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PRIVILEGING LATE N DRESSING ON WINTER WHEAT INCREASES RECOVERY AND EFFICIENCY (YIELD AND QUALITY) OF FERTILIZER N RESULTS OF 3 YEARS FIELD EXPERIMENTS USING STABLE ^{15}N

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Abstract

Grain yield and protein content of winter wheat (*Triticum aestivum* L.) are depending on N removed by crops originating from soil (mineralization) and N fertilizer. Not only the total rate of fertilizer N applied but also the timing of dressing and the splitting schedule appear important in order to simultaneously reach the objectives of yield, quality of harvest and minimising environmental pressure (the highest recovery of fertilizer N is required).

In the loamy region of Belgium studies were conducted during three years (2002, 2003 and 2004), with the aim to investigate a large range of fertilizer N rates (0-300 kg N ha $^{-1}$) with different splitting schedules at three growth stages GS 25, 30 and 37. ^{15}N labelled NH_4NO_3 has been used to measure the recovery of each split dressing.

Results show that N rates more than N splitting schedule had a significant effect on grain yield (GY) (9000 kg-12000 kg.ha^{-1}) and grain protein content (PC) (10.2 % -12.9 %). Efficiency of use of fertilizer N (ranging from 8 to 33 kg grain per kg N) was positively influenced by rate of fertilizer and generally by privileging late N dressing . Moreover, when total fertilizer N was applied late (by suppressing GS 25 and enhancing flag leaf dressings), recovery of total fertilizer N as slightly increased due to a very high recovery of GS 37 dressing (>70 %).

Key words: N fertilizer; ^{15}N labelled; Nitrogen Use Efficiency; fertilizer nitrogen recovery; grain yield; grain protein content.

Introduction

In temperate climate, both grain yield and protein content are determining of the profitability of winter wheat crop (*Triticum aestivum* L) (Falisse and Bodson, 1984; Destain et al., 1991., Goffart et al. 1992., Destain et al., 1997 and Leygue, 2005). To ensure the economic goal, and to minimise the environmental pressure, it is necessary to fine tune the fertilizer application to the crop needs leading to the highest recovery of the fertilizer. This challenge appears always actually as it is observed all other the world that only about 33 % of the total N applied for cereal production is actually removed in grain (Raun et al., 2002).

In Belgium, fertilizer nitrogen applied to winter wheat (*Triticum aestivum* L.) is generally divided into three split dressings applied at tillering (GS25), stem elongation (GS30) and flag leaf (GS37). Increasing interest based on experimental data (Bodson et al., 2005) have been found for a splitting schedule in two fractions, avoiding the application at tillering and privileging flag leaf fraction.

This paper is devoted to test the influence of these different splitting schedules for a range of fertilizer N rates, on grain yield, protein content and both efficiency and recovery of fertilizer N.

Material and Methods

During three years (2002, 2003, and 2004), in loamy region, hapludalf soils (temperate climate with a mean temperature of 9°C and annual rainfall of 800 mm), experiments were conducted in order to compare a large range of fertilizer N rates (0-300 kg N ha $^{-1}$) and different splitting schedules at three growth stages GS 25, 30 and 37.

Experimental designs were randomised block with four (2003 and 2004) to 6 (2002) replicates. The size of an experimental plot was 16 m^2 N fertilizer was applied as NH_4NO_3.

Grain yield was measured at maturity (15% humidity). Protein content was measured by near infrared reflectance spectrometry (NIRS).

In order to measure the recovery of the N fertilizer split dressing, ^{15}N labelled NH_4NO_3 (2.16 % ^{15}N) has been used in stainless-steel cylinders (length, 30 cm; internal diameter, 30 cm) pressed into the soil of the young winter wheat crop (var. Corvus) (micro plots). In these micro plots where N is applied according to the 2 or 3 splitting schedules labelling had concerned the total dressing or GS 30 and GS37 fraction separately.

At harvest time, plants of each micro plots were cut at ground level and divided into stems and ears. The samples were oven-dried at 80°C until constant weight, weighed and milled. Plant N content and its isotopic composition were analysed by mass spectrometry (Europe scientific) coupled to a Dumas combustion apparatus.

The software SAS procedure was used to analyse the data.

