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Winter triticale yield formation and quality affected by N rate, timing and splitting

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The field experiment was conducted to study the effects different nitrogen (N) quantities (N0–120 kg ha^{-1}) and application regimes (N applied at stages of tillering BBCH28–30 and flag leaf sheath opening BBCH47) on (i) the formation of winter triticale above ground biomass (AGB), (ii) the grain yield (iii) the yield quality, and also (iiii) to find more suitable N fertilizing regimes for winter triticale depending on their utilization. Winter rye and winter wheat were used as reference crops.

The efficiency of applying all N at the tillering stage (N100%+N0) was the highest for the grain yield of triticale. N application at development stage of plants BBCH47 increased the grain protein concentration significantly and the increase by 1 kg N was the highest in triticale cultivars. More stabile grain yield was produced by triticales in application regime N+N. N splitting did not influence significantly either the duration of the grain-filling period or the dry matter accumulation rate of triticale. N splitting affected Hagberg falling number (HFN) indirectly through the effect on the grain yield formation and grain protein concentration. HFN was positively correlated with the grain yield and negatively with the grain protein concentration. The suitable N regimes are: 1) triticale as the energy plant – N60+N0 – N applied at the tillering stage of plants and suitable N norm is not more than 60 kg N ha^{-1}; 2) triticale as a feed or food – N60+N60 – High grain yield, protein and lysine concentration level are assured then.

Key-words: nitrogen rate, timing and splitting, triticale, cultivar, energy plant

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Introduction

The fertilizing regime affects the formation of different crops above ground biomass (ABG), the grain yield level and the grain yield quality. The influence of splitting application of nitrogen (N) on several cereals yield quality has investigated quite well. For example Garrido-Lestache and coworkers (2005) found that the timing and splitting of N fertilizer had no clear effect on either durum wheat (*Triticum turgidum* L.) grain yield or quality indices. Leaf application of N at ear emergence increased only grain protein concentration, vitreous kernel count and grain ash content. The response of grain yield and grain protein concentration to fertilizer N differed from that reported for temperate climates.

In intensive farming systems, farmers split up and apply the N fertilization to winter cereals (barley and wheat) and oilseed rape at several dates to meet the need of the crop more precisely (Sieling and Beims 2007). All three crops utilized the splitting rates differently depending on the time of application. 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 or bud formation. In contrast, N applied later in the growing season was taken up more quickly, resulting in higher fertilizer N-use efficiency.

The effects of nitrogen (N) applications on Hungarian, French and Serbian winter wheat cultivars were studied from 1996 to 2003 in a central Hungarian region. Different N fertilizer rates were applied at the tillering phase and after anthesis. The increasing N top dressing rate and its division resulted in an outstanding quality despite the unfavourable ecological circumstances. Nitrogen top dressing stabilized the falling number values (Szentpétery et al. 2005).

Nitrogen could act through delaying the maturation of the grain (Gooding et al. 1986), by increasing the grain drying rate (Kettlewell 1999), or by reducing grain size and affecting morphology (Clarke et al. 2004). Delayed maturation of grains in humid local conditions increases the risk to pre-harvest sprouting and low Hagberg falling number (HFN) values (Santiveri et al. 2002, Clarke et al. 2004). One of the most limiting factors for the seasonal development of triticale in cool and humid climatic conditions is the plant's sensitivity to sprouting. Yield losses due to lodging and pre-harvest sprouting caused by the application of large amounts of nitrogen fertilizer as an early single dressing are quite usual. Possible ways to avoid lodging are either by moderate fertilizing or by dividing the N fertilizer application into parts and applying them at different plant development stages (Sticksel et al. 1999). A number of experiments in winter cereals have shown that adjusting fertilizer rate and splitting of N fertilizer application are strategies to improve nitrogen use efficiency (NUE; Alcoz et al. 1993, Sieling et al. 1998, Lopes-Bellido et al. 2006, Subedi et al. 2007, Arregui and Cuemada 2008). The timing of application has a significant effect on the N uptake by the crop (Dilz 1988). Low efficiency attributed to N fertilizer application in autumn has been observed in a large number of studies, and justifies N applications in spring (Sowers et al. 1994, Ottman et al. 2000). Supplying N in two or three applications in spring is a common fertilizer recommendation to increase NUE in temperate Europe (Limaux et al. 1999).

There are many possibilities of using for different triticale cultivars, for example, as food (triticale flour blended with wheat flour), as feed for pigs and poultry, as energy plants (above ground biomass for fuel or grain yield for ethanol). Annual crops cultivated as an alternative energy source, such as wheat, rye or triticale, are easy to rotate in the crop cycle, and do not require the farmer to make any substantial investment. Whatever the proposed end usage of the crop cultivation, fertilization and harvesting techniques are essential to ensure optimal use of resources (Lund 1999). The production of a grain crop as a biofuel proved to be competitive compared to cultivation of other crops, so long as the ABG attained 10 t ha^{-1} (Bewa 1998). However, the identification of cereal species and varieties with high biomass yield, high combustibility, low ash content and low potential for boiler corrosion, remains an on-going priority.

Winter triticale (*X. Triticosecale Wittmack)* is quite new crop in Baltic States and little information is available about triticale yield stability in very changeable weather conditions found here, about possibilities to decrease the fluctuations of grain yield quantity and quality, and above ground biomass formation affected by splitting the application of N fertilizer. Field experiments were conducted to investigate the effects of different N quantities and application regimes on (i) the formation of winter triticale AGB, (ii) grain yield and (iii) yield quality (protein and lysine concentration, test weight, grain moisture content during grain filling period, crop maturation and HFN), and also (iiii) to discover more suitable N fertilizing regimes for different triticale cultivars depending on their utilization.

