DOES NITROGEN BALANCE SURPLUS DONE AT FIELD LEVEL HELP TO ASSESS ENVIRONMENTAL EFFECTS OF VARIABLE NITROGEN APPLICATION IN WINTER WHEAT?

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ABSTRACT

Increased nitrogen use efficiency (NUE) is important as a specific consideration to decrease negative impacts of nitrogen (N) on the environment and provide better crop quality. One of the methods available to increase NUE is to use sensor-based diagnostic information for variable N application (VNA). To assess the environmental effect of VNA, field strip-trials were conducted using early spring soil N_{min} sampling, an active optical sensor (AOS) – OptRx (Ag Leader Technology), spatial grain yield data, and dense spatial information on wheat N content in straw and grain to calculate nitrogen surplus (N_{sur}). Strips were fertilized alternately with a variable or uniform N dose. The use of AOS for variable N application did not significantly reduce N_{sur} within both investigated fields. However, the site-specific N balance maps indicate where the areas more prone to N_{sur} are located within the fields. This allows investigation of which site-specific factors are most responsible for N_{sur} in these regions and what could be done to reduce the negative effect of N_{sur} on the environment in the future.

Keywords: winter wheat, active optical sensor, N balance surplus

INTRODUCTION

Current agricultural management practices seek to increase NUE to meet the need for increased food production, to improve on-farm profitability and, hence, to improve the economic resilience of the EU's farmers (Diacono et al., 2013), while at the same time reducing N pollution associated with crop production. Therefore, in many European countries N is used with restrictions required by EU regulations that were enacted to increase NUE. This is particularly important in wheat production because this crop in EU accounts for about 48% of cereal production and uses about 25% of total N-fertilizer applied (Sutton et al., 2011). One of the methods applied to increase NUE is the use of sensor-based diagnostic

information for variable N application (McVeagh et al., 2012; Solie et al., 2012). However, due to the complex N turnover, NUE is difficult to measure at field level and thus to assess environmental effects of different N management approaches, including VNA. Calculation of NUE as grain production per unit of N applied has the disadvantage that NUE increase is not directly proportional to N rate increase. However, implementation of VNA does not always reduce N rates in comparison with uniform N application. On fields showing high spatial variability of N soil availability (N_{min}), the use of VNA often redistributes N within the field to minimize N surplus (N_{sur}).
The aim of the research was to determine if N balance surplus done at field level helps to assess environmental effects of variable nitrogen application in winter wheat.

MATERIALS AND METHODS

The research was conducted in 2012/2013 growing season in Poland on two production fields of similar size of 20.5 ha each, cropped with winter wheat (*Triticum aestivum* L.). Field A located in central Poland (52° 4' N 21° 10' E) was sown with cv. *Bamberka*. Field B located in Lower Silesia, Poland (50° 48' N 17° 5' E), was sown with cv. *Julius*. Field A is characterized by flat surface with denivelation of ~1 m, while field B has undulated surface with denivelation of ~ 9 m and maximum slope up to 6%, in south-western and north-western parts of the field. Soils of field A and B are characterized in Table 1.

Table 1. Soil characteristics of field A and B.

Field	Parent material (CBDG, Geological map 1:500000)	Texture		Soil Reference Group WRB 2007
		Plough layer	Subsoil	
A	Alluvial: sands and silts	Silt loam (54 %), loam (43 %), sandy loam (3 %)	Sandy loam, loamy sand, silt loam, loam and others.	Mainly Haplic Fluvisols
B	Fluvial sands gravels and silts (West part), tills, glacial sands and gravels (North-East part) and clays, silts, sands and gravels with lignite (South East part).	Silt loam (86 %), loam (11 %) and sandy loam (less than 2 %).	Silt loam, sandy loam, loam and others.	Mainly Haplic, Luvic and Gleyic Phaeozems

The amount of monthly rainfall for the period from March to July was: 18.2; 25.8; 109.2; 165.4 and 37 mm on field A and 14; 55.1; 127; 94.7 and 20.1 mm on field B, respectively.

Strip-trial experimental design was implemented using precision agriculture techniques for on-farm research (Griffin et al. 2006). The fields A and B were divided respectively into 18 and 24 m wide strips going across the entire field length. On field A and B respectively, ten and six strips were fertilized alternately with a variable or uniform (fixed) N dose, allowing side-by-side comparison of the two N application techniques. Total N applied (N_{app}) was calculated as the sum of the first uniform N rate and second uniform or variable N rate (Table 2).

Table 2. Rates and dates of nitrogen application.

Field name	Nitrogen rates (kg·ha^{-1})		
	First, whole field uniform	Second (GS 32†)	
		uniform	range of variable rate
A	60 (GS 24†)	80	55-105
B	73.6 (GS 21†)	48	30-70

† - growth stage according to Zadoks et al. (1974)

All agricultural managements, except for N application, were performed by the wheat producers. In spring time, before the first uniform N application, soil samples were collected to determine Nmin content in the layer 0-60 cm. Locations to take soil samples were chosen to cover different wheat growing conditions. Each soil sample represented an area of approximately 1 ha.

