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Strategies for site-specific nitrogen fertilization with respect to long-term environmental demands

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Abstract

Long-term field trials were implemented in three regions of Germany, differing in climatic conditions and soil properties, to evaluate different site-specific nitrogen fertilization approaches over several years with regard to N efficiency, yield and environment. The strategies tested were mapping approaches on the basis of site-specific yield potential and spectral information and, alternatively, an on-line approach using the Hydro N sensor. Results from the first year are presented. N efficiency could be increased by mapping approaches on sites with low yield potential. Total yield however was not noticeably affected. Sensor based N application reduced variability in the field but only slightly increased total yield. On the other hand, N efficiency was significantly reduced on shallow soils. The first results indicate that including yield potential in site-specific N recommendation could be an essential step to make plant nutrition more environmentally sound.

Keywords: site-specific N application, yield potential, mapping, N Sensor, N efficiency

Introduction

Site-specific nitrogen application focuses on optimum yield in each part of the field. Partly, fertilization strategies aim at reducing spatial heterogeneity of crops (Wollring et al., 1998). A commonly used approach is a sensor based on-line fertilizer application (Hydro N sensor) (Lammel et al., 2001). Frequently, spatial differences in yield are not due to N supply but due to soil physical properties influencing water availability to plants (Maidl et al., 1999; Cupitt and Whelan, 2001). The efficiency of nitrogen fertilization is significantly reduced on sites of low water availability (Geesing et al., 2001). Thus, from an environmental point of view, site-specific N fertilization should aim at adjusting application rate more closely to local yield potential rather than at making crops more homogeneous.

So far, few results are available on long-term effects of any fertilizing strategy on site-specific yield, soil fertility or nitrogen losses. Therefore a number of long-term field trials were implemented. In the following, the different fertilizing strategies applied will be discussed by presenting results from the first year of these experiments.

Materials and methods

The trials, being performed at least till 2005, were designed as static strip plots (non-randomized strips, 12 or 15 m broad, 6 to 10 replications depending on field). They are located in three regions of southern Germany, differing in climatic conditions and soil properties. The crops change from year to year due to farm-specific crop rotation. In this paper, results only from winter cereals will be presented, being grown on two fields in 2002 (Table 1).

Table 1. Characteristics of the trial fields.

		field A	field B
farm		Gieshügel	Scheyern
average temperature	[°C]	8.9	7.6
average precipitation	[mm]	550	805
field area	[ha]	15	6
soil type		silty loam to loamy clay	sandy to clayey loam
source of heterogeneity		soil depth, clay content	soil texture, topography

The strategies tested each year on the same strips are:

I uniform fertilizer application corresponding to farmers' practice and official recommendations

II site-specific fertilizer application according to mapped yield zones and spectral information based on reflection measurements of biomass and N-content (mapping approach). The amount of nitrogen applied depends on expected yield potential and soil properties (water availability, potential N mineralization). In general, this means low N input on water limited sites with low yield expectation and vice versa. Exception on field B: reduced N input also on sites with high yield potential because of high N supply from colluvial soil.

III only at Gieshügel (field A): sensor controlled fertilizer application (Hydro N-Sensor, on-line approach).

For the delineation of yield zones (strategy II), several years of yield maps, soil maps, remote sensing or tractor based reflectance measurements are used. The evaluation of the different instruments as suitable tools for on-farm application is part of on-going investigations. For the year 2002, yield zones (low, medium, high) were demarcated predominantly according to yield patterns (3 years of yield maps), which were stable on both fields. The zones corresponded to about less than 85 % ('low'), 85 to 110 % ('medium') and more than 110 % ('high') of average yield in most of the years.

Nitrogen fertilization (amount, date) varied depending on site and cultivated crop (Table 2). With strategy II all three N dressings were varied on field A, whereas on field B the first dressing was kept constant. For strategy III, only the second and third dressing were varied on-line with the Hydro N-sensor, while the first dressing was applied uniformly at a reduced rate according to Hydro's recommendation.

The nitrogen status of crops and the biomass were mapped three times in the growing period, particularly at flowering or ripening, based on spectral reflectance measurements (Hydro N-sensor) (Lammel et al., 2001). Yield maps were recorded from each field using combine harvesters with yield monitors. In addition, yield was determined by hand cuts at 7 sites on field A and nitrogen uptake was determined. On every site and strip (strategy), 6 micro-plots (0.4 m^2 each) were sampled. On field B, larger plots (1.5 m x 12 m) distributed over the field (81 plots in total) were harvested with a plot harvester.

Statistical analysis was done with the software package SPSS 11.0 using a general linear model procedure. Relative nitrogen efficiency was calculated as percentage of applied N withdrawn by grain: relative N efficiency [%] = N withdrawal / N fertilization · 100.

