Slow-release fertilizer to increase grain N content in spring wheat

Ari Rajala and Pirjo Peltonen-Sainio

MTT Agrifood Research Finland, Plant Production Research, 31600 Jokioinen, Finland

e-mail: ari.rajala@mtt.fi

Low grain protein often restricts the use of grain lots for milling in Finland. Nitrogen availability during grain-filling may restrict grain protein accumulation, particularly in high yielding environments. Slow-release fertilizers could potentially sustain nitrogen availability during the grain-filling period. The aim of this study was to increase plant nitrogen uptake, grain yield and grain protein response of spring wheat cultivar 'Amaretto', using combinations of a regular and slow-release compound NPK fertilizer. Fertilizer treatment effects on grain yield was modest, however, slow-release fertilizer treatments lowered grain protein content as well as grain, straw and total plant N compared with control treatment. The total plant N was 10 to 27 kg ha^{-1} lower following application of slow-release fertilizer. The results clearly indicate that the release of N by the slow-release fertilizer tested in this trial was too slow for cool Finnish growing conditions.

Key words: grain, nitrogen, protein, slow-release fertilizer, yield, wheat

Introduction

Grain protein content and falling number are key traits that characterize spring wheat (*Triticum aestivum* L.) quality in Finland. Low grain protein often restricts use of a grain lot for milling (Evira 2012). Grain yield and grain protein content typically correlate negatively in cereals (Foulkes et al. 2009). In spite of an extremely short growing season, and wheat being the latest maturing cereal grown in northernmost Europe, represented by Finland, cultivars differ in earliness: their requirement for cumulated degree-days from sowing to ripeness ranges from 930 to 1050 °Cd (Peltonen-Sainio et al. 2013). Even with such a modest variation in earliness, late maturing cultivars with high yield potential tend to produce lower grain protein content (Peltonen-Sainio et al. 2012), which is often too low to meet milling requirements (Kangas et al. 2012, Peltonen-Sainio et al. 2012).

Finnish farmers tend to prefer high yielding cultivars and wheat is becoming a popular crop in the northern regions, which previously were considered to represent too high a risk for meeting yield and quality requirements (Peltonen-Sainio and Niemi 2012). This likely results from advanced onset of the thermal growing seasons, earlier sowing of cereals and higher cumulated degree-days experienced particularly in the late 1990s and 2000s (Kaukoranta and Hakala 2008, Peltonen-Sainio et al. 2013). Climatic conditions during the 2000s have often favored wheat cultivation (Peltonen-Sainio et al. 2013).

Of the plant nutrients, nitrogen (N) plays essential role in determining grain protein content in wheat grains. Nitrogen availability during the growing period determines yield and N accumulation in grains (Peltonen-Sainio and Peltonen 1994, Muurinen 2007, Foulkes et al. 2009). Grain protein originates from remobilized plant N resources and from N taken up during grain filling (Bancal et al. 2008). In Finnish growing conditions, post-anthesis N uptake contributes roughly 30% of total nitrogen uptake (Muurinen et al. 2007). This is comparable with the figures presented by Bancal et al. (2008).

Nitrogen availability depends on amount and form of applied N, soil available N and soil type and conditions, crop rotation and cultivation history of the field, as well as on temperature and precipitation during the growing season (Aucklah et al. 1991, Poutala 1998, Przulj and Momcilovic 2001, Muurinen 2007). National environmental subsidy policy limits N fertilizer application. Without any yield level correction justified in the case of above average grain yields in earlier years, 120 kg N ha^{-1} is the maximum application rate for spring wheat. Hence, limited N use may be associated with reduced grain protein content in growing seasons when yields are high.

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According to common cultivation practice in Finland, seed and fertilizer are applied simultaneously with a combined placement drill. Also, in most cases, all fertilizer is applied in a single dose at sowing. Under favorable conditions, N application alone in the spring may be sufficient to promote high yields, but may result in insufficient N availability during grain filling, leading to low grain protein content (Peltonen-Sainio and Peltonen 1994). To improve N availability for grain protein construction, late application of a N supplement can be applied at heading or during the grain filling period (Peltonen 1992, Peltonen 1993). Additional N fertilizer application increases labor and machine costs and is economically feasible only if it increases grain protein content sufficiently and results in milling quality grain rather than feed quality grain. Use of slow-release fertilizers may represent an opportunity to avoid additional costs. Furthermore, delays in fertilizer-derived N release may offer a means for better allocation of N to filling grains (Alvin and Helm 1990, Shaviv and Mikkelsen 1993, Wang and Alva 1996). The aim of this study was to evaluate N uptake dynamics, and grain yield and grain protein response of the spring wheat cultivar 'Amaretto' to applications of regular and slow-release compound NPK fertilizer in the short growing seasons of Finland.