Two active OptRx™ optical sensors (Ag Leader Technology) installed on front tractor mounted brackets were used for variable N rate applications based on crop reflectance. This data coupled with geographical coordinates were logged and used to calculate the Normalized Difference Vegetation Index (NDVI) (Rouse et al., 1973). A built-in algorithm for winter wheat grown in Poland, supplied with the Integra datalogger and software (Ag Leader Technology) was used to generate and apply the variable N rates. During the second topdress application, more N was applied to the poorly developed areas in the field to maintain tillers and grain number. Before harvest time 352 and 234 samples of 10 whole wheat tillers with spikes, respectively on field A and B, were hand collected to determine: dry matter and N content of grain and straw and a harvest index (HI). Grain yield (GY) was measured utilizing the yield monitors mounted on Class Mega 360 and Class Lexion 580 harvesters, respectively on field A and B, equipped with DGPS data logging. Grain protein content was measured using a FOSS Infratec™1241, straw N content was determined using Kjeldahl method. Information on grain and straw N content, HI and GY allowed to calculate total above-ground plant N uptake (N_{upt}). N_{sur} within a field was calculated, after a modification of the methodology given by Zillman et al., (2006), as the difference between the sum of N_{min} determined at the beginning of spring vegetation and total N applied (N_{app}) and total N_{upt} at harvest.

$$N_{sur} = (N_{min} + N_{app}) - N_{upt}$$

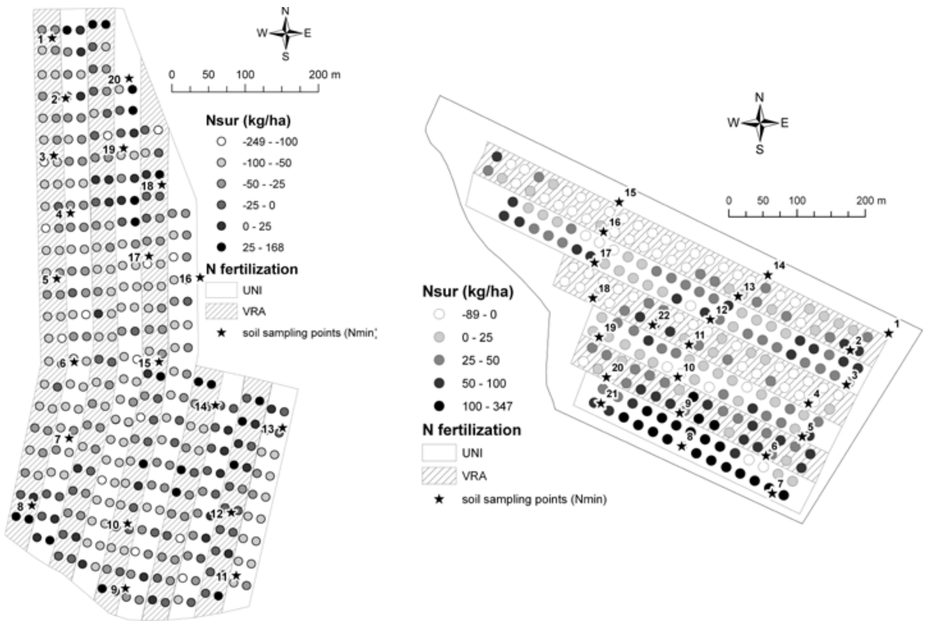
To receive N_{sur} data for each of the plant sampling locations, N_{min}, N_{app} and GY data were interpolated using ordinary kriging method, implemented in ArcGIS 9.3 software (Esri). Analyses to assess environmental effects of variable N application on N_{sur} were performed using Statistica 10 (StatSoft Inc.) statistical software.

RESULTS

In both investigated fields N_{sur} was unaffected by the mode of N application. Independently from N application method, in locations where the N rate applied was relatively low but N_{upt} was high due to high GY and high N_{min} content, the difference resulted in a negative value designated as N deficit (N_{def}) (Fig. 1A and 1B, Table 3). N_{def} was confirmed for 84.7 % (298) and 27.4 % (64) of the plant sampling points respectively within the whole field A and B. This indicates that field A, with flat surface was less prone to N_{sur} after harvest than field B distinguished by undulated surface. This observation is consistent with the fact that on the foot and toe slope on southern, part of field B, N subsuperficial runoff took place as soil N_{min} content in soil sampling point no. 8 equalled 225 $kg \cdot ha^{-1}$ versus 60.3 $kg \cdot ha^{-1}$ of the field A average (Fig. 1A). On other lower, northern part of this field (sampling points 15 and 16), where rather superficial water flow took place, negative or only slightly positive N balance was observed. Analysis of correlation between N_{sur} and its components showed that on field A, N_{upt} effected N_{sur} in the highest degree, independently from the N application mode (R^2=0.86-0.92). The same regularity was confirmed for strips fertilized with variable N rate on field B (R^2=0.52), but in areas where uniform N rate was applied, N_{sur} showed the highest correlation with N_{min} content (R^2=0.71). Variable N rate showed relatively week relationship with N_{sur}, with R^2 of 0.15 and 0.16, respectively for field A and B.

Table 3. Influence of nitrogen application mode on N_{sur} ($kg \cdot ha^{-1}$)

Nitrogen application mode	average	min	max	CV (%)
	Field A			
variable	-26.5	-248.7	168.0	141.3
uniform	-41.9	-115.9	53.7	81.2
$LSD_{0.05}$	36.4			
	Field B			
variable	11.9	-89.0	112.4	554.4
uniform	57.6	-66.1	347.0	124.1
$LSD_{0.05}$	71.7			



A B

Fig. 1. Maps presenting N_{sur} variability within examined fields A and B

CONCLUSIONS

The use of AOS for variable N application did not significantly reduce N_{sur} within both investigated fields. However, the site-specific N balance maps indicate where the areas more prone to N_{sur} are located within the fields. This allows investigation of which site-specific factors are most responsible for N_{sur} in these regions and what could be done to reduce the negative effect of N_{sur} on the environment in the future. Soil and topography related factors, effecting N_{min} content and N_{upt} seem to influence stronger N_{sur} than the method of N application. Consequently, the algorithms used for variable application of N in winter wheat should also take these factors into consideration.

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