Table 2. Cultivated crops and nitrogen fertilization in the trials 2002.

		field A		field B
Crop		triticale (*Triticum aestivum L. x Secale cereale L.*)		winter wheat (*Triticum aestivum L.*)
cultivar		Ticino		Biskay
growth stages	BBCH-Code*	25 / 32 / 59		24 / 31 / 51
N fertilization:			kg N ha^{-1}	
I uniform		70 / 40 / 40		60 / 70 / 70
II mapping	high yield	70 / 60 / 65		60 / 60 / 60 **
	medium yield	70 / 40 / 40		60 / 70 / 70
	low yield	60 / 30 / 20		60 / 50 / 50
III sensor	field average	60 / 55 / 50	-	

* Lancashire et al., 1991 ** colluvial soil

Results and discussion

As expected, the nitrogen application according to yield potential (strategy II) increased the spatial variability of biomass in the fields, while the sensor controlled N application on field A made triticale more homogeneous. This was shown by sensor recordings at the stage of flowering (BBCH 65 (Lancashire et al., 1991)) (Figure 1). The same trend was found in yield measurements, as discussed below (Tables 3 and 4). The correspondence of crop scanning and yield confirm results by Schmidhalter et al. (2001) who showed that the N sensor, used during ripening of cereals, is a suitable instrument to predict yield.

The hand cuts sampled at seven representative sites of field A (Table 3) as well as by plot harvests all over the field B (Table 4) show that strategy II decreased yield on sites with low yield

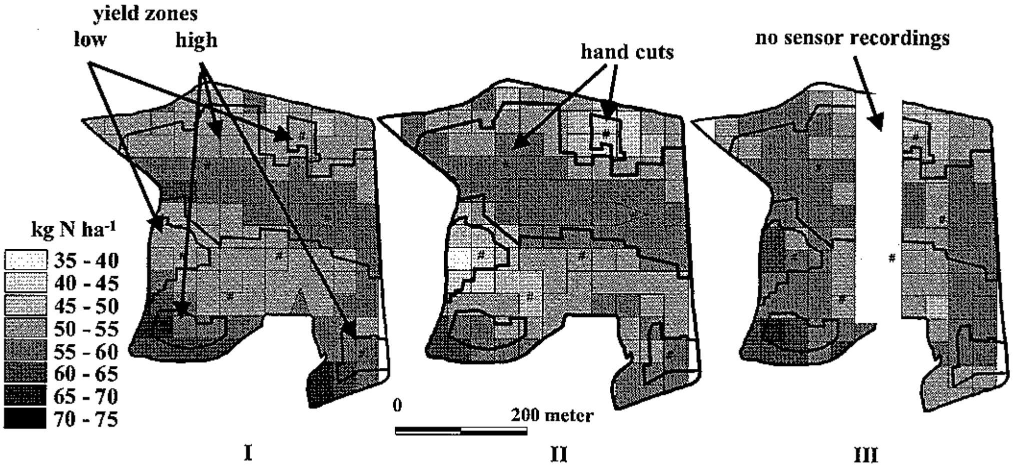

Figure 1. Scanning of triticale on field A at flowering stage by Hydro N sensor on adjacent strips (12 m width) of uniform application (I), mapping approach (II) and sensor based on-line application (III). Sensor recordings expressed as N application rate (low rate means low biomass and vice versa). Interpolation grid size: 36m x 36m. Points show site of hand cuts, bold polygon lines show low and high yield zones.

expectation by 0.4 to 0.7 t ha^{-1} when compared with uniform nitrogen application (strategy I). This was due to a reduced amount of nitrogen on these parts of the field. In high yielding areas, no significant differences in yield between the two strategies could be detected on either field. The apparent increase by 0.1 t ha^{-1} on field A was not significant and cannot be ascribed to the higher amount of nitrogen applied with strategy II (+ 45 kg N ha^{-1}). The same difference was found on zones with medium yield potential where N input was the same for both strategies (range of error). Since N rates for uniform application had been derived from expected average yield and the level of mineral N in soil at the beginning of vegetation period (N_{min}) was almost the same (about 45 kg N ha^{-1}) all over the field, this might indicate that on high yielding parts of the field it is not necessary to balance N in- and output for reaching yield potential, at least for a short time. On field B, comparable results were found, although with strategy II, nitrogen rate was reduced on sites with high yield expectations by 20 kg N ha^{-1}. This shows the necessity of taking into account a high nitrogen supply from soil when calculating N rates for sites with high yield potentials. However, no methods are available for mapping the site-specific potential of soil nitrogen supply.

