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Effect of organic and mineral fertilisers on maize nitrogen nutrition indicators and grain yield

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Abstract

The study examined the effect of organic and mineral fertilisers on soil nitrogen (N) supply, maize grain productivity and correlation of mid-season plant and soil indicators with grain yield and soil mineral nitrogen (N_{min}) at harvest. Field experiments using the short-season maize (*Zea mays* L.) cultivar 'Agiraxx' were conducted in 2015–2017 on a sandy loam soil in Central Lithuania. Prior to sowing, the soil was applied with 170 kg ha^{-1} of N as ammonium nitrate, pelletized cattle manure (PCM), pelletized poultry manure (PPM) or green waste compost (GWC), or as a combination of ammonium nitrate and organic fertilisers. The effects on soil N_{min}, maize nitrogen nutrition index (NNI), nitrogen uptake and grain yield were investigated. Mid-season measurements of NNI and soil N_{min} made at tasselling stage (VT) were strongly correlated (R^2 = 0.73–0.88). Sufficient maize N nutrition (NNI > 0.9) was achieved via the application of ammonium nitrate, PPM or the combination of ammonium nitrate and organic fertilisers. In these treatments at harvest N_{min} accumulation was also significant. PCM and GWC application resulted in insufficient maize N nutrition with mid-season NNI values below 0.85.
Thus, while PPM can be used as the main source of nitrogen for grain maize, PCM and GWC should be applied in combination with N_{min} such as ammonium nitrate.

Key words: green waste compost, nitrogen nutrition index, nitrogen uptake, pelletized manure, soil mineral nitrogen.

Introduction

Grain maize expansion beyond the present northern limit of traditional growing areas opens up new opportunities for local arable farmers; however, it raises new challenges of securing high yield levels and maintaining a good environmental status of soil and water. Although maize is a plant with a high yield capacity, the use of high levels of fertiliser inputs, without paying proper attention to the dynamics of biomass and nitrogen (N) accumulation, can lead to nitrogen overuse and even to lower grain yields (Yan et al., 2016). As demonstrated by Valkama et al. (2013), fertilisation recommendations, which are based on the grower's expectation, can lead to significant errors in nitrogen management. The creation of optimum nitrogen nutrition conditions using only organic fertilisers is especially complex, because mineralisation does not coincide with the nitrogen uptake dynamics of the crop (Delin, Engström, 2010).

The mineralisation of the organic fraction of farm manures under field conditions takes several years, with the rate depending on manure type, temperature regime and other factors (Bhogal et al., 2016). Farmers should also take into account variation in the nitrogen replacement value of organic fertilisers, as well as the requirements of the Nitrates Directive of the European Union (91/676/EEC), which limits manure application rates to 170 kg of N per year in nitrate-vulnerable zones (Schröder et al., 2013). The effects of long-term organic fertiliser application have been studied widely, with the potential benefits and risks well known (Management of agroecosystem components, 2010; Merbach, Schulz, 2013; Duan et al., 2014). On the basis of long-term experiments covering a wide range of European climate and soil conditions, Zavattaro et al. (2017) found that bovine farmyard manure produced slightly lower crop yields when used alone and higher yields when used in combination with N fertiliser. According to this study, significant factors affecting crop yield in manure treatments were conditions that favour manure nitrogen mineralization and nitrogen uptake – lighter soil texture, higher temperature, longer mineralization period and shallower incorporation depth.

In contrast to cattle manure, poultry manure has much higher first-year nitrogen availability and a greater effect on grain maize yield (Muñoz et al., 2008). However, although pelleted manure is more convenient to handle, its characteristics may differ from those of its raw components (Hadas et al., 1983). In addition to traditional animal manure, a wide range of wastes

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generated from municipal and agricultural activities can be used as a nutrient source for agricultural crops. Field experiments on sandy loam soil have shown that composts derived from biogas production waste, green waste or sewage sludge can significantly increase spring barley grain yield and have an effect comparable to that of cattle manure (Staugaitis et al., 2016). However, the heterogeneity of such organic amendments results in a range of nitrogen mineralisation patterns, depending on quality parameters such as total N content, form of nitrogen and the C:N ratio (Mohanty et al., 2013). In arable farming, periodical application of organic fertilisers in addition to regular mineral fertilisation can be an effective means to mitigate soil organic carbon loss and overcome yield stagnation, which are urgent issues for Central and Northern Europe as indicated by a recent study of Wiesmeier et al. (2015). Chivenge et al. (2011) concluded that maize yield after combined organic and mineral fertiliser application increased with decreasing quality of organic source, with a greater effect observed on sandy than clayey soils.