Results

Grain yield, protein content and nitrogen use efficiency

The highest grain yields (12000 kg ha^{-1}) combined with the lowest protein contents (10.1 to 11.4 %) were observed in 2004 (Table 1). Use efficiency of fertilizer N (NU) defined as ([grain yield of fertilized plot - grain yield of control at 0 N] /total N fertilizer applied) appeared highest for the same 2004 year (>30 kg grain kg N^{-1}). Lowest yield combined with lowest NUE were observed in 2002 with respective values of 8700 to 9700 kg ha^{-1} and 8 to 19 kg grain kg N^{-1}. With regards to control 0N, grain yield showed a limited variation between years (5700 to 6200 kg grain kg N^{-1}) probably due to similar potential of mineralization of the soil, and limited amounts of mineral nitrogen in soils after sugar beet previous crop (60 kg Nmin ha^{-1}).

Considering the fertilizer rate, the highest rate (240 to 300 kg N .ha^{-1}) leaded to the highest yield in 2003 and 2004, although nitrogen use efficiency (NUE) appeared to decrease from 33 and 25 to 24 and 20 for 2004 and 2003 respectively. In 2002, the highest level of N applied lead to the lowest yield (8700 kg.h^{-1}) and to an important decrease of nitrogen use efficiency (from 19 to 8 kg grain kg N^{-1}), due to a limited crop yield potential.

With regards to the splitting schedule, only in 2004 when highest yields were observed, the three split dressing appeared to be more efficient than the two split dressing. Privileging a high rate of N at flag leaf showed a positive effect on protein contents (+ 0.8% in 2002, + 0.4 % in 2003, + 1.3 % in 2004). A high rate of N at stem elongation leads to intermediate results.

Table 1: Influence of rate and splitting schedule of fertilizer N on grain yield (kg ha^{-1}), grain protein content (%) and Nitrogen Use Efficiency (NUE) (kg grain kg N^{-1})

Year (date of sowing)	Nitrogen application (kg. ha^{-1})				Grain yield (Kg.ha^{-1}) (±sd) at 15 % H_2O	Grain protein content (%) (±sd)	NUE (Kg grain kg N^{-1})(±sd)
	Rates	GS25 (Tillering)	GS30 (Stem elongation)	GS37 (Flag leaf)			
2002	300	100	100	100	8703 (±501) b	12.3 (±0.3) a	8 (±2) c
(17/10/01)	235	50	60	125	8928 (±428) b	11.9 (±0.2) b	12 (±4) b
	185	50	60	75	9225 (±360) ab	11.2 (±0.1) c	16 (±2) a
	185	0	110	75	9748 (±683) a	11.6 (± 0.3) b	19 (±4) a
	185	0	60	125	9194 (±454) ab	12.0 (± 0.2) ab	16 (±3) a
	0	0	0	0	6217 (±168) c	9.3 (± 0.4) d	-
2003	240	60	60	120	10453 (±400) a	12.9 (±0.6) a	20 (±2) b
(23/11/02)	180	60	60	60	10116 (±109) a	12.0 (±0.3) b	24 (±2) a
	180	0	120	60	9892 (±302) a	11.5 (±0.2) b	23 (±2) a
	180	0	60	120	10135 (±411) a	12 (±0.1) b	25 (± 3) a
	0	0	0	0	5683 (±67) b	8.4 (±0.8) c	-
2004	300	100	100	100	12439 (±351) a	11.4 (±0.3) a	24 (±7) b
(15/10/03)	240	60	60	120	12166 (±273) ab	11.2 (±0.2) a	28 (±6) ab
	185	0	60	125	11464 (±360) bc	11.4(±0.1) a	30 (±5) ab
	180	60	60	60	12029 (±491) ab	10.1 (±0.3) c	33 (±4) a
	180	0	120	60	11792 (±456) abc	10.6 (±0.3) b	32 (±4) a
	180	0	60	120	11060 (±111) c	11.4 (±0.1) a	28 (±3) ab
	0	0	0	0	5974 (±758) d	7.8 (±0.1) d	-

For each year values within each row followed by the same letter are not significantly different at the 0.05 probability level

Recovery of fertilizer nitrogen by wheat

Total recovery of fertilizer ^{15}N (FNR) has appeared to vary from 62.6 to 75.6 % and was not influenced by fertilizer N rates and splitting schedules (Table 2). Lowest values were observed in 2003, highest in 2004. The same observation is valuable for fertilizer N recovery in ear (FNRe) with a bigger difference for the year 2004, where all values observed were higher than 60 %.

