Residual effects of different N fertilizer treatments on wheat growth and yield

Klaus Sieling[1], Henning Kage[1] and Olaf Christen[2]

[1] Christian-Albrechts-University, Institute of Crop Science and Plant Breeding, Hermann-Rodewald-Str. 9, 24118 Kiel, Germany,
www.pflanzenbau.uni-kiel.de, Email sieling@pflanzenbau.uni-kiel.de; kage@pflanzenbau.uni-kiel.de
[2] Martin-Luther-University Halle-Wittenberg, Institute of Crop Science and Agronomy, D-06099 Halle/Saale, Germany
www.landw.uni-halle.de/lfak/inst/iap/allgbau.html, Email: christen@landw.uni-halle.de

Abstract

In 1990/91-1998/99, different N treatments including slurry and mineral N fertilization were tested on a pseudogleyic sandy loam (Luvisol) in NW Germany. Simple N balance of the plots varied between –710 kg N/ha and +1,490 kg N/ha. In 1999/2000 –2001/02, unfertilized wheat crops were grown to investigate the residual effects of the former N fertilization on N mineralization and crop growth and grain yield. Grain yield decreased from 692 g/m^2 in 2000 to 357 g/m^2 in 2002 and N uptake by the grain and straw from 109 kg N/ha in 2000 to 59 kg N/ha in 2002. Wheat recovered less than 3 % of the differences in the N balance in the 3 years.

Media summary

Differences in the N balance of 2,200 kg N/ha due to varying N fertilization resulted in small differences (65 kg N/ha) in N offtake by the wheat grain during the following three years without N fertilizers.

Key Words

Residual effects; winter wheat; N fertilization; critical N dilution curve.

Introduction

In the long term, changes of N input (e.g. amount of N fertilization) or N output (e.g. N offtake by the grain) can affect soil N dynamics (Glendining et al. 1996). A negative N balance leads to nutrient exhaustion. In contrast, a large N surplus increases soil N amount, and, in consequence, potential soil N mineralization, which may promote crop growth and support yield formation. In general, organic fertilizers as slurry or farm yard manure boost soil organic matter more than mineral fertilizers (Glendining and Powlson 1995; Jenkinson et al. 1994).

In 1990/91-1998/99, 12 different management treatments including slurry and mineral N fertilization were tested (Sieling et al. 1998). In 1999/2000-2001/2002, all plots remained unfertilized in order to investigate residual effects of the former N treatments without any interaction with the actual N fertilization.

The working hypothesis assumed that differences in the N balance of 2,200 kg N/ha (Table 1) between the two extreme treatments accumulated over 9 years affect the N mineralisation and crop growth, depending on the date and the extent of N release. In this paper, results obtained in winter wheat are presented.

Methods

Site and Soil

The factorial field experiment was performed at Hohenschulen, an experimental farm of the Christian-Albrechts-University of Kiel (NW Germany; 10.0? E, 54.3? N, 30 m a.s.l.)) on a pseudogleyic sandy loam (Luvisol: 170 g/kg clay, pH?6.7, 9 mg/kg P, 15 mg/kg K, 13 g/kg C_{org}). The climate of NW Germany can be described as humid. Total rainfall averages 750 mm annually at the experimental site, with ca. 400 mm received during April - September, the main growing season, and ca. 350 mm during October – March.

Treatment and design

In the growing seasons 1990/91 to 1998/99, soil tillage (conservation tillage without ploughing, conventional tillage), application of pig slurry (none, autumn, spring, autumn + spring), mineral N fertilization (0 - 240 kg N/ha) and application of fungicides (none, applications against pathogens of the stem, leaf and ear) were all varied in an oilseed rape (c.v. Falcon) – wheat (c.v. Orestis) – barley (c.v. Alpaca) rotation. Each year, the treatments occurred in all three crops of the rotation and were located on the same plots. After 9 years, the simple N balance (N fertilization minus N offtake by the grain minus N leaching) varied from –710 kg N/ha in the unfertilized plots up to +1,490 kg N/ha in the treatments receiving each year 240 kg N/ha as mineral fertilizer plus 80 kg N/ha as slurry in autumn plus in spring (Table 1). Based on the N balance, Brase (2003) estimated changes in the amount of total soil N that correlated significantly with measured values.