Arable farmers have two main options: to rely on the first-year effect of organic sources with high nitrogen mineralisation potential, or to combine organic fertilisers (with a slow mineralisation rate) with commercial nitrogen fertiliser. Nevertheless, poorly coordinated application of fertiliser can lead to over-fertilisation and may contribute to the leaching of nitrates and eutrophication of water bodies, as observed in the Baltic Sea (Andersen et al., 2014). Successful implementation of the aforementioned fertilisation strategies under local climatic and farming conditions requires a more comprehensive understanding of grain maize nitrogen economy and related traits. Despite the considerable research conducted in the region on arable crop nitrogen fertilisation, grain maize nitrogen nutrition has received limited attention so far in the north-east Baltic region. The present study was thus aimed at answering the following questions: (i) What is the contribution of organic fertilisers of different origin to soil nitrogen supply and maize grain productivity? (ii) Can organic fertilisers replace part of ammonium nitrate input without loss of maize productivity? and (iii) How well do mid-season plant and soil nitrogen status indicators correlate with grain yield and soil mineral N content at harvest?

Materials and methods

Experimental location. The study was conducted using the short-season grain maize (*Zea mays* L.) cultivar 'Agiraxx' (FAO No. 190) in 2015–2017 at Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry in Akademija (55°39′ N, 23°86′ E), Central Lithuania, on a sandy loam *Hypocalcic Stagnic Luvisol* (*LV-st-wc*) (loamic, drainic) according to WRB (2014). The soil is characterised by a neutral pH, relatively low humus levels and medium plant-available phosphorus and potassium contents.

Experimental treatments and design. Maize was applied with 170 kg ha^{-1} of nitrogen (N) as ammonium nitrate (AN) plus $P_{85}K_{170}$ (AN170), pelletized cattle manure (PCM), pelletized poultry manure (PPM) or green waste compost (GWC), or as a combination of ammonium nitrate and one of the three organic fertilisers (AN + PCM, AN + PPM and AN + GWC) at a rate of N90 + N80. Additional treatments included (1) without fertilisers (control), (2) ammonium nitrate at a rate of 90 kg ha^{-1} N without PK (AN90) and (3) with $P_{45}K_{90}$ (AN1). The main characteristics of the organic fertilisers are shown in Table 1.

Table 1. Chemical characteristics of pelletized cattle and poultry manures (PCM and PPM) and green waste compost (GWC)

	Content		
	PCM	PPM	GWC
pH	9.5	6.6	8.4
Dry matter %	82.3	81.1	70.3
In dry matter:			
Organic matter %	65.0	74.7	16.1
Total nitrogen (N) %	2.8	4.7	0.6
Total phosphorus (P_20_5) %	1.2	2.4	0.3
Total potassium (K_20) %	7.10	3.60	0.80

Treatments were arranged in a randomised complete block design with four replicates. Individual plots contained four rows of maize with a total plot size of 30 m^2 (10 × 3 m); however, only the two central rows (8 × 1.5 m = 12 m^2) were harvested for grain yield measurement.

Agronomic practises. Fertilisers were broadcast and incorporated into the soil prior to maize drilling. In 2015–2017 maize was sown on 8–10 May at a density of 70,000 plants ha^{-1} (0.75 m row spacing, 0.18 m plant spacing) at a depth of 6–8 cm. Weeds were controlled by the herbicide Maister OD (a.i. oil dispersion containing 30 g L^{-1} foramsulfuron + 1 g L^{-1} lodosulfuron, rate 1.7 L ha^{-1}). In 2015–2017 maize was manually harvested on 10–12 October after the first autumn frosts.

