



Nitrogen efficiency of strip-till combined with slurry band injection below the maize seeds

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ARTICLE INFO

Keywords:

Ammonium depot
Broadcast application
Nitrate leaching
Nitrification inhibitor
Strip tillage

ABSTRACT

The slurry strip-till technique (STR) allows the combination of reduced tillage (strip tillage) with placed injection of slurry below the plant seed position. This technique should improve nitrogen (N) use efficiency of organic fertilizers. The present study aimed at evaluating the N use efficiency of the strip-till technique compared to conventional broadcast slurry application (CONV) to maize (*Zea mays* L.). Field trials with five treatments (unfertilized control, slurry strip-till with and without nitrification inhibitor (NI), conventional surface broadcast slurry incorporation with and without NI) were conducted on loamy sandy soils in northern and central Germany for three study years (2014–2016). Soil samples were taken from three soil layers (0–30 cm, 30–60 cm, 60–90 cm) in rows and interrows and analysed for soil mineral N (SMN) contents to ascertain N displacement out of the top soil. Furthermore, maize dry matter (DM) yields and N uptakes were determined to calculate N recovery efficiency (NRE) of the studied application systems.

SMN analyses showed an increased proportion (+60%) of ammonium nitrogen (NH₄-N) in SMN by addition of NI until 34–40 days after fertilization. Nevertheless, DM yields and N uptakes of STR treatments were not significantly different from CONV treated plots. The largest differences between treatments were observed at the earlier harvest dates compared to main harvest presumably due to the observed high NH₄-N concentrations in the slurry band, which are known to positively affect early growth of maize plants and better preservation of soil moisture in the STR system. The addition of NI did not lead to significantly increased DM yields and N uptakes. This was most probably due to negligible nitrate leaching in the early growth stages, i.e. NH₄-N stabilization took place but could not display its full potential. The STR treatments (STR and STR + NI) showed the highest N recovery efficiencies (up to 78%) among all treatments indicating the lowest potential N losses of this application system. Significant differences between STR and CONV treatments were found, however, only in 2014 and partially in 2015. Thus it can be assumed that the STR system is beneficial to enhance N efficiency of slurry application but further research is required to prove this.

1. Introduction

Today, one of the main challenges in agriculture is to mitigate nitrogen (N) losses related to fertilization and thus prevent harmful environmental effects due to nitrate leaching and greenhouse gas emissions. In the last decades several fertilization technologies have been developed to enhance N use efficiency. One of these is the slurry strip-till system which combines reduced tillage in the form of strip-tillage with placed injection of slurry below the plant seed position (Herrmann et al., 2012). Strip-tillage is a tillage system for row crops which originally became widespread in the USA for cotton, corn, peanuts, soya beans and others (Mitchell et al., 2009). In the strip-tillage method only the prospective seed row is loosened whereas the interrow space

remains un-tilled and covered by crop residues (Röseler et al., 2010). Recently developed techniques with auto-guidance systems allow injection of liquid organic fertilizers (slurry) below the subsequent seed row simultaneously with the tillage operation. Usually organic fertilizers are applied to the surface before being incorporated into the soil within four hours using a disc harrow or field cultivator as required by the current EU Nitrates Directive (91/676/EEC) and German Fertiliser Ordinance (FO, 2017). In contrast to broadcast surface application, injection of liquid manure is an effective method to mitigate ammonia (NH₃) emissions (Sommer and Hutchings, 2001; Hansen et al., 2003). However, it was shown recently that deep placement of organic fertilizers might enhance nitrous oxide (N₂O) emissions due to improved denitrification conditions (Chadwick et al., 1999; Leick, 2003).

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Nitrification inhibitors (NI) can contribute to reduce these N_2O emissions (e.g. Ruser and Schulz, 2015). Furthermore, NI are able to reduce nitrate ($\text{NO}_3\text{-N}$) leaching and increase the N use efficiency (Ruser and Schulz, 2015). The yield response of maize to NI added to fertilizers injected in spring strongly depends on the soil and site properties (e.g. temperature, pH, organic matter) (Schmitt et al., 1995).

