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Enhanced nutrient use efficiencies from liquid manure by positioned injection in maize cropping in northwest Germany

Carl-Philipp Federolf[a,b,*], Matthias Westerschulte[a,b], Hans-Werner Olfs[a], Gabriele Broll[b], Dieter Trautz[a]

[a] Osnabrück University of Applied Sciences, Faculty of Agricultural Sciences and Landscape Architecture, Am Krümpel 31, 49090 Osnabrück, Germany
[b] University of Osnabrück, Institute of Geography, Seminarstraße 19 a/b, 49074 Osnabrück, Germany

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ABSTRACT

Maize (*Zea mays* L.), the dominating crop in northwestern Germany usually receives mineral nitrogen (N) and phosphorous (P) fertilizer side dressed (MSD) at planting as a starter to ensure proper early-growth development, on top on a usually nutrient demand covering manure application. Recently developed injection techniques, along with auto-guidance systems allow liquid manure injection below the maize seeds in a separate operation. Thus, the need for starter fertilizer might be obviated.

Field trials were conducted on seven sites in northwestern Germany to compare liquid manure broadcast application versus injection at recommended rate with and without addition of a nitrification inhibitor in 2013. Several treatments were tested with and without MSD (23–10 kg N–P ha^{-1}). In 2014, the trials were adapted to a proper two-factorial setup with additional reduced manure application rate treatments. Biomass accumulation and nitrogen uptake were assessed at V8 growing stage and at harvest.

Compared to broadcast application with MSD, liquid manure injection without MSD showed retarded early-growth, but equal yield and N uptake at harvest in both years. Adding a nitrification inhibitor to injected liquid manure led to equal early-growth and yield, but significantly increased N uptake by 7% in 2013 and 6% in 2014, respectively. Regarding the proper performance of reduced rate injection treatments, the increase in N use efficiency is even more noticeable. The reduction of P input did not influence early growth and yield. P use efficiency from manure is higher when manure is injected prior to planting.

These results indicate that liquid manure injection might reduce N and P surpluses in maize growing and therefore benefit farmers and environment.

1. Introduction

In northwestern Germany livestock husbandry traditionally has a major share in agricultural production. Long-term use of manures (often at rates higher than the phosphorous (P) demand of the crop) has led to P accumulation in many agricultural soils (Warnecke et al., 2010). Soil test values for P indicate no necessity for P fertilization on a large proportion of farmland in this area (Leinweber, 1996). In the last decade biogas plants, producing energy from the digestion of manure and plant biomass came up in the region leading to a further increase in manure formation. As nitrogen (N) and P in manures on many farms outbalance crop nutrient demand by far, large amounts of manure have to be exported out of this region (Warnecke et al., 2010).

Maize (*Zea mays* L.) is the dominating crop in the area, used as fodder and substrate for biogas plants (Keckl, 2015). Low soil temperatures at maize planting typically limit bioavailability of certain nutrients (Barber, 1995), as low root zone temperatures reduce the diffusion speed for P as well as nutrient acquisition due to reduced root growth (Imran et al., 2013). Ohlrogge (1962) showed a positive interaction of phosphate and ammonium applied in a band near maize seeds, when compared to the application of each nutrient alone. This interaction typically enhances crop early growth development and thus, farmers commonly apply a mineral starter fertilizer containing ammonia-N and water-soluble P. On farms with livestock, starters are commonly applied on top of the usual application of manure, which in most cases already covers N and P demand of the crop. This practice leads to N and P accumulations

* Corresponding author at: Osnabrück University of Applied Sciences, Faculty of Agricultural Sciences and Landscape Architecture, Am Krümpel 31, Osnabrück 49090, Germany.
E-mail address: c.federolf@hs-osnabrueck.de (C.-P. Federolf).

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in the soil, which are then prone to leaching and runoff (Touchton, 1988; Withers et al., 2000).

According to several studies from Europe (e.g. Petersen et al., 2010; Schröder et al., 2015) and North America (Beauchamp, 1983; Sawyer et al., 1991; Schmitt et al., 1995) manure injection appears promising to ensure proper early growth development and high nutrient use efficiencies. Bittman et al. (2012) and Chen et al. (2010) showed the importance of planting maize close to the injection bands, as higher distances impair early development and finally yields when compared to placed injection or banded mineral starter fertilizer. This gain in crop performance is due to increased chemical and spatial nutrient availability. Furthermore, injection of liquid manure is an effective method to mitigate ammonia emissions (Sommer and Hutchings, 2001), but N_2O emissions can be higher (Dosch and Gutser, 1995).

Using nitrification inhibitors in crop production can contribute to minimize nitrogen losses to the environment, as they are able to reduce nitrate leaching, as well as N_2O emissions and finally increase the nitrogen use efficiency (Ruser and Schulz, 2015). However, according to studies from McCormick et al. (1984) and Schmitt et al. (1995), yield response of maize to nitrification inhibitors added to spring injected manure is variable. Several soil and site properties (e.g. temperature, pH and organic matter) as well as management practices (placed injection versus soil incorporation) might impact the effectiveness of nitrification inhibitors (Bundy and Bremner, 1973; Keeney, 1980). Up to now most research was done with the compounds nitrapyrin (McCormick et al., 1984; Schmitt et al., 1995), dicyandiamid (Amberger, 1986) and dimethylpyrazol-phosphate (Zerulla et al., 2001).