Table 1. Simple N balance† (kg N/ha) after 9 years (mean of all 3 crops)

	Mineral N fertilization (kg N/ha) in 1991-1999		
	0/0/0	40/40/40	80/80/80
Slurry application in 1991-1999 (80 kg N/ha each date)			
No slurry	-712	-231	+596
Slurry in autumn	-120	+152	+1,071
Slurry in autumn plus spring	+197	+571	+1,489

† N input minus N offtake by the grain minus N leaching

The wide range of difference in the N balance allowed us to investigate the residual effects of the former N treatments. To avoid interactions with current N fertilization, no slurry or mineral N fertilizers were applied in the following 3 years. Soil tillage was maintained as before, and fungicides were applied if required. Crop management not involving the treatments (e.g. seed date, application of herbicides and insecticides) was handled according to standard farm practice. The straw remained on the plots.

Before winter and in spring and summer fortnightly, plant samples were taken from 0.25 m^2, and tiller number and dry matter determined. At harvest, grain plus straw yield, ear number and thousand grain weight were measured. All values were corrected to 1 m^2. In addition, plant N concentration was measured using NIRS-method. Total N uptake was calculated by multiplying dry matter and corresponding N concentration.

Nmin (NO_3- plus NH_4-N) was determined on four dates (‘after drilling’, ‘end of autumn growth’ before winter, ‘beginning of spring growth’ before N fertilizer application, and ‘after harvest’) to 90 cm in 30 cm horizons. In spring, Nmin in 0 – 30 cm was quantified according to plant sampling.

Statistical analysis

Analyses of variance were done using the SAS statistical package. The year was used as a blocking factor. $LSD_{0.05}$ for former slurry treatment effects are based on year x tillage x slurry interaction effects, those for former mineral N treatments and slurry x mineral N interaction effects are based on year x tillage x slurry x mineral N interaction effects. Former tillage and fungicide effects were small and are not presented. Plant N concentration N_t (%) has been related to the aerial biomass DM (t/ha) according to the general equation:

$$N_t = a\mathrm{DM}^{-b}$$

a and *b* are constants, which were estimated using the NLIN procedure of SAS.

Results and Discussion

On average of all treatments, grain yield of wheat decreased from 692 g/m^2 in 2000 to 687 g/m^2 in 2001 and 357 g/m^2 in 2002. The corresponding figures for N uptake by the grain and straw of wheat are 109 kg N/ha in 2000, 76 kg N/ha in 2001 and 59 kg N/ha in 2002, respectively. Due to the former N treatments, average N uptake varied between 72 kg N/ha in the unfertilized plots and 93 kg N/ha in the plots receiving slurry in autumn and in spring plus 240 kg mineral N/ha each year (Table 2). During the growth period, Nmin in 0-30cm remained unaffected indicating that the crop utilized all N mineralized. At the beginning of the experiment in autumn 1999, Nmin in 0-90 cm was higher in the fertilized plots; however, these differences disappeared in the following years.

Table 2. Effect of former N treatments (slurry and mineral N fertilization in 1991-1999) on average annual N uptake by straw plus grain (kg N/ha) of winter wheat at harvest without actual N fertilizers (mean of 2000-2002)

	Mineral N fertilization (kg N/ha) in 1991-1999			Mean
	0/0/0	40/40/40	80/80/80	
Slurry application in 1991-1999 (80 kg N/ha each date)				
No slurry	71.8	74.5	77.4	74.6
Slurry in autumn	73.0	83.9	91.5	82.8
Slurry in spring	73.3	79.3	89.8	80.8
Slurry in autumn plus spring	74.7	85.0	93.4	86.4
Mean	74.7	80.7	88.0	

$LSD_{0.05}$ for slurry treatment: 8.8

$LSD_{0.05}$ for mineral N treatment: 9.0

$LSD_{0.05}$ for slurry x mineral N treatment: n.s.