Material and methods

Field trial, experimental details

The experimental field trial was carried out in 2001/02, 2002/03 and 2003/04 at the Institute of Agricultural and Environmental Sciences of Estonian University of Life Sciences near Tartu (58°23´N, 26°44´E) on Stagnic Luvisol (WRB 1998 classification) soil (sandy loam surface texture, organic matter 2.1%, pH_{KCl} 6.0).

The influence of N fertilizer on the grain yield and yield quality of winter triticale was investigated in the trial. The factors were: 1) the N top dressing rate with four levels from 0 to 120 kg; 2) the timing of N application with three factor levels, namely all at BBCH28–30 developmental stage, split 50/50 at BBCH28–30 and BBCH47, and all at BBCH47 (see Table 1); 3) the winter triticale cultivars *Modus* (from Saaten-Union GmbH) and *Tewo* (Danko; from Aivar Niinemägi’s farm) were used in this experiment. The winter rye *Vambo* (Jõgeva Plant Breeding Institute) and the winter wheat *Kosack* (Svalöf; Farm Plant Eesti AS) acted as reference crops with the same N treatments; 4) trial years 2001/02–2003/04. All the experimental plots received at the same time of sowing the 60 kg ha^{-1} P_2O_5 as superphosphate and 80 kg ha^{-1} K_2O as potassium chloride. The N fertilizer was not applied at sowing time, the N fertilizer was applied directly on the soil surface as solid mineral fertilizer NH_4NO_3.

Seeds were sown in the first week of September to a depth of 3–5 cm, with 15-cm intervals between the rows, at a density of 400 germinating seeds m^{-2}. The experiment was performed in a randomized complete block design with three replications. The experimental plots were 10 m^2, of which 9 m^2 were harvested by combine to assess grain yield.

The yield measurements

The total grain yield of the plots was measured and converted to 86% dry matter (DM) content. Plants from 0.3 m^2 area were taken from each plot before the harvest and the plants height, ear-bearing tillers per plant, the AGB was estimated from these samples. The AGB yield as g m^{-2} was calculated

Table 1. N regimes (growth stages of application and quantities, kg ha^{-1}) for winter triticale fertilizing trial 2001/02–2003/04

N total kg ha^{-1}	Control Group	N+0	0+N	N+N
		BBCH 28–30	BBCH 47	BBCH 28–30 + BBCH 47
0	0+0			
60		N60+0	0+N60	N30+N30
90		N90+0	0+N90	N45+N45
120		N120+0	0+N120	N60+N60

at 14% moisture content. Lodging was estimated only in 2004. For lodging estimation was used the 9 points scale, where 9 point means, that cultivar stands very well and 1 point, that plants were lodged entirely. Samples of 10 spikes from each cultivar were collected every 3–4 days during the seed-filling period, to establish the seed DM content. Five kernels were sampled from external flowers of the middle spikelets of each spike, i.e. a total of 50 kernels from each cultivar. The grains were oven-dried at 70 °C for 48 hours to calculate their dry weight. Since physiological maturity (PM) is defined as maximum kernel dry weight, the PM stage for each crop could be determined; but the moisture content level at PM of 30–45% is too high for combine harvesting, the best level being 20–25%.

Chemical analyses

Hagberg Falling Number (HFN; CC Standard nr. 107) and grain protein concentration from each treatment were measured (Tecator Kjeltec apparatus, N × 6.25), and the lysine concentration (98/68/EC HPLC UV) of grains of winter triticale *Tewo* harvested in 2002 and 2003 from treatments N0+N0, N0+N120, N60+N60, N120+N0 was calculated. The winter wheat *Kosack* harvested in 2003 was used as a reference crop.

Weather conditions

The meteorological station in Eerika, near the trial field, supplied the weather data. The temperature and precipitation data from May up to August are presented, because in local conditions the winter cereals post-hibernation vegetation period continues during this period. The temperature and precipitation data varied remarkably year to year during the trial (see Table 2). The 2002 temperature data for the post-hibernation growth period was much higher and the precipitation amount was much lower than the long-term average. The temperatures in 2003 from the beginning of May to the second week of July (plant development stages BBCH30–70) were lower than the long-term average and therefore plants matured very slowly. The temperatures in 2004 were similar to the long-term average. There was above average precipitation in both 2003 and 2004. The total amount of precipitation from May to the end of August for both 2003, 420 mm, and 2004, 475 mm, was higher than the long-term average, which was 311 mm.

Data recording and statistical analyses

The trial data were processed using correlation and variance analyses and descriptive statistics (STATISTICA 8). The means are presented with their standard

Table 2. The temperature (ºC) and the precipitation data (mm) in 2002–2004 (for the post-hibernation growth period)

Month	The temperature (ºC)				The precipitation (mm)			
	Year 2002	Year 2003	Year 2004	Long-term average	Year 2002	Year 2003	Year 2004	Long-term average
May	13.9	11.7	12.6	11.3	15	142	34	57
June	16.5	12.9	13.4	15.4	81	71	212	79
July	20.1	19.4	17.0	17.3	45	104	113	81
August	19.2	15.3	17.0	16.0	22	133	116	94

Source: Eerika Meteorological Station

errors (±S.E.). The level of the significance $p<0.05$, 0.01 and 0.001 was calculated in all cases. If the data are given as an average of trial years, then TYAv is used. The coefficient of determination (R^2) is used to measure the significance, relative importance and ordinal effect of the factors (cultivars, the trial year, N rate and application time; Draper and Smith 1998, Everitt 2002). R^2 compares the explained variance (variance of the model's predictions) with the total variance of the data.