Plants and soil measurements. Vegetative growth stages of maize were determined using the leaf collar method (Ritchie et al., 1986), whereas reproductive stage assessments were based on visual grain indicators. Total above-ground biomass was sampled twice per growing season. At tasselling stage (mid-season) five randomly chosen plants from each plot were cut at soil surface for biomass measurements. At reproductive stage R6 (physiological maturity), when more than 50% of the plants showed a visible black layer at the base of the kernel, two central rows of each plot from an area of 8 × 1.5 = 12 m^2 were cut to identify final biomass and grain yield. Biomass samples were dried at 65 ± 5°C to a constant dry weight. Samples taken at maize mid-season and physiological maturity were further used to determine nitrogen concentration. Total N was determined by the Kjeldahl method. Maize N uptake and removal with grain were calculated by multiplying nitrogen concentrations by yields. For each season maize N nutrition index (NNI) values were obtained according to Lemaire and Meynard (1997) by dividing the actual biomass N concentration by the critical N concentration required for non-limiting growth:

$$NNI = N_{observed} / N_{critical},$$

where $N_{observed}$ is the actual N concentration in the plant, while $N_{critical}$ – the minimum N concentration required for unlimited growth of C_4 maize species, determined as $N_{critical} = 3.4 \times W^{-0.37}$; here, 3.4 is the minimum plant N concentration for W = 1 t ha^{-1}, and −0.37 – the dimensionless coefficient for maize. Plant nutrition is considered to be optimal at NNI = 1, with NNI > 1 and NNI < 1 indicating excess or insufficiency, respectively. Soil samples for mineral N (N_{min} = N-NO_3 + N-NH_4) measurements were taken at mid-season and on the second day after harvest from 0–60 cm depth in each plot. In each plot, the soil sample (300–400 g) consisted of four to five sub-samples, taken at randomly selected places. Mineral nitrogen (N_{min}) was measured via a spectrometric method as described by Arbačauskas et al. (2018).

Climatic data. Daily weather data were collected from the local Dotnuva Meteorological Station, located ~500 m from the experimental fields. Data including average air temperature (°C) and precipitation (mm) were compared to the climate normal for the 1981–2010 period (Table 2).

Table 2. Comparison between daily average climatic parameters (air temperature, precipitation) for the 2015–2017 seasons and the climate normal (average for 1981–2010)

Year	Growth stage	Average air temperature °C	Total precipitation mm
2015	VE–VT	14.7	126.8
	VT–R6	15.2	67.4
2016	VE–VT	17.0	211.0
	VT–R6	15.1	167.4
2017	VE–VT	15.5	229.7
	VT–R6	14.4	219.1
1981–2010	VE–VT	16.0	166.0
	VT–R6	14.0	126.0

VE – emergence, VT – tasselling, R6 – physiological maturity

Statistical analysis. Three years' data of grain yield, nitrogen uptake and soil N_{min} were subjected to combined analysis of variance (*ANOVA*) as described by Petersen (1994). Significance of year and treatment, as well as, year × treatment interaction effects was checked using *F* test. Significant differences between experimental treatments were determined using Tukey's test at the 0.05 probability level. Linear correlation-regression analyses were performed to estimate the relationships between plant measurements and yield, soil N_{min} content and NNI. All main calculations were performed in software *SAS 9.4* (SAS Institute Inc., USA).

Results and discussion

Crop N uptake, soil mineral nitrogen (N_{min}) and nitrogen nutrition index at maize mid-season. The grain maize vegetative period from sowing to tasselling was cool and very dry in 2015, warm and wet in 2016 and cool and wet in 2017. Due to water deficit in 2015, nitrogen uptake at mid-season was 7.9–33.4% and 11.5–39.4% lower than in 2016 and 2017, respectively (Table 3).

