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НОВЫЕ МЕТОДЫ И РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЙ ЛАНДШАФТОВ В ЕВРОПЕ, ЦЕНТРАЛЬНОЙ АЗИИ И СИБИРИ

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This monograph shall inform you about up to date methodologies and recent results in landscape research. It is intended as a guide for researchers, teachers, students, decision makers, stakeholders interested in the topic of landscape science and related disciplines. It provides information basis for decision makers at various levels, from local up to international decision bodies, representing the top level of landscape science in a very short form.

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ABSTRACT. The slurry strip-till technique (STR) allows the combination of reduced tillage (strip tillage) with placed injection of slurry below the later plant seed position. The present study aimed at evaluating the nitrogen (N) use efficiency of the STR technique compared to conventional broadcast slurry application to maize (Zea mays L.). Field trials were conducted on loamy sandy soils in northern and Central Germany. The results of three study years showed smaller N displacement out of the top soil of the STR treatments compared to broadcast slurry application. By addition of nitrification inhibitor (NI) an increased share of ammonium (NH4+) on soil mineral N up to 60% until 34 to 40 days after fertilization were determined. Nevertheless the NI did not lead to significant increased dry matter yields and N uptakes. Significant differences only were observed at the earlier harvest dates. The STR treatments (STR and STR+NI) showed the highest N recovery efficiencies (up to 56%) among all treatments indicating the lowest N losses of this application system. Thus the STR system can be assumed as a suitable approach to enhance N efficiency of organic fertilizers.

Резюме. Метод внесения жидкого навоза при полосной обработке почвы позволяет сочетать минимальную (полосную) обработку с местным внесением жидкого навоза ниже слоя последующей заделки семян. Настоящее исследование имело целью оценку эффективности использования азота жидкого навоза, вносимого при полосной обработке почвы под кукурузу (Zea mays L.), в сравнении с традиционным сплошным применением. Полевые опыты были проведены на супесчаных почвах в северной и центральной Германии. Результаты трех лет исследований показали меньшие потери N из верхнего слоя почвы в вариантах с использованием жидкого навоза при полосной обработке, в сравнении со сплошным применением. Использование ингибитора нитрификации повышало долю аммония в минеральном азоте почвы до 60% в период до 34-40 дней после внесения удобрения. Тем не менее, применение ингибитора нитрификации не привело к существенному увеличению выхода сухого вещества и выноса N. Существенные различия наблюдались только при ранних сроках уборки. Коэффициент использования N в вариантах с внесением жидкого навоза при полосной обработке почвы был максимальным (до 56%) среди всех вариантов, что указывает на наименьшие потери N при использовании этой технологии. Таким образом, рассматриваемую технологию можно считать подходом, обеспечивающим повышение эффективности N органических удобрений.

KEYWORDS: ammonium depot, broadcast application, nitrate leaching, nitrification inhibitor, strip tillage

Ключевые слова: аммониевый депо, широковещательная заявка, нитратное выщелачивание, ингибитор нитрификации, полосная обработка почв

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 technologies of fertilization have been developed to enhance N use efficiency. One of this is the slurry strip-till system which combine reduced tillage in the form of strip-tillage with placed injection of slurry below the later plant seed position [1]. In the strip-tillage technique only the
subsequent seed row being loosened whereas the interrow space remained un-tilled and covered by crop residues [2]. Recently developed techniques with auto-guidance system allow injection of liquid manure below the subsequent seed row simultaneously with tillage. In contrast to the commonly broadcast surface application, injection of liquid manure is an effective method to mitigate ammonia (NH₃) emissions [3]. Otherwise it was shown recently that deep placement of organic fertilizers might enhance nitrous oxide (N₂O) emissions due to improved denitrification conditions [4]. Using nitrification inhibitors (NI) can contribute to reduce N₂O emissions [5]. Furthermore, they are able to reduce nitrate (NO₃⁻) leaching [5]. 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 slurry broadcast surface application versus injection (slurry strip-till) with and without NI to: i. quantify yields, N uptakes and N balances, ii. evaluate stability of ammonium (NH₄⁺) depots, iii. determine NO₃⁻ displacement into deeper soil layers and iv. calculate N recovery efficiency to evaluate N losses.