Accumulated over 3 years, a surplus of 2,200 kg N/ha resulting from the former N treatments caused a difference in N uptake of 65 kg N/ha. The wheat crop has used less than 3 % of the N surplus. Without mineral N, slurry N effect seemed to be negligible. They were more pronounced if combined with 120 or 240 kg/ha mineral N fertilizer.

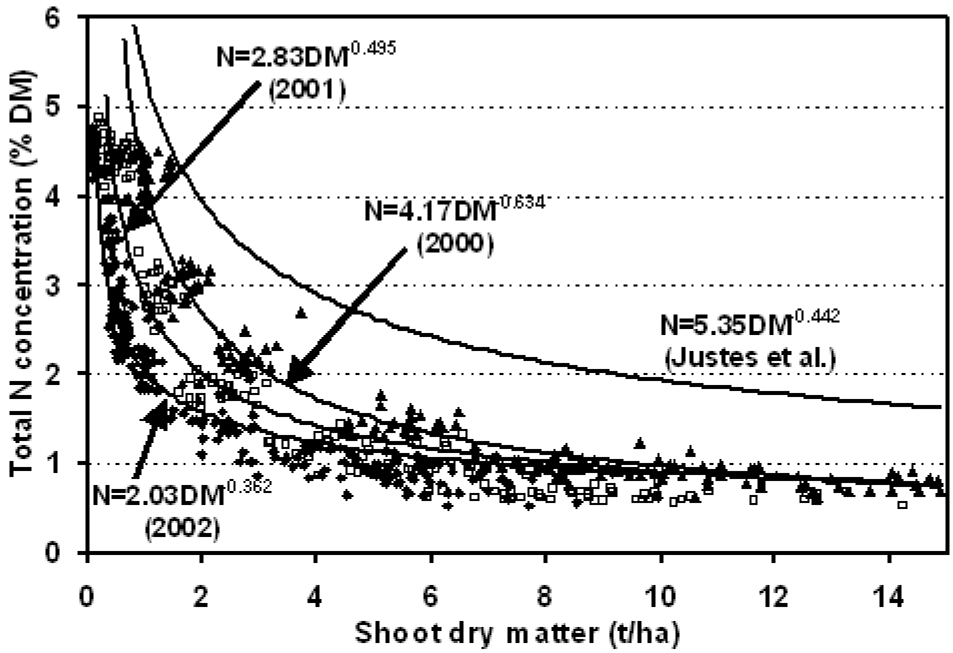

Figure 1. Critical N dilution curve of winter wheat in 2000 (▲), 2001 (□) and 2002 (?). The curve published by Justes et al. (1994) represents optimal growth conditions.