Materials and methods

A two-year field experiment was conducted during 2008–2009. Trials were established at the experimental farm of MTT Agrifood Research Finland in Jokioinen, situated in southern Finland (60° 48′ 3 N, 23° 28′ 5 E). The high yielding spring wheat cultivar 'Amaretto' was sown at 600 viable seeds per square meter in plots of 10 m^2. Plots were fertilized with combinations of regular compound NPK fertilizer (N-P-K: 20–3–8) and resin-coated slow-release Osmocote Exact Standard NPK fertilizer (N-P-K: 16–4–10, N release within 3 to 4 months depending on conditions). Nitrogen application rate was adjusted to 140 kg of N ha^{-1} in all treatments. Fertilizer treatment combinations are shown in Table 1. Weeds were controlled using MCPA, clopyralid and fluoroxypry compounds (trademark Ariane S). At heading, 30 plants were randomly collected from each plot to determine biomass (mg $plant^{-1}$) and N content (% dm, Kjehdahl-method). At physiological maturity, 50 plants were randomly collected from each plot to determine vegetative biomass (mg $plant^{-1}$), grain yield (mg $plant^{-1}$), harvest index (HI, %), N harvest index (NHI, %) and N concentration in grain and vegetative above-ground biomass (% dm, Kjehdahl-method). Grain, vegetative and total plant N (kg N ha^{-1}) were calculated. Plots were harvested with a combine harvester and grain yield (kg ha^{-1} at 15% moisture content), hectoliter weight (HLW, kg) and single grain weight (SGW, mg) were measured.

Statistical analyses were carried out with Statistical Analysis System software (SAS 9.2, SAS Institute Inc., 2002–2008). For all measured traits LSMEANS and differences among LSMEANS were estimated using PROC MIXED. Trial set up was randomized complete block design. In the model, treatment and year were considered to be fixed effects and block a random effect. Comparisons between treatment levels were conducted using a t-test type contrast. Spearman correlation coefficients were calculated for various N parameters using PROC CORR (SAS 9.2, SAS Institute Inc., 2002–2008).

Table 1. Fertilizer treatments

Fertilizer treatment	NPK kg N ha^{-1}	OSMOCOTE kg N ha^{-1}
1	140	0
2	120	20
3	100	40
4	80	60
5	60	80
6	40	100
7	20	120
8	0	140

Results and discussion

Slow-release fertilizer associated with reduced grain N

Slow-release fertilizer did not affect grain yield markedly. Only the second highest application rate reduced yield significantly compared the control treatment (Table 2). However, fertilizer treatment had an apparent consistent effect on grain number, the key trait that determines grain yield. When the level of slow-release fertilizer exceeded NPK/Osmocote 120/20 kg N ha^{-1}, it clearly resulted in reduced grain number (Table 2). Availability of N during the pre-anthesis phase was shown to influence grain number potential in wheat (Peltonen 1993, Fischer 1993, Peltonen-Sainio and Peltonen 1995, Jeuffroy and Bouchard 1999). Hence, reduction in grain number resulting from application of slow-release fertilizer was likely a result of lower N availability prior to anthesis. Furthermore, N content and biomass at heading stage provided more evidence for this assumption as both fell with increase in proportion of slow-release fertilizer (r=-0,96*** and r=-072*, respectively) (Table 2). Although slow-release fertilizer had a negative effect on grain number, it slightly increased single grain weight (Table 2). This positive effect resulted from the negative correlation between grain number and grain weight (Miralles and Slafer 1995, Frederik and Bauer 1999).