Several studies reported an improvement of early growth and development of maize (*Zea mays* L.) and high N use efficiency following slurry injection (Schmitt et al., 1995; Petersen et al., 2010; Schröder et al., 2015). Field trials in northwestern Germany have shown that liquid manure injection with added NI led to increased N uptake and equal early growth and yields compared to broadcast application combined with starter mineral fertilization (N and phosphorus) (Federolf et al., 2016). Stabilization of slurry N in the ammonium form (49–69%) by adding NI could be ascertained up to 61 days after fertilization (Olfs et al., 2015) decreasing the risk of $\text{NO}_3\text{-N}$ leaching.

Studies determining $\text{NO}_3\text{-N}$ leaching in slurry strip-till systems are scarce up to now (Al-Kaisi and Licht, 2004). In studying dynamics of soil mineral N, Westerschulte et al. (2017) found significantly smaller N displacement out of the top soil after slurry injection compared to broadcast application. It was suggested that the reduced soil disturbance of the strip-till system might result in a decrease of soil organic N mineralization and thus contribute to smaller $\text{NO}_3\text{-N}$ contents of soil. However, previous studies which compared different soil tillage systems reported contradictory results. On the one hand lower mineral N contents in soil and $\text{NO}_3\text{-N}$ leaching were found in no-till and reduced soil tillage systems (e.g. Addiscott, 2000; Halvorson et al., 2001). However, no effect of tillage on $\text{NO}_3\text{-N}$ leaching was reported elsewhere (e.g. Shipitalo et al., 2000). Indeed, some studies showed higher $\text{NO}_3\text{-N}$ leaching with no-till compared to plough treatment due to the presence of macropores (e.g. earthworm tunnels) (Weed and Kanwar, 1996).

The main objective of this study was to evaluate whether slurry strip-till might contribute to an enhanced N use efficiency. Field trials in maize crops in Germany were conducted for three study years comparing surface broadcast slurry application versus injection (slurry strip-till) with and without NI to:

- i quantify yields, N uptakes and N balances
- ii evaluate stability of ammonium ($\text{NH}_4\text{-N}$) depots
- iii determine $\text{NO}_3\text{-N}$ displacement into deeper soil layers and
- iv calculate N recovery efficiency to evaluate potential N losses.

Gaseous N losses through N_2O and NH_3 emissions associated with slurry strip-till and broadcast application were recently reported for one of the study sites (Pietzner et al., 2017).

2. Material and methods

2.1. Field sites

Field trials were conducted at two sites in Saxony-Anhalt (northern and central Germany), 2014 in Lückstedt, 2015 and 2016 in Quellendorf (Table 1). Soil class of the study sites was loamy sand. Climate is continentally influenced with a long-term precipitation level of 564 mm (Lückstedt) and 532 mm (Quellendorf) and a long-term mean temperature of 9.2 °C (Lückstedt) and 9.7 °C (Quellendorf), respectively (long-term mean from 1981 to 2010).

Yearly precipitation during the study period amounted to 636 mm (2014), 493 mm (2015) and 391 mm (2016) and average temperature was 10.7 °C (2014), 10.3 °C (2015) and 11.4 °C (2016). Usable field capacities (UFC) of the soils were in the range of 26% (2016)–88% (2014) during the vegetation period (Fig. 1).

2.2. Experimental design and treatments

The trials were conducted using a randomized complete block

Table 1

Location and soil properties of the field trial sites.

