *vs* N_{120}	1.0**	−4.5**	3.4 ns	−0.28 ns
N_{60} *vs* N_{150}	1.7**	−6.6**	5.6 *	−0.38 ns
N_{60} *vs* N_{180}	1.9**	−7.2**	4.1 ns	−0.47*
N_{90} *vs* N_{120}	0.5**	−2.5 ns	1.6 ns	−0.17 ns
N_{90} *vs* N_{150}	1.2**	−4.6**	3.8 ns	−0.27 ns
N_{90} *vs* N_{180}	1.4**	−5.2**	2.3 ns	−0.19 ns
N_{120} *vs* N_{150}	0.7**	−2.1 ns	2.2 ns	−0.10 ns
N_{120} *vs* N_{180}	0.9**	−2.7 ns	0.7 ns	−0.19 ns
N_{150} *vs* N_{180}	0.2 ns	−0.6 ns	1.5 ns	−0.09 ns
Basic fertilization *vs* additional fertilization				
N_{90} *vs* $N_{60} + N_{30}$[c]	0.5**	0.4 ns	6.3*	0.29 ns
N_{150} *vs* $N_{90} + N_{30}$[c] $+ N_{30}$[d]	0.6**	0.5 ns	3.4 ns	0.21 ns

Notes. [a] – different letters in column denote a statistically significant difference (at $P \leq 0.05$ according to LSD) between years' mean and trial mean; [b] – different letters in column denote a statistically significant difference (at $P \leq 0.05$ according to LSD) between fertilized treatments and unfertilized treatment; [c] – N splitting at stem elongation growth stage (BBCH 32–33); [d] – N splitting at the end of booting–beginning of heading (BBCH 49–51). *, ** – difference is significant at $P \leq 0.05$ and $P \leq 0.01$, respectively; ns – not significant.

N. Comparison of treatments showed that the highest values of NUE_{yield} (15.5 kg kg^{-1} N) were established by applying the lowest N_{60} rate. The lowest NUE_{yield} (8.3 kg kg^{-1} N) was determined under N_{180} fertilization. Like in the previous study where liquid NPK fertilizers were applied for spring triticale (Janušauskaitė, 2009), NUE_{yield} consistently decreased. Basic fertilization rates were the main factor determining (30.5%) the significant ($P \leq 0.01$) differences in NUE_{prot} between treatments (Table 5). Year and interaction between year and N rate also significantly ($P \leq 0.01$) influenced NUE_{prot}, but explained 18.6% and 18.8% of the total variability of NUE_{prot} on basic fertilization backgrounds. The highest NUE_{prot} (19.7 mg in 100 g DM^{-1} kg N), which was 53.9% higher than the trial mean, was obtained in a dry year 2008 (Table 6). Basic fertilization at N_{90}, N_{120}, N_{150}, N_{180} enhanced NUE_{prot} by 17.8, 33.7, 55.4 and 40.6 %, respectively, compared to the lowest N_{60} rate. $NUE_{prot\ yield}$ was significantly ($P \leq 0.01$) influenced by year and N rates, and N rate explained the main part (50.9%) of the total variability of $NUE_{prot\ yield}$ (Table 5). The year influence on $NUE_{prot\ yield}$ was significant ($P \leq 0.01$), but the year determined the differences in $NUE_{prot\ yield}$ between treatments only in 7.9%. The influence of year × N rate interaction on $NUE_{prot\ yield}$ was insignificant. The meteorological conditions influenced the $NUE_{prot\ yield}$. The highest (1.92 kg kg^{-1} N) $NUE_{prot\ yield}$ was obtained in a dry year 2008, and the lowest (1.17 kg kg^{-1} N) in a wet year 2010. The highest $NUE_{prot\ yield}$ was 1.88 kg kg^{-1} N for the lowest N_{60} rate of basic fertilization, whereas N_{90}, N_{120}, N_{150} and N_{180} rates reduced $NUE_{prot\ yield}$ by 5.9, 14.9, 20.2 and 25.0 %, respectively, compared with N_{60}.

The impact of N splitting on grain yield, yield components and NUE. Analysis of variance for grain yield and yield components showed that year was the main factor determining the differences in values of parameters between additional fertilized treatments, compared with basic fertilized treatments (Table 3). The variability of grain yield, ears m^{-2}, grains ear^{-1}, productivity g ear^{-1} and TGW was mainly due to year (39.8, 25.6, 19.5, 19.3 and 89.2 % of the total variability, respectively). The influence of N and year × N rate interaction on all mentioned parameters under N splitting regime was insignificant.