For the three years, FNRe appeared slightly higher (although not significant) when 2 splitting schedule was applied or when flag leaf dressing rate was enhanced. Both FNR and FNRe of flag leaf dressing always appeared higher than those of stem elongation dressing (Table 3).

Table 2: Recovery of fertilizer nitrogen (FNR) by winter wheat in micro plots (% of N applied)

Year	Nitrogen application (kg. ha $^{-1}$)				FNR of each split dressing (%) (±sd)	FNRe of each split dressing (%) (±sd)
	Rates	GS25 (Tillering stage)	GS30 (Stem elongation stage)	GS37 (Flag leaf stage)		
2002	300	**100**	**100**	**100**	66.0 (±3.0)	54.5 (±3.3)
	235	**50**	**60**	**125**	69.8 (±4.0)	58.7 (±3.5)
	185	**50**	**60**	**75**	65.3 (±4.5)	55.3 (±4.2)
	185	0	**110**	**75**	68.7 (±1.5)	57.7 (±0.8)
	185	0	**60**	**125**	70.1 (±4.7)	60.2 (±5.1)
2003	240	**60**	**60**	**120**	67.5 (±2.4)	59.8 (±2.7)
	180	**60**	**60**	**60**	62.6 (±4.0)	55.0 (±3.3)
	180	0	**120**	**60**	67.6 (±2.3)	59.9 (±2.2)
2004	300	**100**	**100**	**100**	75.6 (±7.4)	68.2 (±7.4)
	240	**60**	**60**	**120**	73.5 (±2.9)	66.6 (±3.9)
	235	**50**	**60**	**125**	73.7 (±6.4)	66.8 (±7.2)
	180	**60**	**60**	**60**	69.3 (±2.1)	61.5 (±1.5)
	180	0	**120**	**60**	71.4 (±7.2)	63.3 (±7.9)
	180	0	**60**	**120**	71.1 (±7.0)	64.5 (±6.4)

Table 3: Recovery of GS30 and 37 N dressing by winter wheat in micro plots (% of N applied)

Year	Nitrogen application (kg. ha $^{-1}$)				Total labelled Fertilizer Nitrogen Recovery (%) (±sd)	Fertilizer Nitrogen Recovery in ears (%) (±sd)
	Rates	GS25 (Tillering stage)	GS30 (Stem elongation stage)	GS37 (Flag leaf stage)		
2002	185	0	**110***	**75***	68.7 (±1.5)	57.7 (±0.8)
	185	0	**60***	125	59.8 (±7.4)	47.7 (±8.6)
	185	0	60	**125***	75.1 (±3.4)	66.2 (±3.3)
2003	180	0	120	**60***	73.9 (±4.3)	66.8 (±4.0)
	180	0	**60***	120	64.0 (±1.9)	53.5 (±2.1)
2004	180	0	**120***	60	67.4 (±5.6)	58.5 (±5.7)
	180	0	120	**60***	74.8 (±5.0)	69.3 (±5.1)
	180	0	**60***	120	66.3 (±12.6)	55.9 (±11.6)
	180	0	60	**120***	74.4 (±4.2)	68.9 (±3.8)

*Labelled with ^{15}N

Fertilizer and soil-derived nitrogen

In Table 4, variation of soil derived nitrogen in wheat appeared to be low (90-125 kg N). The highest values were obtained in 2002. Variation in total N removed by cereal followed the fertilizer rate with about 320 kg N for 300 kg N rate, 260 kg to 240 kg N rate, 220 kg N for 180 kg N rate. This variation was parallel to that observed in N derived from fertilizer N.

Table 4: Fertilizer and soil-derived nitrogen for different nitrogen application in micro plots

Year	Nitrogen application (kg. ha $^{-1}$)				N derived from soil (N kg.ha^{-1}) (±sd)	N derived from fertilizer (N kg.ha^{-1}) (±sd)	Total N in plant (N kg.ha^{-1})
	Rates	GS25 (Tillering stage)	GS30 (Stem elongation stage)	GS37 (Flag leaf stage)			
2002	300	**100**	**100**	**100**	125 (±14)	198 (±8)	323
	235	**50**	**60**	**125**	112 (±11)	164 (±9)	276
	185	**50**	**60**	**75**	103 (±12)	121 (±8)	224
	185	0	**110**	**75**	107 (±11)	127 (±2)	234
	185	0	**60**	**125**	115	128	243
2003	240	**60**	**60**	**120**	91 (±8)	162 (±6)	253
	180	**60**	**60**	**60**	95 (±14)	113 (±7)	207
	180	0	**120**	**60**	91 (±9)	122 (±4)	212
2004	300	**100**	**100**	**100**	104 (±25)	227 (±22)	330
	240	**60**	**60**	**120**	89 (±19)	176 (±7)	265
	235	**50**	**60**	**125**	101 (±13)	173 (±15)	274
	185	**50**	**60**	**75**	92 (±19)	111 (±3)	202
	180	**60**	**60**	**60**	94 (±10)	125 (±4)	219
	180	0	**120**	**60**	113 (±10)	128 (±13)	242

