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RESPONSE OF SEVERAL WINTER WHEAT CULTIVARS TO REDUCED NITROGEN FERTILIZATION

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ABSTRACT

Reducing Nitrogen fertilizer rates might contribute to improving wheat production economic efficiency and to reducing the impact on environment through nitrate leaching, use of fossil fuels for manufacture and application, as well as nitrous oxide (N_2O) emissions. Seventeen winter wheat cultivars were tested with recommended and reduced N fertilization during 4 years in three locations. Relative grain yield, protein concentration and protein yield per hectare under reduced fertilization, as percentage from the performance with recommended N fertilization, showed very large variation due to environment, the effect of cultivars being much smaller, but still significant. The effect of reduced N fertilization was larger for grain yield than for protein concentration. For grain yield and protein yield per hectare the highest reduction was found in cultivars originating from the Fundulea breeding program, while the smallest reduction was found in cultivar Adelina (bred at Şimnic), suggesting a possible relationship with the natural soil fertility at the breeding site.

Key words: low nitrogen, reduced fertilization, nitrogen use efficiency, wheat.

INTRODUCTION

Nitrogen fertilizers have been a key factor in the increased yields achieved by modern agriculture and or the last 30 years, the use of mineral nitrogen to fertilize crops has widely increased.

Presently, Nitrogen (N) fertilizer represents a significant cost for the grower (Foulkes et al., 1998). In Romania the cost of N fertilizer is about 25-30% of the total expenses for the wheat crop. Moreover, this cost seems to be increasing faster than the wheat price.

N fertilization may also have environmental impacts through nitrate leaching, use of fossil fuels for manufacture and application, as well as nitrous oxide (N_2O) emissions, a greenhouse gas with approximately 300 times the global warming potential of carbon dioxide (CO_2). In USA, in 2015, the Agriculture sector was responsible for emissions of 522.3 MMT CO2 Eq., 1 or 7.9 percent of total U.S. greenhouse gas emissions and emissions of N_2O by agricultural soil management through activities such as fertilizer application and other agricultural practices that increased nitrogen availability in the soil were the largest source of U.S. N_2O emissions, accounting for 75.1 percent (Environmental Protection Agency, 2017).

In parallel, the problem of nitrate pollution in superficial and underground water has emerged. To limit the loss of nitrates to aquifers, European directives favour Good Agricultural Practices, including the reduction of both organic and mineral nitrogen fertilization.

It has been estimated that only a third of nitrogen inputs to cereal crop worldwide are recovered in grain for consumption, resulting in a huge waste of resource with major negative impacts on the environment (Hawkesford, 2017). Improving Nitrogen Use Efficiency (NUE) is therefore a major present goal in agricultural research.

Both agricultural technologies or practices and breeding show promise for

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improving NUE. United Kingdom has improved cereal grain NUE by 23 percent, while estimates for wheat from France show an NUE increase from traditional breeding of about 29 percent and Mexico has improved wheat NUE by about 42 percent over 35 years (Gurian-Sherman and Gurwick Noel, 2009). Reducing nitrogen fertilizer application could be used both as a climate change mitigation strategy (Stuart et al., 2014) and for improving the economic efficiency of wheat crop.

Sylvester-Bradley and Kindred (2009) recommended that breeding and variety testing should be conducted at some sites with more than one level of applied N, in order to have the chance of identifying cultivars with improved nitrogen use efficiency. On this line, the wheat breeding program at the National Agricultural Research & Development Institute (NARDI) Fundulea has organized for many years cultivar testing in several locations, both with the recommended and at a lower level of N fertilization. This paper reports results obtained in 4 years, at three locations from South Romania.

MATERIAL AND METHODS

Yield trials using square lattice design with 25 cultivars in 3 replications, with recommended (standard) N fertilization and with reduced N fertilization were grown alongside. Out of the 25 cultivars, 17 were common during the 4 years in the three locations included in this study, and were analysed in this paper. These included 16 Romanian semidwarf winter wheat cultivars plus Bezostaya 1, a normal height Russian cultivar used as long term check.

A short characterization of the environmental conditions at the 3 locations during the four years of testing is presented in Table 1.

Table 1. Short description of the environmental conditions at the three testing locations with: a) recommended level of N fertilization; b) reduced N fertilization level

Location	Year	Soil type	Preceding crop	N fertilization (kg N ha^{-1})			Rainfall (mm) (October – July)
					in autumn	in spring	
Fundulea	2014	chernozem, pH:6.3-6.8; humus: 3%.	peas	a	0	137	536.5
				b	0	0	
	2015		peas	a	0	137	551.1
				b	0	0	
	2016		peas	a	0	137	435.10
				b	0	0	
	2017		peas	a	0	137	652.7
				b	0	0	
Albota	2014	brown luvisoil pH:5.02-5.03; humus: 2.70%.	sunflower	a	30	90	997.9
				b	30	0	
	2015		sunflower	a	30	90	564.2
				b	30	0	
	2016		sunflower	a	30	90	647.6
				b	30	0	
	2017		sunflower	a	24	110	568.4
				b	24	0	
Şimnic	2014	luvisoil, pH: 5.7-5.9; humus: 1.8%.	sunflower	a	50	85	817.5
				b	50	0	
	2015		sunflower	a	40	90	643.5
				b	40	0	
	2016		peas	a	40	90	730.9
				b	40	0	
	2017		peas	a	40	90	452.4
				b	40	0	

As shown in Table 1, conditions in the three locations were different, from the soils, (characterized with humus content of 3% in Fundulea and only 1.8 in Şimnic, and acidity almost neutral in Fundulea and acidic in Albota), to autumn fertilization with N (0 in Fundulea and 40 kg N ha^{-1} in Şimnic). However, in the plots with reduced N fertilization no N fertilization was applied in spring.