Nitrogen use efficiency (NUE) or increase of above ground yield and grain yield (kg kg^{-1} N) was calculated: NUE_{AGB} and NUE_{YIELD}, respectively. Different NUE were calculated according to the formulas:

$$NUE_{AGB}\,(\text{kg kg}^{-1}\text{ N}) = \frac{AGB_{NX} - AGB_{N0}}{NX}, \qquad (1)$$

where AGBNX is AGB (kg ha-1) from fertilized treatments and NX is N input quantity (kg N ha^{-1}; N60, N90 or N120), AGBN0 is the biomass from control group N0+N0;

$$NUE_{YIELD}\,(\text{kg kg}^{-1}\text{ N}) = \frac{YIELD_{NX} - YIELD_{N0}}{NX}, \qquad (2)$$

where $YIELD_{NX}$ is grain yield (kg ha^{-1}) from N fertilized treatments and $YIELD_{N0}$ is grain yield from control group.

Nitrogen uptake efficiency NU_PE or increase of grain protein concentration (mg in 100 g DM^{-1} kg N) was calculated according to the formula:

$$NU_PE\,(\text{mg in100 g DM}^{-1}\text{ kg N}) = \frac{PROT_{NX} - PROT_{N0}}{NX},$$

$$(3)$$

where $PROT_{NX}$ is grain protein concentration (mg in 100 g DM) in N fertilized treatments and $PROT_{N0}$ is grain protein concentration in control group.

Results

The trial year had the greatest effect on different agronomic traits from all trial factors studied, but the effect of N quantities was not significant. If the quantities of N fertilizer would have been higher then probably the effect of quantities would have become evident. But, the other hand, it revealed from our earlier studies that N fertilizer quantities greater than 60 kg ha^{-1} applied in plant tillering stage did not increase the grain yield of winter triticale cultivars significantly, in turn, the risk to lodging increased remarkably. Hereinafter the R^2 values are presented to illustrate the relative importance of different factors.

Influence of different N quantities and application regimes on lodging

One of the aims of the divided N fertilizer application was to prevent lodging. N application at BBCH47 increased the tolerance to lodging ($R^2=0.22$; $p<0.05$), because of the shorter stems of the triticale plants ($R^2=0.29$; $p<0.01$). Supplements of N in early spring will support tillering and ear density and therefore will make the crop more susceptible to lodging (see Table 3). In this trial the lodging happened only in wet 2004, when plants in treatments fertilized with N lodged more or less (see Fig. 1).

Table 3. Plant height and number of ear-bearing tillers per plant affected by N regime from descriptive statistics (± S.E.)

N regime	Plant height (cm)	Number of ear-bearing tillers per plant
N+0*	$107 \pm 2.8^{a**}$	2.6 ± 0.09^{a}
N+N	105 ± 3.0^{a}	2.3 ± 0.10^{b}
0+N	99 ± 3.2^{b}	2.0 ± 0.11^{c}

*N+0 – all N applied at BBCH28–30

N+N – half of total N amount applied at BBCH28–30 and the other half at BBCH47

0+N – all N applied at BBCH47

** different letters denote significant difference

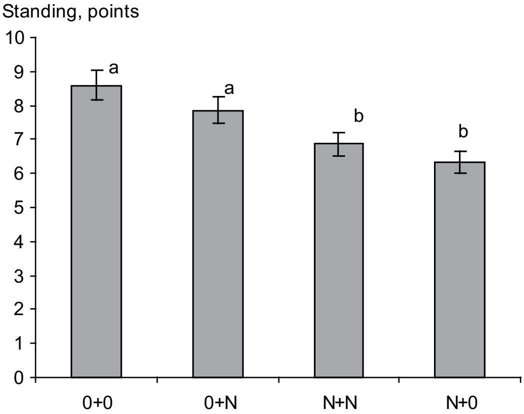

Fig.1. Influence of N regime on plants standing in 2004 (average over N quantities and cultivars)
*different letters denote significant difference

Influence of different N quantities and application regimes on biomass formation

According to R^2 the major influencing factor for the AGB formation was trial year ($R^2=0.54$; $p<0.001$), followed by N application regime ($R^2=0.29$; $p<0.01$) and the cultivar ($R^2=0.28$; $p<0.01$). The triticale biomass in the dry and warm conditions of 2002 varied between 1841–2370 g m^{-2}, but in the cool and humid conditions of 2003 the data showed a substantial decrease to between 757–1179 g m^{-2} (see Table 4). The AGB increase by 1 kg N was averagely over cultivars and N regimes in trial year 2002 0.74 ± 0.60, in 2003 1.84 ± 0.32 and in 2004 1.29 ± 0.27 kg AGB kg^{-1} N, respectively. NUE_{AGB} index for the trial year 2003 was the highest, because the above ground biomasses from control regime N0+N0 were relatively low. Above ground biomasses in 2003 were small because of cold and wet weather conditions in May, which caused the inhibition of all winter crops growing. In 2002 the AGB in control group was relatively high, but major part of this was straw, in treatments with N the Harvest Index increased remarkably.

The TYAv biomass yield of rye was 1547 ± 46 kg ha^{-1}, which was significantly higher than the same indices for the other cultivars. The AGB of winter triticale and wheat cultivars did not differed from each other significantly. The TYAv AGB for Modus, Tewo and Kosack were 1488 ± 94, 1444 ± 93 and 1442 ± 59 kg ha^{-1}, respectively.