McCarty and Bremner (1989) proved that both active ingredients (1,2,4 Triazol and 3-Methylpyrazol) of the product PIADIN® (SKW Piesteritz, Wittenberg, Germany) are able to inhibit nitrification separately. However, up to now only few publications on the use of this product exist (e.g. Misselbrook et al., 2014; Hu et al., 2013).

A series of field trials was established to monitor the growth response of maize to liquid manure broadcast application versus injection. The importance of mineral starter fertilizer was in scope as well as the addition of a nitrification inhibitor. The primary objective of the study was to evaluate placed liquid manure application to obviate the use of mineral starter fertilizers and therefore reduce N and P inputs without impairing maize yield and quality.

2. Material & methods

2.1. Sites

In 2013 and 2014, maize trials were conducted in cooperation with the extension service (i.e., the Chambers of Agriculture) in Lower Saxony (LS), North Rhine-Westphalia (NRW) and Schleswig-Holstein (SH, see Table 1 for details). Five sites (2; 4; 5; 6; 7) are located in regions with intensive animal farming on sandy soils. Due to long-term manure application, these soils are typically high to very high in soil P test levels (see Table 1). The Luvisols at sites 1 and 3 in cash cropping areas were medium to high in plant available soil P and did not receive high amounts of organic manure over the last decades.

Northwestern Germany is characterized by maritime climate. Mean annual air temperature at the study sites ranges from 8.6 °C to 10.4 °C from north to south, and mean air temperature from May to September ranges from 13.8 °C to 15.4 °C. Mean annual precipitation ranges from 742 mm to 880 mm (Ø 826 mm) with rainfall from May to September ranging from 323 mm to 376 mm (Ø 364 mm). In 2013, air temperature was 0.85 °C above long-term average and May to September rainfall was 73 mm below average for NRW and LS sites, but 20 mm above for SH sites, with a lack of precipitation in July and August. Temperatures were rather low in April delaying planting of maize at LS and SH sites. In 2014, air temperature was 1.3 °C above long-term mean with May to September precipitation rather close to average, but unusual rainfall distribution with high rainfalls in May and July. Despite of above-average air and soil temperatures in spring 2014 manure application and planting was delayed by two weeks at sites 4 and 6 due to unfavorable weather conditions. For further details, see Table 1.

2.2. Experimental design

The trials in 2013 were conducted using a complete randomized block design with four replicates and six treatments. The preliminary results demanded a more thorough investigation of the topic and thus in 2014 setup and treatments were adapted to a proper two-factorial setup. It was obvious to change to a two factorial setup to distinguish the main effects of liquid manure application (LMA) from mineral side dressing (MSD). Therefore, in 2014 it was a split-plot design with four replications. The treatment factors were liquid manure application (LMA, main plot) and mineral side dress (MSD, subplot). Each plot in 2013, as well as each subplot in 2014 were 7 m in length, 3 m in width and consisted of four rows (75 cm row spacing).

2.3. Treatments

In 2013 the following treatments were conducted: (1) a control treatment without any fertilization (C−), (2) manure surface banding followed by immediate incorporation into the top 10 cm of soil with MSD (B+), (3) LM injection treatment without and with MSD (I− and I+, respectively) and (4) injection with the nitrification inhibitor 1,2,4 Triazol and 3-Methylpyrazol (PIADIN®, SKW Piesteritz, Wittenberg, Germany) at a rate of 3 l ha^{-1}, also without and with MSD (I(N)− and I(N)+, respectively). For all injection treatments, the top of the manure band was placed 12 cm below the soil surface. The injectors used (Kotte Premaister (Kotte Landtechnik, Rieste, Germany) in NRW and Vogelsang X-Till (Vogelsang Maschinenbau, Essen (Oldb.), Germany) for LS and SH sites) both had four injection shares placed 75 cm apart and were equipped each with a 1000 l slurry tank, a rotary piston pump, and a precision dispenser to provide proper lateral and longitudinal distribution.

Maize was later planted directly above the manure band. Planting density was set to nine plants per m^2 on all sites. The planters had extra shares to place MSD next to the maize row. The MSD treatments were (1) no MSD (−) and (2) with MSD (+) using a blend of calcium ammonium nitrate (CAN, 50 kg ha^{-1}) and diammonium phosphate (50 kg ha^{-1}) to apply 23 kg N ha^{-1} and 10 kg P ha^{-1}. For "no MSD"-plots N-compensation of 23 kg N ha^{-1} of CAN was broadcast post-planting to keep nitrogen levels consistent. The nitrogen fertilization rate was calculated according to local standards (Baumgärtel et al., 2010). The recommended nitrogen fertilization rate is 180 kg N ha^{-1} reduced by preplant soil mineral nitrogen (SMN), N applied via MSD and site-specific conditions like recent organic fertilizer application and catch cropping. Application rates, liquid manure composition and applied nutrients are displayed in Table 2.

In 2014, the treatments for the factor LMA were: (1) control treatment without LM; (2) LM broadcast treatment (B) with surface banding followed by soil incorporation (0–10 cm), (3) LM injection treatment (I) and (4) injection with the nitrification inhibitor (1,2,4 Triazol and 3-Methylpyrazol, PIADIN®, SKW Piesteritz, Wittenberg, Germany) at a rate of 3 l ha^{-1} (I(N)). While for B, I and I(N) treatments the manure application rate was identically (further referred to 100%), another set of I and I(N) treatments was installed with reduced manure rates (66%; Ir and Ir(N), respectively). MSD treat-