MATERIAL AND METHODS
Field trials were conducted at two sites in Saxony-Anhalt (northern and Central Germany), 2014 in Lückstedt (52°50’N, 11°35’E), 2015 and 2016 in Quellendorf (51°75’N; 12°13’E). Soil class of the study sites is loamy sand with the main soil types Stagnic Gleysol-Luvisol (Lückstedt) and Gleysol (Quellendorf). Climate is continentally influenced with a precipitation level of 564 mm and 532 mm and average temperature of 9.2 °C and 9.7 °C for Lückstedt and Quellendorf, respectively on the long term (mean from 1981 to 2010). The trials were conducted using a complete randomized block 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). For the stabilized treatments NI (PIADIN®- SKWP, VIZURA®- BASF) at a rate of 3 l ha⁻¹ was added. In the STR treatments manure was injected as manure band placed about 15 cm below the soil surface using an X-Till S machine (Vogelsang, Essen/Oldenburg, Germany). Maize was later planted directly above the manure band. In the CONV treatments manure was immediately incorporated close to the soil surface (depth of 6-8 cm) by a disc harrow (AMAZONE Catros, Hasbergen, Germany). An amount of 30 m³ ha⁻¹ cattle slurry (2014), 19 m³ (2015) and 17 m³ digestate (2016) with N fertilization rates of 151 kg N ha⁻¹ (2014), 112 kg N ha⁻¹ (2015) and 126 kg N ha⁻¹ (2016) were applied (Figure 1).

Soil samples were taken in depths of 0-30, 30-60 and 60-90 cm before fertilization and at different times until harvest of maize plants and then analysed for their soil mineral N (NO₃⁻+NH₄⁺) contents [6]. Aboveground biomass was collected at three different times (mid of July, August and September) in an area of 2 m². Fresh weight was measured and a representative sample was taken to determine dry matter (DM) content and total N contents to calculate N uptake of plants. N balance was calculated by the subtraction of applied fertilizer-N from plant N uptake for each treatment. Nitrogen recovery efficiency (NRE) was calculated in accordance to Federolf et al. [7]

Figure 1- Strip-Till application of liquid manure on the experimental field
RESULTS AND DISCUSSION

Stability of ammonium depots and N displacement in soil. Analyses of soil mineral N (SMN) of fertilized rows in the STR treated plots showed that the addition of NI resulted in 53 % (2014), 60 % (2015) and 31 % (2016) higher NH$_4^+$ contents 34 to 40 days after slurry application, respectively. By contrast, no significant effect of NI was found at slurry broadcast application. Reason for this might be the higher contact surface for microorganisms as reported by [8]. During the whole study period (2014 and 2015) higher proportion of SMN were observed in the top soil (0-30 cm) of the STR treated plots when compared to the broadcast application (Figure 2), which indicates that N displacement was distinctly smaller for the slurry injection. This observation also was confirmed by other studies [9, 10]. Thus, SMN is more plant available [11].

Dry matter yields and N uptakes. Highest DM yields of all three study years were observed in 2014 (max. 207 dt ha$^{-1}$) whereas in 2016 DM reached only 38 % of the respective value of 2014. These differences were caused by low precipitation during vegetation period in 2016 (only 151 mm from May to September). At final harvest mean DM of maize plants in the CONTROL treatment was significantly lower than DM of the fertilized STR treatment in all three seasons, whereas no significant differences between STR and CONV treatments were found (Figure 3).

These results contradict the findings of other studies which reported higher yields at injection of liquid manure compared to broadcast application [11, 12]. Significant differences between the STR and CONV treatments only were observed at the earlier harvest dates in July and August. These observations are in accordance with the study of Federolf et al. [7].