The application regime N+0 produced the highest TYAv biomass yields. The TYAv biomass yields were compared with the control regime N0+N0. The data revealed increases of up to 135% for winter wheat *Kosack*, 125% for winter triticale cultivar *Modus* and 121% for *Tewo*. The increase for rye *Vambo* was 109%. The increases of AGB kg^{-1} N influenced by N regimes N+0, N+N and 0+N were 2.08 ± 0.60, 1.76 ± 0.41 and 0.03 ± 0.27 kg kg^{-1} N, respectively. NUE_{AGB} index was the highest in the application regime N+0, because N in tillering stage increased the number of tillers per plant significantly (see Table 3). The Harvest Index was higher in all three N regimes than in the control regime, by 1–13% for triticales and 3–4% for rye. The Harvest Index of winter wheat *Kosack,* on the other hand in the same three regimes decreased by 5–15% (see Fig. 2).

Table 4. Above ground biomass (AGB; g m^{-2}) of different cultivars affected by trial year from descriptive statistics (± SE)

Year	Modus	Tewo	Vambo	Kosack
2002	2098 ± 62^{a*}	2068 ± 45^{a}	2070 ± 30^{a}	1961 ± 33^{b}
2003	999 ± 48^{b}	1003 ± 42^{b}	1278 ± 77^{a}	1043 ± 60^{b}
2004	1367 ± 41^{a}	1263 ± 55^{b}	1287 ± 55^{ab}	1324 ± 81^{ab}

*different letters denote significant difference within rows

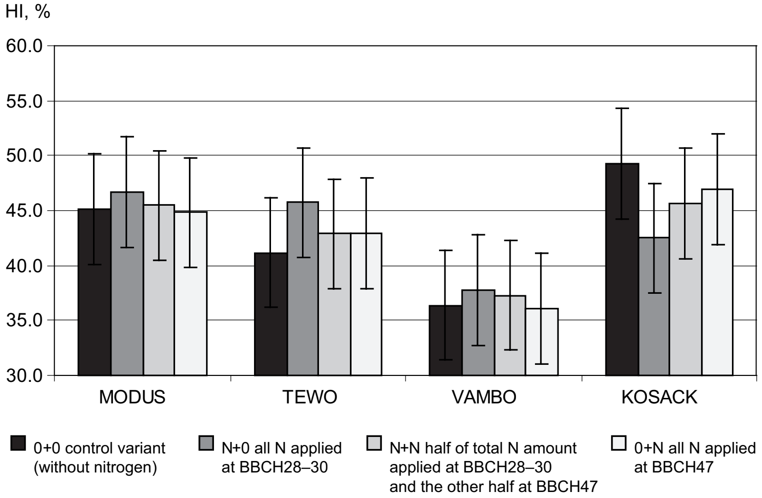

Fig. 2. Harvest index (HI, %) of different winter crops at different N regimes as an average of years.

Influence of different N quantities and application regimes on grain yield formation

The greatest influence on grain yield formation had the trial year ($R^2=0.50$; $p<0.001$) followed by cultivar ($R^2=0.29$; $p<0.01$) and N regimes ($R^2=0.26$; $p<0.01$; see Table 5).

Dry and warm weather conditions in 2002 were favourable for winter triticale cultivars *Modus* and *Tewo*. The grain yield of triticales in 2002 exceeded winter rye's and winter wheat's by 12–43%. The lower grain yield levels of winter crops in 2003 were caused by much lower temperatures in May (the tillering stage of wheat and stem elongation stage of rye and triticale plants) and a higher total of precipitation in July (during the grain filling period). The grain yield of triticale in the wet and normal temperatures in 2004 exceeded the grain yield of wheat and rye by 7–17%. The most grain-producing cultivar TYAv was winter triticale *Modus,* which exceeded the other studied cultivars 8–23% (see Table 6).

N applied at different plant development stages influenced the grain yield significantly ($R^2=0.26$; $p<0.01$). N regimes, where all or half of N was applied at tillering stage of plants, produced statistically the similar grain yield (see Table 7). These N regimes produced higher grain yield, because N in tillering stage increased the number of ear-bearing tillers per plant TYAv up to 29% comparing with control regime (see table 3). The grain yields of cultivars under 0+N regimes were not significantly different in comparison to those of the control regime.

Stability of grain yield over trial years was calculated. Both triticale cultivars produced the most stable grain yield in N+N regime, where the grain yield of triticale cultivars *Modus* and *Tewo* varied over trial years up to 3094 and 2581 kg ha^{-1}, respectively. The grain yield of rye and wheat were more stable in application regime N+0, where their grain yield varied up to 1238 and 2015 kg ha^{-1}, respectively. Cultivars with lower productivity were more stabile (see Table 5).

As supposed, the grain yield increase by 1 kg N was the greatest in application regime N+0. To compare the cultivars with each other the highest indices of NUE_{YELD} had triticale cultivars *Modus* and *Tewo* (see Table 8). NUE_{YELD} for *Modus* and *Tewo* in regime N+0 was TYAv 14.5 ± 1.4 and 16.7 ± 2.7 kg kg^{-1} N.