These results correlate with those of other researchers who found that in many species, including maize, water shortage reduces plant nitrogen uptake (Pandey et al., 2000). In all experimental years, treatment effect was highly significant ($p < 0.01$), with the highest nitrogen uptake recorded in AN170 and AN + PPM and the lowest in control and GWC treatments. However, a significant year × treatment interaction prevented the pooling of the three years' data. Soil N_{min} content at 0–60 cm depth (Table 3), an important indicator of readily available N supply, varied significantly ($p < 0.01$) among treatments; however, the year × treatment interaction was again significant ($p < 0.05$). It is noteworthy that the treatments (AN170 and AN + PPM) with the highest soil N_{min} content also exhibited the highest nitrogen uptake, while the lowest values were specific to control, PCM and GWC treatments. NNI values suggested that in all years, maize N nutrition in AN170, AN + PCM, AN + PPM and AN + GWC treatments was sufficient or even excessive (NNI > 1). In contrast, maize N nutrition in AN90, AN1 and PPM treatments was below optimum (NNI 0.85–0.99), while insufficient N nutrition (NNI 0.66–0.85) was common in PCM, GWC and control treatments. As expected, the correlation between soil N_{min} content and nitrogen uptake was significant, with R^2 values higher in the two wet seasons (0.64 in 2016 and 0.89 in 2017, $p < 0.05$) than in the dry season of 2015 (0.48, $p < 0.05$). A strong significant correlation was found in all years between NNI and N_{min}, as well as between NNI and nitrogen uptake. The latter result is not surprising, because the calculation of both indicators involved the use of biomass and plant nitrogen concentration data.

Table 3. Maize nitrogen (N) uptake and soil mineral nitrogen (N_{min}) content (kg ha^{-1} N) at 0–60 cm depth at mid-season

Treatment	N uptake			N_{min} content		
	2015	2016	2017	2015	2016	2017
Control	53.9 D	81.0 D	74.5 E	51.9 D	69.0 C	56.6 D
AN90	69.2 C	96.8 BC	101.1 B	148.6 BA	116.4 CB	122.9 BDAC
AN1	71.0 C	109.3 BA	89.4 C	138.2 BAC	122.9 CB	110.2 BDAC
AN170	100.6 A	109.3 BA	113.7 A	144.7 BAC	226.1 A	169.6 A
PCM	69.4 C	76.6 D	83.9 DC	62.6 DC	73.8 CB	59.6 DC
AN + PCM	81.1 BC	105.1 BAC	108.4 BA	170.5 A	123.8 CB	129.8 BDAC
PPM	78.4 BC	97.6 BC	106.2 BA	82.3 BDC	117.6 CB	130.3 BAC
AN + PPM	85.3 BA	110.9 A	107.0 BA	166.0 A	148.0 B	145.9 BA
GWC	51.3 D	75.2 D	84.6 DE	64.3 DC	69.1 C	82.4 BDC
AN + GWC	87.3 BA	94.0 C	103.3 B	137.0 BAC	129.0 CB	150.1 BA

Note. Control – without fertilisers, AN90 – ammonium nitrate (AN) at a rate of 90 kg ha^{-1} N without PK, AN1 – AN at a rate of 90 kg ha^{-1} N with $P_{45}K_{90}$, AN170 – AN at a rate of 170 kg ha^{-1} N with $P_{85}K_{170}$, PCM – pelletised cattle manure at a rate of 170 kg ha^{-1} N, AN + PCM – AN at a rate of 90 kg ha^{-1} N and PCM at a rate of 80 kg ha^{-1}, PPM – pelletised poultry manure at a rate of 170 kg ha^{-1} N, AN + PPM – AN at a rate of 90 kg ha^{-1} N and PPM at a rate of 80 kg ha^{-1}, GWC – green waste compost at a rate of 170 kg ha^{-1} N, AN + GWC – AN at a rate of 90 kg ha^{-1} N and GWC at a rate of 80 kg ha^{-1}; different combinations of letters indicate significantly differing means ($p < 0.05$).