Pre-anthesis N availability was lower for slow-release fertilizer treatments and more N was potentially available for plant uptake and for use in grain protein synthesis during grain filling. However, lower grain N content (Table 2) clearly indicated that the type of slow-release fertilizer used in this trial did not release N at a sufficient rate to meet the demand of wheat to facilitate similar grain protein synthesis as in the control treatment. Also lower N uptake parameters (grain, straw and total plant N) compared with the control treatment resulted in lower N availability in treatments with slow-release fertilizer (Table 2): the total plant N was 10 to 27 kg lower with slow-release fertilizer treatments. All in all, in this study there was clear negative correlation with all parameters defining plant N status and Osmocote N rate (Table 2). However, in the literature, various results have been reported for slow-release N fertilizer response; reduced yield, grain N and N uptake (McKenzie et al. 2007), increased yield and reduced grain N (Beres et al. 2010), and no yield effect, but increased grain N and N recovery (Haderlein et al. 2001).

Lower N availability had a relatively small effect on grain yield, but a marked effect on grain N and consequently the potential end-use of the grain lot. Price for baking quality grain is higher than for feed quality. If cultivation and plant protection are used at a similar level, then the grain lot with too low protein content for milling inevitably results in reduced input cost-efficiency. Also, lower total plant N uptake with slow-release fertilizers likely increases risk for environmental nutrient loading.

Nitrogen content at heading phase correlated positively with grain and straw N parameters at maturity (Table 3). This highlights the importance of efficient pre-anthesis N uptake. On the other hand, N content at anthesis tended to correlate negatively with NHI (Table 3). Nitrogen harvest index is an indicator of N allocation efficiency into grains (Fisher 1993). Accordingly, the higher plant N content at anthesis indicated lower N allocation and/or remobilization efficiency (Table 3). The negative correlation between NHI and N content at anthesis in this dataset is likely a direct result of differences in N availability between fertilizer treatments. Low N availability was shown to correlate positively with NHI (Cox et al. 1986, Fisher 1993, Gaju et al. 2011) as well as improve N remobilization efficiency (Gaju et al. 2011). Accordingly in this trial, lower N availability in slow-release fertilizer treatments resulted in lower grain N, but concurrently enhanced the allocation of plant N to grains, as expressed as a higher NHI and also as a lower straw N content (Table 2).

Table 2. Fertilizer and year effect on yield, yield related traits and nitrogen uptake and utilization. Differences among least square means were compared with 140/0 as a control treatment. Also Spearman correlation coefficients (r) for the relation between Osmocoate N rate and measured traits are shown. Level of significance is shown next to the mean value, * p<0.05, ** p<0.01, *** p<0.001.

	Biom at heading	N at heading	Yield	SGW	GRAINO	HI	Grain N	Straw N	Grain N	Straw N	tot N	NHI
	g plant^{-1}	%	kg ha^{-1}	mg	grains m^{-2}	%	%	%	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	%
NPK/OSMOCOATE												
kg N ha^{-1}												
140/0	1.51	2.08	6 499	39.7	16 277	46.4	2.12	0.60	118	37	155	75.2
120/20	1.43	2.01	6 524	39.8	16 266	45.8	2.03	0.52*	113	33	146	76.3
100/40	1.35	1.94*	6 341	40.6	15 503**	46.0	1.98**	0.52*	108**	32*	139**	76.2
80/60	1.39	1.91**	6 298	40.2	15 587**	45.8	2.03	0.57	109*	35	144*	74.6
60/80	1.38	1.84***	6 527	40.9*	15 857	46.5	1.98**	0.48**	111	30**	140**	77.9*
40/100	1.38	1.72***	6 449	41.5**	15 436**	45.7	1.92***	0.46***	106**	30**	136***	77.3
20/120	1.22	1.67***	6 180*	41.0*	961***	45.8	1.90***	0.46***	101***	28***	128***	77.5
0/140	1.36	1.74***	6 358	40.5	15 583**	46.8	1.98**	0.47***	108**	28***	136***	78.5**
stderr	0,096	0,056	95,7	0,36	224	0,75	0,047	0,043	3,1	1,7	5,0	1,26
r	-0,72*	-0,96***	-0,38	0,69	-0,71*	-0,05	-0,81*	-0,85**	-0,71*	-0,91**	-0,86**	0,76*
Year												
2008	1.38	1.94	5 242	35.2	14 835	42.3	2.03	0.58	92	35	127	71.7
2009	1.37	1.78	7 552	45.9	16 532	49.9	1.95	0.44	126	28	154	81.6
		p-value	*p*-value	*p*-value	*p*-value	*p*-value	*p*-value	*p*-value	*p*-value	*p*-value	*p*-value	*p*-value
Year	0.83	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Fertilizer	0.19	<0.0001	0.013	0.01	<0.0001	0.52	0.002	0.002	0.001	0.002	0.001	0.02
Year x fertilizer	0.35	0.15	0.69	<0.0001	0.12	0.21	0.69	0.79	0.95	0.51	0.94	0.39