Table 5. Grain yield (kg ha^{-1}) of different cultivars affected by trial year and N regime from descriptive statistics (± SE)

Year, N regime	Grain yield (kg ha^{-1})			
	Modus	Tewo	Vambo	Kosack
2002				
N+0**	7289 ± 33^{a*}	6922 ± 322^{a}	5534 ± 102^{a}	4638 ± 181^{a}
N+N	7144 ± 155^{a}	6728 ± 189^{ab}	5197 ± 45^{b}	4309 ± 130^{b}
0+N	6744 ± 285^{a}	6232 ± 354^{b}	5033 ± 98^{c}	4176 ± 151^{b}
2003				
N+0	4542 ± 118^{a}	4375 ± 122^{a}	4296 ± 150^{a}	4729 ± 41^{a}
N+N	4444 ± 182^{a}	4147 ± 62^{b}	4029 ± 236^{a}	4501 ± 217^{a}
0+N	3573 ± 156^{b}	3400 ± 228^{c}	3200 ± 80^{b}	3530 ± 135^{b}
2004				
N+0	7881 ± 123^{a}	7463 ± 224^{a}	5188 ± 566^{a}	6653 ± 85^{a}
N+N	7538 ± 288^{ab}	6570 ± 221^{b}	5827 ± 122^{ab}	6487 ± 46^{b}
0+N	6406 ± 288^{b}	5408 ± 214^{c}	5840 ± 40^{b}	5958 ± 93^{c}

*different letters denote significant difference within a column per year

**0+0 – control variant (without nitrogen)

N+0 – all N applied at BBCH28–30

N+N – half of total N amount applied at BBCH28–30 and the other half at BBCH47

0+N – all N applied at BBCH47

Table 6. Grain yield (kg ha^{-1}) and grain protein concentration (%) of different cultivars from descriptive statistics (± SE)

Cultivar	Grain yield kg ha^{-1}	Grain protein concentration (%)
Winter triticale Modus	6173 ± 296^{a*}	12.30 ± 0.303^{b}
Winter triticale Tewo	5694 ± 271^{a}	13.78 ± 0.343^{a}
Winter rye Vambo	4730 ± 253^{b}	12.27 ± 0.242^{b}
Winter wheat Kosack	5709 ± 279^{a}	13.43 ± 0.318^{a}

*different letters denote significant difference

Table 7. Grain yield and grain protein concentration affected by the N regimes from descriptive statistics (± SE)

N regime	Grain yield kg ha^{-1}	Grain protein concentration (%)
N+0*	5934 ± 260^{a}	12.61 ± 0.251^{b}
N+N	5741 ± 241^{a}	13.05 ± 0.251^{b}
0+N	5029 ± 257^{b}	13.84 ± 0.277^{a}

[*] different letters denote significant difference within a column per year

[**] N+0 – all N applied at BBCH28–30

N+N – half of total N amount applied at BBCH28–30 and the other half at BBCH47

0+N – all N applied at BBCH47

Table 8. Grain yield increase (NUE$_{YELD}$; kg kg^{-1} N) of different cultivars affected by trial year and N regime from descriptive statistics (± SE)

Year,	NUE$_{YIELD}$ kg kg^{-1} N			
N regime	Modus	Tewo	Vambo	Kosack
2002				
N+0**	17.6 ± 3.5^{a*}	23.0 ± 2.7^{a}	8.9 ± 2.2^{a}	9.0 ± 1.5^{a}
N+N	16.5 ± 4.6^{a}	18.0 ± 4.2^{a}	5.2 ± 3.5^{ab}	3.5 ± 1.2^{b}
0+N	11.0 ± 3.6^{a}	11.2 ± 3.8^{a}	2.0 ± 0.8^{b}	1.2 ± 0.3^{c}
2003				
N+0	12.7 ± 1.2^{a}	8.3 ± 0.7^{a}	14.8 ± 1.3^{a}	10.8 ± 2.2^{a}
N+N	11.3 ± 1.1^{a}	6.1 ± 1.5^{ab}	11.2 ± 0.5^{b}	7.0 ± 1.4^{a}
0+N	1.4 ± 1.8^{b}	3.0 ± 2.4^{b}	1.9 ± 0.8^{c}	3.0 ± 1.3^{b}
2004				
N+0	13.2 ± 1.3^{a}	18.9 ± 4.6^{a}	–6.5 ± 5.1^{b}	6.6 ± 2.1^{a}
N+N	9.1 ± 2.9^{a}	9.4 ± 4.7^{b}	–1.4 ± 1.4^{ab}	4.5 ± 1.3^{ab}
0+N	2.6 ± 2.8^{b}	4.8 ± 2.2^{b}	–0.9 ± 0.6^{a}	2.2 ± 1.5^{b}

* different letters denote significant difference within a column per year

**N+0 – all N applied at BBCH28–30

N+N – half of total N amount applied at BBCH28–30 and the other half at BBCH47

0+N – all N applied at BBCH47

Influence of N quantities and application regimes on grain protein concentration

The second aim of the divided N+N application was to increase the grain protein concentration. The greatest influences on the grain protein concentration, from those factors investigated according to R^2, were trial year (R^2=0.36; p<0.001), followed by N application regimes (R^2=0.34; p<0.001) and the cultivar (R^2=0.24; p<0.05; see Table 9). Higher values of grain protein concentrations were in 2003, which were caused by much lower grain yield level in this trial year. It was in turn in 2002, when grain yield level was high.

More favourable N regime for increasing of grain protein concentration was 0+N, where N was applied at plant development stage BBCH47. The plants fertilized according to application regime 0+N had significantly higher grain protein concentration values than plants kernels in application regimes N+0 or N+N: for example winter wheat Kosack in regime 0+N had up to 2.6 % higher protein concentration comparing with other application regimes.