Site	Lückstedt	Quellendorf
Latitude	52°50'N	51°75'N
Longitude	11°35'E	12°13'E
Soil Class	sandy loam	sandy loam
Soil type ^a	Stagnig Gleysol Luvisols	Gleysol
pH (CaCl_2)	6.5	5.7
Corg (%)	0.9	1.1
N_t (%)	0.08	0.1
CEC ($\text{cmol}_c \text{ kg}^{-1}$)	7.6	
P CAL ($\text{mg } 100 \text{ g}^{-1}$)	2.3	3.8
K CAL ($\text{mg } 100 \text{ g}^{-1}$)	4.0	14.9
Mg CaCl_2 ($\text{mg } 100 \text{ g}^{-1}$)	6.0	6.0

^a IUSS Working Group WRB (2014), CEC: cation exchange capacity.

design with four replicates and five treatments: (1) control treatment without any fertilization (CONTROL), (2) slurry strip-till without NI (STR), (3) slurry strip-till with NI (STR + NI), (4) conventional broadcast surface slurry incorporation without NI (CONV) and (5) conventional broadcast surface slurry incorporation with NI (CONV + NI). Blocks were arranged adjacent to each other. Each plot had a size of 12 m × 50 m. Before field trials started, crop rotation was sugar beets – maize – winter wheat. Soil tillage for these crops was plough based. A frost-sensitive non-leguminous catch crop mixture of phacelia (*Phacelia tanacetifolia* Benth.), sunflower (*Helianthus annuus* L.), flax (*Linum usitatissimum* L.) and buckwheat (*Fagopyrum esculentum* Moench) was sown and frozen off completely over the winter before treatments started. NI with the active ingredients 1H-1,2,4-Triazol and 3-Methylpyrazol (PIADIN[®], SKW Piesteritz, Wittenberg, Germany) was applied in Lückstedt and 3,4-Dimethyl-Pyrazol Phosphate (VIZURA[®], BASF, Ludwigshafen, Germany) in Quellendorf at a rate of 3 l ha⁻¹. In the STR treatments slurry was injected as a slurry band placed about 15 cm below the soil surface using an X-Till S machine (Vogelsang, Essen/Oldenburg, Germany) equipped with eight injection shares placed 75 cm apart. Soil was loosened by ploughshares which are placed in front of the injector at a depth of about 25 cm. Maize (*Zea mays* L., cv. ES Bombastic) was planted on 17 April 2014, on 30 April 2015 and on 18 April 2016 directly above the slurry band with a planting density of eight plants per m² and a row spacing of 75 cm in all treatments. In the conventional broadcast and control treatments shallow (6–8 cm deep) non-turning soil tillage was performed using a compact disc harrow. Slurry was applied simultaneously with soil tillage and incorporated close to the soil surface (depth of 6–8 cm) with the same compact disc harrow (AMAZONE Catros pro package system, Hasbergen, Germany) which had a special equipment to connect with a liquid manure barrel (21 m³, Holmer, Zunhammer, Traunreut, Germany) for slurry application. On 12 March 2014 an amount of 30 m³ ha⁻¹ cattle slurry (2.7% total N-N_t, Table 2) and on 9 May 2014 additional 70 kg N ha⁻¹ of mineral fertilizer (calcium ammonium nitrate) were applied to the fertilized treatments (CONV and STR) in Lückstedt. Organic fertilizer application in Quellendorf was conducted on 18 April 2015 with 19 m³ ha⁻¹ digestate (6.0% N_t) and on 9 April 2016 with 17 m³ ha⁻¹ digestate (7.4% N_t). Mineral N was not applied in 2015 and 2016. Total nitrogen fertilization rates were 151 kg N ha⁻¹ (2014), 112 kg N ha⁻¹ (2015) and 126 kg N ha⁻¹ (2016).

2.3. Field measurements, sampling and calculations

Soil samples were taken at depths of 0–30 cm, 30–60 cm and 60–90 cm before fertilization and at different times until harvest of maize plants and then analysed for their soil mineral N (SMN) ($\text{NO}_3\text{-N}$ + $\text{NH}_4\text{-N}$) contents (VDLUF, 2012). In the STR treatments soil was sampled both in the maize row and in the interrow. In the CONV and CONTROL treatments soil was sampled from the whole plot area. Therefore, 10 soil samples were taken per plot and depth and pooled to

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