Discussion and Conclusion

As far as agronomic parameters are concerned (grain yield, protein content and NUE), results are in accordance with previous observations (Destain et al. 1997, Guarda et al., 2004). In a similar site and for a 200 kg N ha^{-1} fertilisation (50-50-100), Destain et al. (1997) observed a yield of 10000 kg ha^{-1}, a protein content of 11.9% and a NUE of 26 kg grain kg N^{-1}. The splitting schedule 0-100-65 shows no difference in yield with the three splitting schedule 50-50-65 (10000 kg ha^{-1}) and in NUE (16 kg grain kg N^{-1}).

Lopez-Bellido et al. (2005), in Mediterranean climate and vertisoil soil conditions demonstrate a similar influence of splitting schedule (50-50-50) or (0-75-75) at sowing- GS25-GS30 on yield (6300 kg ha^{-1} and 6500 kg ha^{-1}) while protein content is 13.2% and 13.5 % respectively due to drier conditions.

It appears that except in 2002, NUE is very high in this experiment when comparing to those obtained in Mediterranean climate, indeed 18 (kg grain. kg N^{-1}) was the highest value obtained with different bread wheat genotype by Guarda et al. (2004).

With regards to the recovery of nitrogen by wheat and in accordance with previous results (Destain et al, 1989 and 1997), the highest recovery obtained for flag leaf dressing could be explained by immediate transfer to ears of N absorbed by wheat in late development (Oscarson,1996). Total recovery obtained here (>70%) is generally very high and again higher than those obtained in Mediterranean climate (30-50%) (Lopez-Bellido et al. 2005) where the same tendency for splitting schedule is measured.

Total nitrogen removed by crop (200 to 330 kg $N.ha^{-1}$) appears higher than those (140 to 240 kg $N.ha^{-1}$) measured by Lopez-Bellido et al. (2005). N derived from fertilizer in our trial is higher than soil derived N, the reverse is obtained by Lopez-Bellido et al. (2005). For the same splitting schedule and the same rate of 240 kg N ha^{-1}, N removed by wheat is similar (276 kg in 2002, 253 kg in 2003 and 265 kg in 2004); but in 2002, 3.1 kg N was necessary for producing 100 kg grain, in 2003 2.4 kg N and in 2004 only 2.2 kg N. At least, with so high fertilizer recovery and efficiency, it is no doubt that as it was observed in similar conditions (Destain et al., 1991) N remains in soil (as organic form) is less than 25% of N applied. Moreover, in the same conditions, mineral residual N at harvest is very limited (<30 kg) (Destain et al., 2005a).

The profitability of cereal production is depending on the efficient use of nitrogen. In Belgium, experiments conducted in 2002, 2003 and 2004 demonstrates that this goal is reached. It remains that more and more, due to the very low price of winter wheat (8.5 € for 100 kg grain), it is expected that the use efficiency must be enhanced. That can be obtained by modifying splitting schedule, going to a two split N schedule instead of three. These two split N schedules have shown to be slightly positive on N recovery and on protein content which also influence price (± 5 to 10%). Moreover, it is well known that cereal growing in early stage in limiting N conditions were more resistant to diseases and less susceptible to lodging (Bodson et al., 2000). One can predict that in a near future and taking into account these advantages and environmental objectives, these approaches of fertilizer reasoning will be privileged perhaps on new winter wheat genotypes more efficient with regards to their N use.

A disadvantage of the schedule in two split dressing could be its negative influence on the straw yield which in some case can be reduced by 20% (Bodson et al., 2005). If the straw is commercialised and utilized for forage or litter, than the profitability can be reduced. It remains, that it is always possible to reduce this disadvantage by applying earlier the first N split dressing (between GS25 and 30).

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