The grain protein concentration as an average of the years and N fertilizing regimes was highest in triticale *Tewo* (13.8 ± 0.34%), followed by wheat (13.4 ± 0.32%), triticale *Modus* (12.3 ± 0.30%) and rye (12.27 ± 0.24%; see Table 6).

NU$_P$E was also mostly affected by weather conditions. The grain protein concentration increase by 1 kg N was the greatest in 2002 (see Table 10). NU$_P$E value as an average of cultivars and N regimes was for trial year 2002 20.9 ± 7.12 mg in 100 g DM^{-1} kg N, the same for 2003 and 2004 were 6.7 ± 1.41 and 12.5 ± 1.21 mg in 100 g DM^{-1} kg N, respectively. Both triticale cultivars had in all N application regimes very high NU$_P$E values in 2002, because triticale plants grown in N0+N0 had extremely low grain protein concentration: *Modus* for example 8.4% and *Tewo* 9.3%, however, the same for rye and wheat were 10.5 and 12.6%, respectively. For all cultivars the grain protein concentration of control regime was relatively high in 2003 and it caused much lower NU$_P$E values in this

Table 9. Grain protein concentration (%) of different cultivars affected by trial year and N regime from descriptive statistics (± SE)

Year, N regime	Protein concentration (%)			
	Modus	Tewo	Vambo	Kosack
2002				
N+0**	9.9 ± 0.32^{b*}	11.0 ± 0.26^{b}	9.9 ± 0.21^{b}	12.2 ± 0.37^{b}
N+N	10.5 ± 0.49^{ab}	11.7 ± 0.58^{ab}	10.5 ± 0.31^{a}	12.5 ± 0.12^{b}
0+N	10.9 ± 0.49^{a}	12.6 ± 0.44^{a}	11.0 ± 0.25^{a}	13.0 ± 0.25^{a}
2003				
N+0	12.7 ± 0.12^{c}	14.8 ± 0.16^{c}	13.1 ± 0.07^{c}	14.0 ± 0.04^{b}
N+N	13.4 ± 0.06^{b}	15.4 ± 0.23^{b}	13.5 ± 0.07^{b}	14.1 ± 0.22^{b}
0+N	14.5 ± 0,16^{a}	16.6 ± 0.23^{a}	14.1 ± 0.20^{a}	14.6 ± 0.22^{a}
2004				
N+0	12.2 ± 0.29^{c}	13.4 ± 0.17^{c}	12.8 ± 0.12^{b}	12.4 ± 0.07^{c}
N+N	12.8 ± 0.29^{b}	13.8 ± 0.02^{b}	12.6 ± 0.32^{b}	12.7 ± 0.04^{b}
0+N	13.9 ± 0.34^{a}	14.7 ± 0.32^{a}	13.6 ± 0.29^{a}	12.8 ± 0.03^{a}

* different letters denote significant difference within a column per year
**N+0 – all N applied at BBCH28–30
N+N – half of total N amount applied at BBCH28–30 and the other half at BBCH47
0+N – all N applied at BBCH47

Table 10. Increase of grain protein concentration (NUPE; mg in 100 g DM^{-1} kg N) of different cultivars affected by trial year and N regime from descriptive statistics (± SE)

Year, N regime	NUE_{PROT} mg in 100 g DM^{-1} kg N			
	Modus	Tewo	Vambo	Kosack
2002				
N+0**	20.4 ± 2.28^{b*}	19.1 ± 1.23^{c}	6.6 ± 0.92^{c}	4.2 ± 0.53^{b}
N+N	22.6 ± 1.06^{b}	26.2 ± 1.40^{b}	17.6 ± 1.24^{b}	8.2 ± 1.21^{a}
0+N	29.3 ± 4.76^{a}	37.9 ± 6.72^{a}	24.3 ± 3.21^{a}	10.3 ± 1.90^{a}
2003				
N+0	-7.3 ± 2.98^{c}	-5.8 ± 0.70^{c}	2.2 ± 0.96^{c}	9.3 ± 2.83^{b}
N+N	1.0 ± 0.53^{b}	1.0 ± 0.53^{b}	7.5 ± 0.86^{b}	12.0 ± 0.26^{b}
0+N	14.4 ± 1.60^{a}	14.2 ± 1.56^{a}	14.1 ± 1.68^{a}	18.3 ± 1.67^{a}
2004				
N+0	7.3 ± 1.72^{c}	6.6 ± 0.72^{c}	9.9 ± 0.80^{b}	4.5 ± 0.90^{b}
N+N	14.9 ± 1.85^{b}	12.2 ± 2.24^{b}	7.6 ± 1.99^{b}	7.9 ± 1.46^{a}
0+N	27.6 ± 1.94^{a}	22.5 ± 0.80^{a}	19.1 ± 0.89^{a}	9.9 ± 2.05^{a}

* different letters denote significant difference within a column per year
**N+0 – all N applied at BBCH28–30
N+N – half of total N amount applied at BBCH28–30 and the other half at BBCH47
0+N – all N applied at BBCH47
DM = dry matter

trial year. For example: for *Modus* 13.2, for *Tewo* 14.9, for *Vambo* 12.9 and for *Kosack* 13.0%.

Plants of both winter triticale cultivars grown in N regimes, where all or half of N was applied at BBCH47, had significantly higher NU_PE indices comparing with application regime N+0. However, the increase of rye *Vambo* grain protein concentration by 1 kg N in application regimes N+0 statistically did not differed from N+N (see Table 11).