Rainfall during wheat vegetation period was different, occasionally excessive, favouring N levigation. Also, preceding crops were different, from sunflower, a big consuming on nutrients, to peas – a good species that leaves nitrogen in the soil.

We determined the following parameters:

- grain yield (kg ha^{-1}) (GY) was calculated at 15% moisture from the grain weight harvested from 5 m^{-2} plots;
- grain protein concentration (%) (GPC) was determined based on NIR determinations, using the Foss-Grain Analyzer – Infratec 1241;
- grain protein yield (kg ha^{-1}) (GPY) was calculated from grain yield and grain protein concentration as GPY = GY*GPC/100.

The effect of reduced N fertilization was estimated from the values of plots with low N expressed as percentage of values at recommended N fertilization.

RESULTS

The average effect of reduced fertilization was different according to both locations and years (Table 2), varying:

- for grain yield from positive effect at Fundulea in 2016 (probably because plots fertilised with recommended N rates were more affected by lodging) to 50% reduction at Şimnic in 2015;
- for grain protein concentration from no effect (Albota, 2015) to 17.5% reduction in Fundulea in 2016;
- for grain protein yield per hectare from 3.7% reduction at Şimnic in 2016 to 53.6% reduction at the same location in 2015. Obviously, grain protein concentration was less influenced by lower N availability than the grain yield or grain protein yield, suggesting that N was more available during grain filling, probably because of more intense nitrification due to higher soil temperatures later in the season.

Table 2. Grain yield, protein concentration and protein yield, averaged over 17 wheat cultivars

Location	Year	Grain yield averaged over cultivars (kg ha^{-1})			Protein concentration averaged over cultivars (%)			Protein yield averaged over cultivars (kg ha^{-1})		
		Recom. N fertiliz.	Reduc. N fertiliz.	Reduc./ standard %	Recom. N fertiliz.	Reduc. N fertiliz.	Reduc./ standard %	Recom. N fertiliz.	Reduc. N fertiliz.	Reduc./ standard %
Fundulea	2014	3426	3421	99.9	15.4	14.5	94.2	528	496	93.9
	2015	7267	5829	80.2	12.3	11.9	96.7	894	694	77.6
	2016	4249	4506	106	15.4	12.7	82.5	654	572	87.5
	2017	6398	5928	92.7	14.1	12.3	87.2	902	729	80.8
Albota	2014	3352	2169	64.7	10.6	9.9	93.4	355	215	60.6
	2015	2992	2209	73.8	12.4	12.4	100	371	274	73.9
	2016	4274	2665	62.4	13.5	11.3	83.7	577	301	52.2
	2017	3035	2065	68.0	15.1	15.0	99.3	458	310	67.7
Şimnic	2014	4154	4084	98.3	12.6	10.6	84.1	523	433	82.8
	2015	4664	2338	50.1	9.6	8.9	92.7	448	208	46.4
	2016	3734	3703	99.2	10.2	9.9	97.1	381	367	96.3
	2017	6853	4995	72.9	9.9	9.6	97.0	678	480	70.8

ANOVA showed that environments had a much higher effect than cultivars on the variation of relative values of studied parameters under reduced N fertilization (Table 3). This was also reflected by the low correlations between the cultivar performances among the trials, which were mostly non-significant and even negative (data not shown).

However, the effect of the differences between cultivars, although smaller was also significant for grain yield and grain protein yield, and very close to significance for protein concentration.

The performance of the 17 cultivars under reduced N fertilization, expressed as percentage from their performance under the recommended N fertilization, is presented in Table 4.

Table 3. ANOVA for grain yield, protein concentration and grain protein yield relative values under reduced N fertilization for the 17 cultivars common to all yield trials

Source of variation	df	F crit	Grain yield		Protein concentration		Grain protein yield ha^{-1}	
			F	P-value	F	P-value	F	P-value
Cultivars	16	1.701	1.954	0.018	1.690	0.052	1.793	0.035
Environments	11	1.843	84.911	2.37E-64	28.477	1.44E-33	58.149	1.04E-52
Error	176							
Total	203							

Table 4. Relative values at reduced N fertilization (% from recommended fertilization) in 17 wheat cultivars