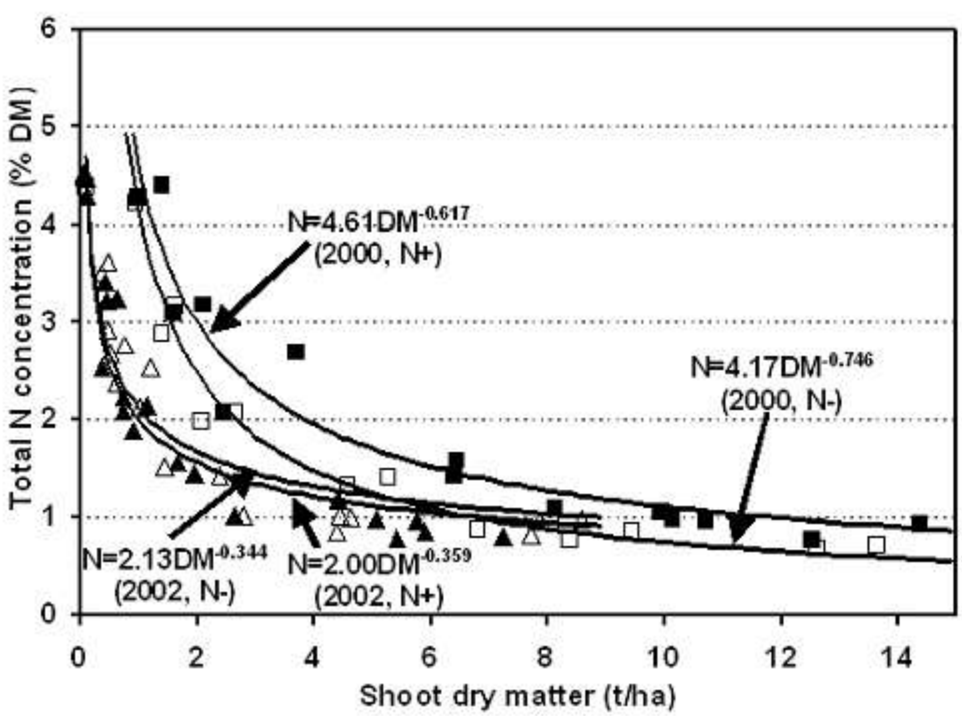

Figure 2. Critical N dilution curve of winter wheat in 2000 (□) and 2002 (r). Open symbols represent the former unfertilized treatment; solid symbols represent the treatment with slurry in autumn and in spring plus 240 kg mineral N/ha in 1991-1999.

N mineralization decreased over the 3 years as indicated by the lower level of the N dilution curve (Fig. 1). The lower level of the curves compared with that published by Justes et al. (1994) which represents optimal growth demonstrates that the wheat crop suffered in all years from N shortage. In the first year (2000), the curves of the two extreme N treatments (no N fertilizers vs. 80 kg N/ha as pig slurry in autumn and in spring plus 240 kg N/ha each year) differed clearly, whereas in the third year (2002) they were similar (Fig. 2).

Changes in the N mineralization affected significantly the number of grains per ear and the thousand grain weight (Table 3). It can be assumed that, due to the climate conditions at this site (slow soil temperature increase in spring), N release mainly occurred in May and June when tillering has already been completed. This is in good agreement with earlier results obtained by Teebken and Sieling (1995) at the same site.

In our trial, both N types led to similar N release and yield effects, which is in contrast to other experiments (e.g. at Rothamsted, GB), where large differences between the residual effects of organic and of mineral N fertilizer were found (Glendining and Powlson 1995; Glendining et al. 1996; Jenkinson et al. 1994). This may be due to the relatively short accumulation period of 9 years and/or to the use of pig slurry as organic fertilizer with 70-75 % NH_4-N compared to farm yard manure.

Table 3. Effect of former N treatments (slurry and mineral N fertilization in 1991-1999) on yield components of winter wheat without actual N fertilizers in 2000-2002

Slurry application in 1991-1999	Mineral N (kg N/ha)	Ears/m^2	Grains per ear	Thousand grain weight (g)	Yield (g/m^2)
No slurry	0/0/0	339	33.9	40.0	461
	80/80/80	366	34.3	39.4	508
Slurry in autumn plus spring	0/0/0	379	32.7	40.9	515
	80/80/80	380	35.4	41.0	572
$LSD_{0.05}$		n.s.	1.1	1.1	94

Conclusion

Due to the former N treatments, simple N balances differed by 2,200 kg N/ha. After 3 years without actual N fertilization, only 3 % of this difference (65 kg N/ha) could be observed in the total N uptake of wheat. This small N use efficiency indicates that N incorporated into soil during the last 9 years was released slowly. Within the years, residual effects of former N treatments decreased.

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