Analysis of the treatments with additional fertilization revealed that grain protein content was significantly influenced ($P \le 0.01$) by N splitting, year and their interaction (Table 5). NUE_{yield}, NUE_{prot} and $NUE_{prot\ yield}$ were mainly explained by the year (29.8, 31.5 and 28.2 %, respectively) and the influence of year was significant at $P \le 0.01$ in all cases. N splitting effect on NUE_{yield} and NUE_{prot} was significant at $P \le 0.01$ and $P \le 0.05$, respectively. However, the influence of N splitting × year interaction on the mentioned parameters was insignificant. Neither N splitting nor the interaction of both factors had any impact on $NUE_{prot\ yield}$. Comparison of the basic fertilization with N rate splitting evidenced that additional fertilization was inefficient and had no effect on grain yield and grain yield components (Table 4). Contrasts of the mentioned indices between N_{90} *vs* $N_{60} + N_{30}$ and N_{150} *vs* $N_{90} + N_{30} + N_{30}$ were positive, but inconsiderable and insignificant. One exception was found – contrast of ears m^{-2} between N_{150} and $N_{90} + N_{30} + N_{30}$ was positive and significant (53*) at $P \le 0.05$. Additional fertilization significantly ($P \le 0.01$) increased grain protein content in both fertilization treatments (Table 6). Contrasts for N_{90} *vs* $N_{60} + N_{30}$ and N_{150} *vs* $N_{90} + N_{30} + N_{30}$ were 0.5% and 0.6%, respectively. Similar data were obtained by Kara and Uysal (2009), who indicated that grain protein content was higher in late-season N application compared with conventional N application. Nitrogen that is accessed by the crop early in the growth stages generally has a major effect on vegetative growth and crop yield while the effect on grain protein content may be low, due to the biological dilution effect of the higher yield. Conversely, late season supplies of N generally affect protein more than yield. Since there is little impact of the late N supply on grain yield, there is less dilution of the protein produced by the enhanced grain production. In addition, N accessed in the later growth stages may be more effectively channelled to the grain, as it is not immobilized in vegetative organs of plant.

Additional fertilization tended to increase NUE_{yield}, NUE_{prot} and $NUE_{prot\ yield}$, but contrasts were insignificant in most of the tested cases. The results of the present study agree with the findings of Alaru et al. (2009) who reported that NUE_{yield} values are under the influence of application regime of N fertilization. Contrary data concerning the effect of N splitting on NUE_{yield} were reported in other studies (Janušauskaitė, 2009) suggesting that N rate splitting tended to decrease NUE_{yield} and NUE_{prot}.

Conclusions

1. In general, nitrogen (N) fertilization gave 35.7% grain yield increase, compared with unfertilized spring triticale. Grain yield and yield components showed that N_{90} treatment was the best compromise for the yield performance, because increase of the grain yield and yield components by applying a higher N_{120} rate was inconsiderable and insignificant. The study revealed that economically and ecologically optimal N rate for spring triticale is $N_{90\text{-}120}$, which gave the highest grain yield (4.81–4.92 Mg ha^{-1}).

2. In terms of grain yield and its components, the N rate splitting did not exhibit any advantage over a single application. N rate splitting significantly ($P \le 0.01$) increased grain protein content.

3. To achieve higher protein content in grain, the maximum N rate was N_{150}, but assessment of nitrogen use efficiency (NUE_{yield}) showed that N_{90} produced sufficiently high NUE_{yield} (13.5 kg kg^{-1} N), or 4.6 kg kg^{-1} N more than N_{150}.

4. The weather conditions, particularly moisture regime, of the experimental years affected spring triticale grain yield performance and protein content in grain, and year had a significant ($P \le 0.01$) influence on all investigated parameters.

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Azoto trąšų normų ir jų skaidymo įtaka vasarinių kvietrugių derliaus formavimuisi

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Santrauka

Yra nedaug duomenų apie vasarinių kvietrugių azoto sunaudojimą ir trąšų efektyvumą. Tyrimų tikslas – ištirti azoto trąšų įvairių normų ir papildomo tręšimo įtaką derliui bei jo komponentams ir nustatyti optimalias vasarinių kvietrugių tręšimo azotu normas. Eksperimentas atliktas 2008–2011 m. Lietuvos agrarinių ir miškų mokslų centro Žemdirbystės institute lengvo priemolio giliau karbonatiniame giliau glėjiškame rudžemyje (RDg4-k2). Vienkartinėmis normomis (N_{60-180}) azoto trąšų tręšta prieš kvietrugių sėją. N_{90} ir N_{150} tręšta per du arba tris kartus. Tyrimo metu vertinta grūdų derlius, jo komponentai (varpų skaičius ploto vienete, grūdų skaičius varpoje, varpos produktyvumas, 1000 grūdų masė), grūdų baltymingumas ir azoto trąšų veiksmingumas. Nustatyta, kad visiems vertintiems rodikliams metai turėjo esminės ($P \leq 0.01$, $P \leq 0.05$) įtakos vienkartinio ir papildomo tręšimo variantuose. Vienkartinis tręšimas azoto trąšomis visais atvejais turėjo esminės ($P \leq 0.01$, $P \leq 0.05$) įtakos tirtiems rodikliams. Trąšų normos skaidymas turėjo esminės įtakos ($P \leq 0.01$, $P \leq 0.05$) grūdų baltymingumui ir daugeliu atvejų azoto veiksmingumo rodikliams, tačiau derliui ir jo komponentams įtaka buvo neesminė. Azoto trąšos grūdų derlių padidino 35,7 %, lyginant su netręštų vasarinių kvietrugių derliumi. Trąšų N_{90-120} normos buvo ekologiškai ir ekonomiškai optimalios, leidusios gauti didžiausią – 4,81–4,92 Mg ha^{-1} – grūdų derlių.

Reikšminiai žodžiai: derliaus komponentai, grūdų derlius, tręšimas, tręšimo azotu režimas, vasariniai kvietrugiai.