They reported major differences between the treatments in June while much of these differences faded out at the harvest. It is known that the application of an NH$_4^+$-based fertilizer with added NI lowered rhizosphere pH and increased P uptake of plants and thus might positively affect early growth of maize plants due to enhanced lateral root and fine root proliferation [13, 14]. Above this covering of soil with plant material at the strip-till system better preserve soil moisture [15] which might have resulted in better growth conditions in the dry spring months of all three seasons compared to conventional soil tillage. The addition of NI did not increase DM yield significantly. However both STR treatments showed highest DM and N uptake in all three seasons. It can be assumed that solely the placement of high N concentrated NH$_4^+$ bands in the STR technique might delay turnover of the applied NH$_4^+$ due to reduced soil-manure interaction [16]. But as shown by Westerschulte et al. [10] the abundance of NH$_4^+$-N in the injected slurry band was higher when a NI was added. For our study it can be suspected that no relevant leaching did occur in the early growth stages of maize because of low precipitation amounts. Consequently, this will cover the effect of NI as also shown by Laurenz [8].

Similarly to DM yields highest N uptakes up to 233 kg ha$^{-1}$ were determined in the 2014 season while in 2016 the significantly lowest N uptakes among all three study years were observed with a maximum of 90 kg ha$^{-1}$. These results go along with the low biomass production of maize plants in this year. Compared to CONTROL and CONV+NI treatments N uptake was significant enhanced in the STR treated plots by 70 and 62 kg ha$^{-1}$ in 2014, respectively. Differences between treatments were markedly lower in 2015 and
2016, but accompanied by a very high spatial variability of N uptakes with high coefficients of variation within replications. Compared to the CONTROL treatment mean N uptake of 2014-2016 was significantly improved in the STR and STR+NI treatments by 38 and 30 %, respectively (cf. Figure 3). N uptake of STR treatments was 28 to 33 kg ha\(^{-1}\) higher compared to CONV treatments. Due to the high variation between replications these differences were, however, not significant.

![Figure 3- Dry matter yields and nitrogen (N) uptakes (means 2014-2016) for the control (CONTROL), strip-till (STR) and conventional treatment (CONV)](image)

**Figure 3**- Dry matter yields and nitrogen (N) uptakes (means 2014-2016) for the control (CONTROL), strip-till (STR) and conventional treatment (CONV).

**N balances and Nitrogen recovery efficiency.** Apart from 2016 N balances were mainly negative indicating reduced potential of NO\(_3^-\) leaching. Similarly results were obtained in the studies of Federolf et al. [7, 11] and show the potential of maize to use high amounts of fertilizer N. In contrast, N balances were positive for the 2016 season because of unfavorable growth conditions resulting in lowest biomass production and lowest N uptake among the three trial years. In accordance to Federolf et al. [7] highest NRE was found in the STR treatments compared to broadcast application. It can be suspected that highest proportion of applied N was recovered in the STR treatments because these systems led to enhanced N uptake, reduced N leaching and reduced NH\(_3\) volatilization by 43 % [17]. The observation of a higher risk of denitrification losses after slurry injection by favored denitrification conditions as shown in several studies [e.g.18] could not be confirmed in our study. As noted by Pietzner et al. [17] no significant differences in N\(_2\)O emissions between the STR and CONV treatment were observed. In general N\(_2\)O emissions were on a low level with maximum 2.1 kg N ha\(^{-1}\) yr\(^{-1}\) (CONTROL) whereas emissions were more affected by the prevailing weather conditions than by the applied application techniques [17].

**CONCLUSIONS**

1. Injection of slurry below the maize seeds by the STR technique led to smaller N displacement out of the top soil layer and thus potentially reduces the risk of NO\(_3^-\) leaching.
2. Higher N uptakes of plants and higher N recovery efficiencies were determined for the STR treatments indicating lower N losses and enhanced N use efficiency of applied organic fertilizer.
3. The effect of added NI inhibitor was primarily detected in the early maize development by providing a stable high NH\(_4^+\) concentration in soil and is generally recommended to avoid NO\(_3^-\) leaching at high precipitation rates.
4. It can be assumed that the STR system is a suitable tool to mitigate nutrient losses in maize.
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