The N+N regime also increased the grain lysine concentration; N60+N60 produced the highest lysine concentration values where the lysine concentration increased by 0.25 g kg^{-1} (in 2002) and by 0.08 g kg^{-1} (in 2003) in comparison with the control regime (see Table 12). The average lysine concentration of grain samples in 2003 of triticale cultivar *Tewo* was 29% higher than the lysine concentration of the winter wheat *Kosack*.

Influence of N quantities and application regime on grain maturation rate, desiccation rate and HFN

The trials' results revealed that in Estonia, different winter crops reach PM at almost the same time. The duration of the grain filling period and the development rate of winter crops' grains correlated strongly with the accumulation rate of the sum of temperatures ($R^2=0.42$; $p<0.001$), and correlated negatively with the sum of precipitation ($R^2=-0.35$;

Table 11. NU_pE of different cultivars affected by N regime from descriptive statistics (± SE)

N regime	Modus	Tewo	Vambo	Kosack
N+0[**]	5,65 ± 1,70[a*]	6,63 ± 0,43[a]	6.06 ± 0.83[a]	6.89 ± 1.25[a]
N+N	12.82 ± 0.72[a]	13.05 ± 0.56[a]	7.51 ± 0.63[c]	9.93 ± 0.62[b]
0+N	23.66 ± 2.21[a]	24.86 ± 2.99[a]	16.60 ± 0.84[b]	14.04 ± 1.74[b]

[*] different letters denote significant difference within rows

[**] N+0 – all N applied at BBCH28–30
N+N – half of total N amount applied at EC28–30 and the other half at BBCH47
0+N – all N applied at BBCH47

Table 12. Lysine concentration in winter triticale cultivar Tewo and winter wheat Kosack affected by N regimes

N regime	Lysine g kg^{-1}	Protein %	Lysine/protein %
2002			
T 0+0	3.21[ab]	13.24[a]	2.42[a]
T 0+120	3.13[ab]	13.43[a]	2.30[a]
T 60+60	3.46[a]	12.63[a]	2.74[a]
T120+0	2.71[b]	11.36[a]	2.39[a]
2003			
T 0+0	4.53[a]	14.86[a]	3.05[a]
T 0+120	4.48[a]	16.90[b]	2.65[a]
T 60+60	4.61[a]	15.88[ab]	2.90[ab]
T120+0	4.41[a]	15.07[a]	2.93[a]
K 0+0	3.17[b]	14.21[a]	2.23[bc]
K 0+120	3.61[ab]	14.84[a]	2.43[abc]
K 60+60	3.04[b]	14.48[a]	2.10[c]
K120+0	2.94[b]	14.64[a]	2.01[c]

* - different letters in column per year denote a statistically significant difference
T – winter triticale cultivar Tewo
K – winter wheat cultivar Kosack

$p<0.001$), but N fertilizer quantities and application times did not significantly influence these data as TYAv. The time to harvest maturity varies considerably, depending on the desiccation rate of the grain. The differences between the desiccation rates for winter crops, after PM, were significant ($R^2=0.67$; $p<0.001$). The desiccation rate after PM was negatively correlated with the amount of precipitation in July and August ($R^2= 0.50$; $p< 0.001$). The HFN values, according to the correlation analysis were not directly influenced by N fertilizer quantities and application times. The effect of N on the HFN was indirect through the effect on the grain yield formation and grain protein content. HFN values were positively correlated with the grain yield of different winter crops ($R^2=0.22$; $p<0.05$) and negatively with the grain protein content ($R^2=-0.25$; $p<0.05$). The effect of the cultivars on the test weight, 1000 Kernel Weight (KW) and HFN was significant ($R^2=0.35$; $p<0.001$, $R^2=0.68$; $p<0.001$ and $R^2=0.71$; $p<0.001$, respectively). HFN values were affected most of all by the sum of precipitation in July and August ($R^2=-0.90$; $p<0.001$) and by the temperature ($R^2=0.91$, $p<0.001$; see Table 13).

Discussion

Triticale is known as a crop for having a high grain yield level at low N input (Varughese et al. 1996a). It accumulates more N during heading and physiological maturity than wheat does. The difference in N accumulation is maximal under lower levels of N application, indicating that triticales are better crops for soils with low N fertility (Varughese et al. 1996a). However, fertilization is required to avoid the decline of soil nutritional value. The choice of an appropriate fertilising regime is important if triticale is to be included at some stage in the crop rotation. Our trials also revealed that the grain yield increase resulting from 1 kg of additionally applied N was the highest in triticale cultivars, followed by wheat. The positive effect of N on the Harvest Index of triticale, which is thought to be due to the comparatively higher rates, than wheat's of leaf area, increases per unit N uptake (Yoshihira et al. 2002a). The efficiency of applying all the N fertilizer at the tillering stage, N100%+N0, was negative for the grain yield of rye, because of vigorous increase of tillers m^{-2} and lodging. N fertilizer quantities higher than 60 kg N ha^{-1} did not increase grain yield significantly and they are not efficient in Estonian local conditions, because of the high risk to lodging and pre-harvest sprouting (Alaru et al. 2004).

The TYAv biomass yields, important for assessing bio-energy potentials were the highest for rye *Vambo,* AGB of winter triticale and wheat cultivars did not differed from each other significantly. The most suitable fertilising regime to maximise the biomass yields for triticale, as energy plants, is to apply all N at the tillering stage, N100%+N0. Affected by N100%+N0 regime the highest increase of biomass yield was in winter wheat *Kosack*, but then the Harvest Index value decreased.

The stabile biomass and grain yield over years is determinative in changeable climate like Baltic

Table 13. Hagber Falling Number (HFN) values of winter crops in 2002-2004 (±S.E.)