Table 3. Effect of fertilizing strategy on yield and relative N efficiency of triticale (*Triticum aestivum L. x Secale cereale L.*) on different yield zones in field A as determined by hand cuts (7 sites). (Yields with same letters do not differ significantly at 95 % level, Tukey test; 'n' indicates number of yield determinations).

	yield [t ha^{-1}]				N efficiency [%]			
	yield zone			average	yield zone			average
	low (n = 2)	medium (n = 2)	high (n = 3)	(n = 7)	low (n = 2)	medium (n = 2)	high (n = 3)	(n = 7)
I uniform	7,88^{c}	9,21^{b}	10,03^{a}	9,04^{AB}	97	110	124	110
II mapping	7,19^{d}	9,34^{b}	10,13^{a}	8,89^{B}	102	112	99	100
III sensor	8,16^{c}	9,47^{b}	10,04^{a}	9,22^{A}	86	106	123	105

To compare on-line N application (strategy III) to the other strategies with results from hand cuts, the exact N rates based on the recordings of the sensor on the harvested plots have to be taken into account. The difference in total nitrogen applied was relatively small among plots. The highest N rate was applied on plots of low yield potential (165 kg N ha^{-1}). On sites with medium and high yield expectation, the total amount of nitrogen applied (156 and 148 kg N ha^{-1}, respectively) was almost the same as with uniform application (153 kg N ha^{-1}). However the sensor applied nitrogen dressings were quite different at different growth stages especially on sites with low and medium yield potential (60+65+40 and 60+56+40 kg N ha^{-1} with on-line sensor versus 69+40+44 kg N ha^{-1} with uniform application). The higher rates applied with the second dressing caused a slight increase in yield on sites with low and medium yield potential (0.25 to 0.30 t ha^{-1}).

On the sites with low yield potential, the differences in yield between the strategies were mainly due to crop density, which was highest for the on-line approach (III) and lowest for the mapping strategy (II). On the medium part of the field a higher grain weight was responsible for the higher yield by sensor-controlled application.

Fertilizing strategies designed to meet environmental demands (reducing the risk of N losses) should not lead to decreased total yields of fields. This was attained by N application based on yield potential as well as based on on-line sensor when compared to uniform application. The results from hand cuts (Table 3) and plot harvesting (Table 4) as well as yields determined by combine harvester (e.g. on field A: strategy I 8.23 t ha^{-1}, strategy II 8.23 t ha^{-1}, strategy III 8.28 t ha^{-1}) show that on both fields yield reduction by the mapping approach (strategy II) was not significant. On the other hand, the slightly higher average yield with sensor based N application determined with hand cuts (0.18 t ha^{-1}) could be neglected when the whole field was harvested (0.05 t ha^{-1}).

Table 4. Effect of fertilizing strategy on yield and relative N efficiency of winter wheat (*Triticum aestivum L.*) on different yield zones in field B as determined by plot harvesting. (Yields with same letters do not differ significantly at 95 % level, Tukey test; 'n' indicates number of yield determinations).

	yield [t ha^{-1}]				N efficiency [%]			
	yield zone			average	yield zone			average
	low (n = 13)	medium (n = 42)	high (n = 26)	(n = 81)	low (n = 13)	medium (n = 42)	high (n = 26)	(n = 81)
I uniform	8,84^{c}	9,47^{b}	9,97^{a}	9,43^{A}	83	90	97	90
II mapping	8,41^{d}	9,52^{b}	10,02^{a}	9,32^{A}	93	91	107	93

Relative nitrogen efficiency corresponded well with N input (higher efficiency with reduced input) on each management zone (Tables 3 and 4). On light or shallow soils (low yield), the highest efficiency was found with strategy II indicating that yield losses by reduced N rates were less distinct than positive environmental effects. This confirm results by Schmidhalter et al. (2002), who found slightly reduced N leaching rates with strategy II on field B. The significant decrease in N efficiency on high yielding parts of field A (Table 3) show that the additional N supply with strategy II could be used by plants only to a limited extent. At the moment, it is not clear whether this is due to a high N mineralization from soil in this particular year (relatively wet season) or it is a general effect, which has to be considered in future management decisions. Nevertheless relative N efficiency was almost 100% indicating that the same amount of N was withdrawn by harvested grains as N applied.

Despite increased yield, the sensor controlled fertilization resulted in the lowest N efficiency on sites with low yield potential. On the other parts of the field, it was almost the same as with uniform nitrogen application. Because the development of this fertilizing system mainly focused on optimizing yield on all parts of the field (Wollring et al., 1998), it is not surprising that on sites with high potential for N losses the ratio of applied to withdrawn nitrogen is increased.

Conclusions

The variation of nitrogen fertilization according to maps of yield potential seems to be suitable to increase the utilization of applied N by plants, in particular on sites with a high risk of N loss. On the other hand, the risk of reduction in total yield seems to be negligible. Nevertheless the amounts of N applied on sites with high as well as low yield expectations have to be optimized.

In addition, the results confirm the potential of the N sensor to optimize the yield on all parts of the field. But from an environmental point of view, the present fertilizing philosophy connected with the N sensor should be improved (N efficiency on light or shallow soils), at least for fields differing strongly in soil characteristics (data not reported). A combination of the sensor and mapping approach may contribute to this.

By discussing these first results, one has to consider that they were gained in a year with comparatively high precipitation over the vegetation period on each experimental site. The applied strategies might have shown some different results in a drier year. Further, the question has to be answered in the forthcoming years how the different strategies influence site-specific potential of yield and N losses in the long term.

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