Variety	Grain yield		Variety	Protein concentration		Variety	Grain protein yield	
	Average	Variance		Average	Variance		Average	Variance
Lv 6113	85.9	390.3	Bezostaya	95.4	49.0	Adelina	80.2	209.0
Adelina	85.3	288.3	Adelina	94.5	42.5	Lv 6113	78.2	279.4
SEMNAL	84.1	587.4	Lv 6125	93.7	47.5	Lv 6125	76.7	272.4
Lv 6110	83.6	326.6	Şimnic 60	93.3	50.2	Bezostaya	76.5	197.2
Izvor	83.4	440.2	Litera	92.5	78.8	Izvor	76.3	349.7
Lv 6111	83.3	232.2	Pajura	92.5	69.8	Şimnic 60	76.1	309.9
Boema 1	82.7	320.7	Glosa	92.4	87.5	Boema 1	75.9	231.9
Lv 6125	82.0	316.8	Boema 1	92.1	50.0	SEMNAL	75.1	368.7
Şimnic 60	81.4	302.2	Lv 6113	91.6	79.0	Lv 6110	74.0	233.5
Bezostaya	80.5	264.2	Izvor	91.6	17.4	Lv 6111	73.5	189.0
Alex	80.3	285.8	Otilia	91.5	63.4	Alex	73.0	194.9
Pajura	79.1	359.0	Alex	91.4	35.1	Pajura	72.8	282.9
Litera	78.2	244.8	Miranda	91.3	55.7	Litera	72.5	261.0
Miranda	78.2	190.8	Pitar	90.2	71.0	Miranda	71.1	137.7
Glosa	77.1	374.3	SEMNAL	90.2	60.1	Glosa	70.9	321.8
Pitar	77.0	330.9	Lv 6110	88.9	51.9	Otilia	70.7	311.8
Otilia	76.8	284.3	Lv 6111	88.7	103.1	Pitar	69.0	242.1

For grain yield the highest reduction (more that 20%) was found in cultivars Otilia, Pitar, Glosa, Miranda, Litera and Pajura, all originating from the Fundulea breeding program, while the smallest reduction (less than 5%) was found in cultivars Lv.6113 (bred at Lovrin) and Adelina (bred at Şimnic).

For grain protein concentration, reductions of more than 10% were found in two lines from Lovrin, while the smallest reductions (less than 7%) were registered in the only normal height studied cultivar (Bezostaya 1) and in three semidwarf cultivars, of which two were originating from the Şimnic breeding program.

The grain protein yield per hectare also showed variation among studied cultivars, with the smallest reduction for cultivar Adelina and the largest in the same Fundulea cultivars, as for grain yield.

DISCUSSION

Differences among the studied cultivars in their response to reduced N fertilization were relatively small, and this could be due to the recent history of wheat breeding in

Romania as in most countries. Breeding for most crops has been conducted over the last 50 years in the presence of high mineral fertilization inputs, thus missing the opportunity to exploit genetic differences under a low level of mineral or organic N fertilization conditions (Ceccarelli, 1995).

It may not be just by chance that cultivars bred at Fundulea on a rich soil and with a legume as preceding crop seem to be less efficient in using lower N fertilization than a cultivar bred at Şimnic on a soil with less humus and therefore less N available through nitrification.

Improving NUE will be necessary to improve profitability of the wheat crop, and reduce the impact on environment, especially the greenhouse gas (GHG) emissions associated with the production of each kg of yield. For example, it has been estimated that N fertilizer accounts for more than 70% of the GHGs associated with the production of wheat (Mortimer et al.. 2004). For this, new cultivars optimised for traits relating to N-use efficiency rather than yield alone will be required (Hawkesford, 2014). Testing the new cultivars under reduced N fertilization should be needed, but, as illustrated by our data, encounters difficulties because of the large variation of many factors influencing N availability from the soil (effect of soil temperatures on nitrification, levigation, etc.), and because of larger errors typical for testing under low N. This is why indirect selection for traits related to NUE improvement (Gajua et al., 2011) and possibly marker assisted or genomic selection could be helpful.

There is general consensus about the existence of real prospects for future agronomic developments and for breeding crops adapted to lower mineral fertilizer input (Hirel et al., 2011). Our data suggest that even in a limited range of adapted cultivars like the one included in our study, there is variability allowing some genetic progress. However, for more substantial progress exploitation of a wider germplasm pool, utilizing land races and ancestral germplasm may be requires (Hawkesford, 2014).

CONCLUSIONS

All parameters describing the performance under reduced N fertilization showed very large variation due to environment, the effect of cultivars being much smaller, but still of interest for further genetic progress.

The effect of reduced N fertilization was larger for grain yield than for protein concentration, suggesting that, in the conditions of this study, Nitrogen was more available during grain filling, as higher soil temperatures favoured nitrification.

Highest reduction of grain yield and protein yield per hectare under reduced N fertilization was found in cultivars originating from the Fundulea breeding program, while the smallest reduction was found in cultivar Adelina (bred at Şimnic), suggesting that selection at Fundulea, a site with high natural N fertility, could have masked differences among genotypes in efficiency of N use.

The limited variation in the response to reduced N fertilization, found among the tested Romanian cultivars, suggests the need for exploitation of a wider germplasm pool, including wild relatives and landraces.

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