Crop	Falling number (s)		
	2002	2003	2004
Triticale	120 ± 14.2^c	62 ± 0.4^b	91 ± 9.6^c
Rye	208 ± 5.8^b	64 ± 0.3^b	219 ± 2.3^b
Wheat	306 ± 7.5^a	208 ± 5.8^a	325 ± 2.3^a

* different letters denote a significant difference

Sea area. The weather conditions in trial years differed extremely from each other and as an average of three trial years more stabile grain yield was produced by triticales in application regime N+N. The critical period in point of view of winter crops AGB and grain yield formation was the beginning of post-hibernation vegetation period. The general grain yield level was dramatically influenced by cold and wet weather conditions in May 2003, which caused the strong deceleration of all winter crops growing. It is impossible to improve this lag in growing by any agronomic treatments later in summer time.

Triticale has considerable potential as a resource of energy and protein (Fernandes-Figares et al. 2000). Hybrid vigour (heterosis) can contribute to yield improvement (Kindred et al. 2005). Heterosis for yield, may be heavily influenced by agronomic conditions, but tends to be higher without N application (Le Gouis et al. 2002). However, much less is known about the interaction between N and heterosis on grain quality. There is according to Simmonds (1995), a strong negative correlation between grain yield and protein content in that a higher grain yield is accompanied by a decrease in grain protein content; this was the case in our trial (R^2=-0.63; $p< 0.001$). N application at development stage of plants BBCH47 (0+N regime) increased the grain protein content significantly and the increase resulting from 1 kg of additionally applied N was the highest in triticale cultivars, followed by rye and wheat. Yoshihira (2002b) concluded that unlike the roots of wheat, those of triticale and rye continue to grow after the flowering stage and the degeneration of the roots of triticale and rye is delayed compared to that of the roots of wheat. This is thought to be the reason for the higher N absorption values of the triticale at the flag leaf stage (Yoshihira et al. 2002a). The differences of N use efficiency between triticale and rye is caused by differences of N partitioning between grain and other plant components of these crops (Yoshihira et al. 2002b) The fertilizing regime N60+N60 guaranteed the 12% protein concentration needed for high-quality pig feed (Lember 2003). It revealed from our earlier studies, that the N+0 regime at the 120kg level (N120+N0) did produce the highest protein yield (841 kg ha^{-1}), but this fertilizing regime is not desirable because of the high risk of lodging. The 120 kg level of the divided N+N regime (N60+N60) produced 818 kg ha^{-1}, which was 4–12% higher than the other regimes and 27% higher than the control regime (Alaru et al. 2004).

The application of N fertilizer at different plant stages influenced the grain protein concentration and therefore the lysine concentration significantly. Usually, when protein concentration increases there is a decrease in the lysine concentration (Bruckner et al. 1998, Fernandez-Figares et al. 2000). N fertilizer applied at the plant development stage EC47 increased lysine concentration. The highest lysine concentration was in variants N60+N60, where the increase was up to 0.08 g kg^{-1} in comparison with control regime.

The major deficiencies of triticale, compared to wheat, grown in humid and cool environments, are an earlier anthesis, a later maturity, and a longer grain-fill duration compared to wheat (Varughese et al. 1996b). N fertilizer application in later development stages of plant may prolong the green leaf area duration and prolong the time of the grain maturation, which carries a relatively high risk for the quality of the grain yield in humid environments. Our experiments revealed that different N quantities and application times did not significantly influence either the duration of the grain-filling period or the dry matter accumulation rate. These data were mostly influenced by local weather conditions (R^2= 0.54; p<0.001) and cultivar (R^2=0.25; p<0.05).

Local weather conditions in July and August every year had direct effect on HFN values. In the absence of lodging, however, N application often increases HFN, but this effect varies with year, cultivar and site (Clarke et al. 2004). In our trial the N quantities and application regimes affected HFN indirectly through the effect on the grain yield formation and grain protein concentration. HFN was positively correlated with the grain yield and negatively with the grain protein concentration. The greatest influencers on the increase of winter triticale cultivars' grain yield were the increase of test weight and 1000 KW. The grain yield increases of wheat and rye were caused by the increase of test weight, 1000 KW and the number of ear-bearing tillers per plant. N fertilizer application at the tillering stage of plants, as per the literature review above, initially increases the grain yield, because of the number of spikelets and grains per ear and so the number of ear-bearing tillers per plant increases. N application at later stages of plant development increases the grains mass and the nitrogen concentration in the kernels (Peltonen 1992, Ramesh et al. 2002). Our experiments confirmed this.

Conclusions

1. The efficiency of applying all N at the tillering stage (N100%+N0) was the highest for the grain yield of triticale;
2. N application at development stage of plants BBCH47 increased the grain protein concentration significantly and the increase resulting from 1 kg of additionally applied N was the highest in triticale cultivars, followed by rye and wheat.
3. Different N quantities and application times did not significantly influence either the duration of the grain-filling period or the dry matter accumulation rate of triticale;
4. N quantities and application regime affected HFN indirectly through the effect on the grain yield formation and grain protein concentration. HFN was positively correlated with the grain yield and negatively with the grain protein concentration;
5. Depending on later utilization of triticale the suitable N regimes are:
   a) triticale as the energy plant – N60+N0 – the suitable N fertilizing time is at the tillering stage of plants and suitable N norm is not more than 60 kg N ha^{-1};
   b) triticale as a feed or food – N60+N60 – High grain yield, protein and lysine concentration level are assured in this N application regime;
6. More stabile grain yield was produced by triticales in application regime N+N.

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