Crop nitrogen uptake, grain yield and soil N_{min} at maize harvest. Daily average air temperature during the reproductive stage of maize (from VT to R6) in 2015 and 2016 was above and in 2017 was slightly below the current climate normal (1981–2010). Nevertheless, maize reached physiological maturity in all years. Rainfall recorded during the aforementioned period varied from 67.4 mm in 2015 to 167.4 mm in 2016 and 219.1 mm in 2017. On average, during this period maize accumulated nearly 40% of the total N found in the above ground part of plants at harvest, a value comparable to that reported by Girma et al. (2010). Maize grain yield varied substantially among years; however, the non-significant ($p = 0.19$) treatment × year interaction enabled the combination of the results for the entire study period (Table 4).

Table 4. Average values of grain yield (dry mass), nitrogen (N) uptake and soil mineral nitrogen (N_{min}) content at maize harvest in 2015–2017

Treatment	Grain yield t ha^{-1}	N uptake kg ha^{-1} N	N_{min} content kg ha^{-1} N
Control	6.43 B	116.0 E	47.3 C
AN90	7.56 A	142.7 D	54.3 C
AN1	7.63 A	158.7 C	57.2 BC
AN170	7.86 A	179.2 A	84.5 AB
PCM	6.90 B	124.3 E	48.1 C
AN + PCM	7.81 A	151.1 CD	62.2 ABC
PPM	7.77 A	164.1 BC	63.9 ABC
AN + PPM	7.98 A	174.8 AB	89.3 A
GWC	6.77 B	125.4 E	46.7 C
AN + GWC	7.97 A	158.6 C	73.2 ABC

Explanation of treatments under Table 3

On average, grain yield in the plots applied with ammonium nitrate (N90) in combination with organic fertilisers (N80) was similar to that in the plots treated with ammonium nitrate (N170) only. However, the use of solely organic fertilisers produced varied results, with grain yield after PPM application 93.7% of that recorded for ammonium nitrate, and after PCM and GWC application only 32.9% and 23.8%, respectively. Maize nitrogen uptake under the cool and dry conditions of 2015 was approximately one third lower than that in more favourable years, likely due to lower nitrogen uptake during the exceptionally dry August of 2015. The highest nitrogen uptake averaged across seasons was determined in AN170 (179.2 kg ha^{-1}) and AN + PPM (174.8 kg ha^{-1}). Nitrogen uptake in PCM and GWC was greater than in the control treatment by 4.7 to 20.3 kg ha^{-1}, but this difference was non-significant in most cases. On average, nitrogen uptake increase after PPM application was 76.1%, after PCM 13.1% and GWC 14.9% compared with ammonium nitrate, values somewhat higher than those reported by Muñoz et al. (2008). At harvest, soil N_{min} content in the 0–60 cm layer varied substantially ($p < 0.01$) among the treatments; however, unlike the results observed for mid-season measurements, the year and treatment × year interaction effects were non-significant. In all years, differences in soil N_{min} content among control, PCM and GWC were non-significant, with values consistently below 60 kg ha^{-1} N (ranging from 40.8 to 59.0 kg ha^{-1} N). In contrast, soil N_{min} content in AN170 and AN + PPM treatments was above 70 kg ha^{-1} N (from 73.7 to 97.7 kg ha^{-1} N), providing additional evidence of nitrogen oversupply in these plots. It is noteworthy that nitrogen in nitrate form (NO_3^-) accounted for as much as ~78.6% of soil N_{min} content.

The high determination coefficient of the linear correlation between maize grain yield and mid-season nitrogen uptake (VT stage) suggests that this trait explains as much as 89% of grain yield variation. A similar association between nitrogen uptake at silk emergence with grain yield was also established in a number of other studies (Ciampiti, Vyn, 2012). Here, although an additional strong correlation was recorded between mid-season NNI values and grain yield (Fig. 1), the different parameters of the response curves representing separate experimental years prevented the pooling of these data into one dataset.