Abbreviations: SGW, single grain weight; GRAINO, grain number; HI, harvest index; tot N, total plant nitrogen; NHI, nitrogen harvest index

Table 3. Spearman correlation coefficients between various N related parameters. Level of significance: * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

	N at heading	Biomass at heading	Grain N	Straw N	Grain N	Straw N	tot N	NHI
	%	g plant^{-1}	%	%	kg N ha^{-1}	kg N ha^{-1}	kg N ha^{-1}	%
N at heading	1							
biom at heading	0.73*	1						
Grain N	0.91**	0.83*	1					
Straw N	0.90**	0.72*	0.89**	1				
Grain N	0.83*	0.80*	0.91**	0.74*	1			
Straw N	0.87**	0.85**	0.87**	0.96***	0.71*	1		
total N	0.92**	0.89**	0.95***	0.90**	0.93***	0.91**	1	
NHI	-0.64	-0.61	-0.62	-0.85**	-0.33	-0.89**	-0.63	1

Abbreviations: tot N, total plant N; NHI, nitrogen harvest index

Similar fertilizer effects under contrasting growing conditions

Mean grain yield was 5242 kg ha^{-1} in 2008 and 7552 kg ha^{-1} in 2009 (Table 2). However, there was no year × fertilizer treatment interaction (Table 2). Even though grain yield was substantially higher in 2009, the N content of the grain was only slightly lower (Table 2). 2009 was apparently favorable for plant N uptake, which was some 27 kg higher in 2009 than in 2008 (Table 2). Weather conditions during the growing season largely determine crop growth and yield. Accumulated monthly temperature sums were rather similar in both years (Table 4). Monthly precipitation, however, differed between years: in July 2008 precipitation was 50% lower than in 2009 (Table 4). In general, water is often limiting at pre-anthesis (Peltonen-Sainio et al. 2011) and it markedly reduces grain number per square meter, while post-anthesis water shortage is associated with reduction in grain weight (Rajala et al. 2009). Of the yield-determining traits, single grain weight was clearly lower in 2008 (Table 2). Various combinations of grain number and grain weight may occur depending on growing conditions, especially timing of growth enhancing and/or inhibiting weather events (Peltonen-Sainio et al. 2007). The most common trend is, however, that these two traits are negatively correlated for wheat (Miralles and Slafer 1995, Frederik and Bauer 1999).

Table 4. Mean monthly temperature sum (base temp. >5°C) and precipitation sum in 2008, 2009 and long term (1981–2010) in Jokioinen

		Mean temp. sum °C	Mean precipitation mm
2008	May	152	20
2008	June	252	85
2008	July	338	31
2008	August	265	112
2009	May	182	20
2009	June	237	62
2009	July	333	60
2009	August	310	59
Long term			
1981–2010	May	144	40
1981–2010	June	268	63
1981–2010	July	363	75
1981–2010	August	309	80

In 2009 vegetative plant N was remobilized and translocated efficiently to grains. This was reflected in lower straw N content and higher NHI than in 2008 (Table 2). Values obtained for NHI in this study are generally in line with those reported in the literature (Fischer 1993, Muurinen et al., 2007, Gaju et al., 2011). Typically, HI in spring wheat cultivars grown in Finland is around 40% (Peltonen-Sainio et al. 2008) and HI in 2008 was close to the typical value, whereas in 2009 it was clearly above the mean value (Table 2).

In conclusion, the release of N by the slow-release fertilizer tested in this trial was too slow for the cool Finnish growing conditions. Slow release of fertilizer N in Osmocoate treatments had an apparent effect on plant N status throughout the growing cycle. Lower N availability reduced plant N content at heading stage. Lower grain and straw N content and lower plant N uptake indicate lower N availability also at grain filling period.

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