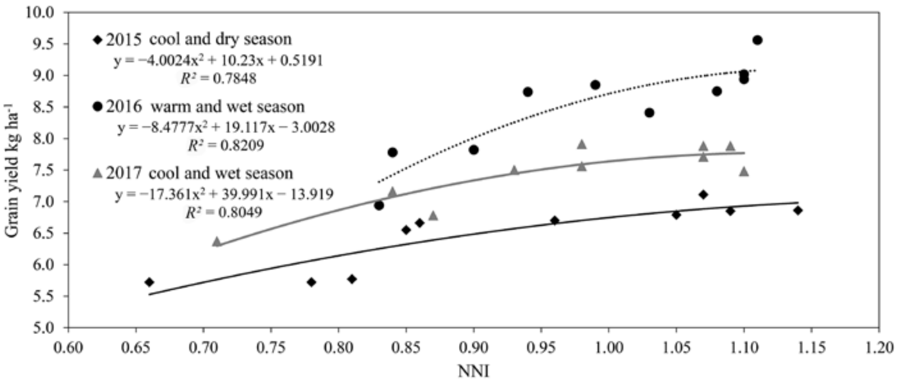

Figure 1. Relationship between grain yield and mid-season nitrogen nutrition index (NNI) for the years 2015−2017

The different grain yield levels recorded in each study year were attained with similar mid-season NNI values, a result attributable to factors other than plant nutrition, such as environmental constraints during grain filling. Furthermore, a significant correlation between mid-season NNI and soil N_{min} content at harvest was also found (Fig. 2). In general, a more apparent accumulation of soil N_{min} content occurred at values above 0.9. Ziadi et al. (2012) reported a similar maize mid-season NNI threshold value of 0.88, above which considerable accumulation of nitrates in soil was recorded at harvest. Nevertheless, it remains essential to minimise nitrate leaching by optimising crop fertilisation, as part of wider practice to limit the nitrate pollution of aquifers and water bodies (Beaudoin et al., 2005).

In general, maize grain yield and total N uptake levels obtained in our experiments in treatment with application of 170 kg ha^{-1} of N as ammonium nitrate are in a good agreement with those reported by other authors. Ciampitti and Vyn (2012) undertook a comprehensive review of data of field experiments from a hundred papers and suggests that grain yield of modern maize cultivars averaged 9.0 t ha^{-1}, total plant N uptake of 170 kg ha^{-1} N, a harvest index (HI) of 50% and a nitrogen harvest index (NHI) of 64%. These authors also noticed that modern genotypes shows higher tolerance to nitrogen

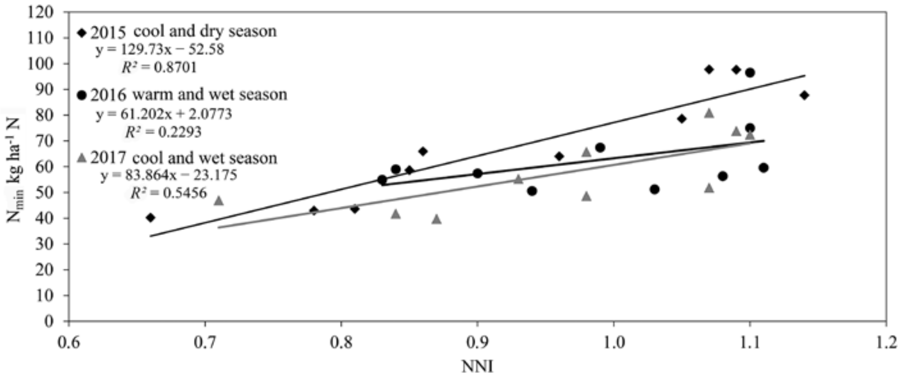

Figure 2. Relationship between soil mineral nitrogen (N_{min}) content at 0–60 cm depth at harvest and mid-season nitrogen nutrition index (NNI) for the years 2015−2017

deficiency stress than older cultivars and are capable of producing higher grain yield when no nitrogen fertiliser was applied. In addition, Yan at al. (2016) indicated that different grain yield levels were associated with different biomass and nitrogen accumulation patterns. Dhital and Raun (2016) summarized 213 site-years data of field experiments performed in USA and found that optimum nitrogen rates for maize varies in a wide range depending on the year and location. They suggest using midseason sensor-based technologies for more accurate prediction of yield potential and optimization of fertiliser nitrogen rates. Results of our study support this opinion.

Chadwick et al. (2000) found in incubations that 56% of the organic N was released from poultry manure, whereas the corresponding value for pig slurry was 37%, for beef manure – 6% and for cow manure – below 2%. In poultry manure large part of nitrogen is in organic compounds, mostly uric acid, which has to be transformed to ammonium or nitrate before plants can absorb it. Nevertheless poultry manure can mineralise sufficiently rapidly if applied in spring (Delin, Engström, 2010). In contrast, farmyard manure or green waste compost had low initial N_{min} content and very slow nitrogen mineralisation.

The results of our study indicate that the maximum N input rate of 170 kg ha^{-1} y^{-1} set by the Nitrates Directive of the European Union for organic fertilisers can be sufficient for short season grain maize cultivars grown in Lithuania on a sandy loam soil when poultry manure is used as nitrogen source. However, when cattle manure or green waste compost is used, combined application with mineral fertilisers should be considered.

Conclusions

1. Pelleted poultry manure applied prior to sowing at a rate of 170 kg of N per ha provided sufficient maize nitrogen nutrition and resulted in a grain yield similar to that achieved using ammonium nitrate. However, excessive accumulation of soil mineral nitrogen (N_{min}) at harvest, which poses a risk of leaching to water bodies, can be expected. In contrast, the effect of cattle manure and green waste compost on soil nitrogen supply and maize grain yield was negligible.

2. The replacement of part of ammonium nitrate with organic fertilisers resulted in lower maize nitrogen uptake, with the exception of poultry manure, under which crop nitrogen nutrition levels were sufficient and no significant grain yield loss was recorded.

3. Mid-season measurements of soil N_{min} and nitrogen nutrition index (NNI) proved to be very helpful tools for the ranking of treatments amended with the different types of organic fertiliser, based on the latter's contribution to maize nitrogen nutrition, and as a result for the estimation of fertiliser impact on grain yield and soil N_{min} content at harvest. However, both methods have some limitations in their capacity to predict actual grain yield in a particular growing season.

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Organinių ir mineralinių trąšų įtaka kukurūzų mitybos azotu rodikliams ir grūdų derliui

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Santrauka

Tyrimo tikslas – įvertinti organinių ir mineralinių trąšų įtaką dirvožemio mineralinio azoto kiekiui, kukurūzų, auginamų grūdams, produktyvumui ir augalų bei dirvožemio diagnostikos indikatorių koreliaciniam ryšiui su grūdų derliumi ir N_{min} kiekiu dirvožemyje po derliaus nuėmimo. 2015–2017 m. Akademijoje, Kėdainių r., lengvo priemolio išplautžemyje (IDj) buvo atlikti lauko eksperimentai su veislės 'Agiraxx' trumpos vegetacijos kukurūzais. Prieš sėją kukurūzai buvo patręšti 170 kg ha^{-1} azoto, naudojant amonio nitratą, granuliuotą galvijų mėšlą, granuliuotą paukščių mėšlą, žaliųjų atliekų kompostą arba amonio nitratą ir organinių trąšų derinį. Nustatyta skirtingų trąšų įtaka dirvožemio mineralinio azoto (N_{min}) kiekiui, kukurūzų azoto mitybos indeksui (NNI), azoto įsisavinimui ir grūdų derliui. Kukurūzų žydėjimo metu nustatyta glaudi koreliacija tarp NNI ir dirvožemio N_{min} (R^2 = 0,73–0,88). Sąlygiškai geras kukurūzų mitybos azotu lygis (NNI > 0,9) buvo pasiektas patręšus 170 kg ha^{-1} amonio nitrato arba granuliuoto paukščių mėšlo ir amonio nitratą derinant su organinėmis trąšomis, tačiau toks tręšimas padidino N_{min} kiekį dirvožemyje derliaus nuėmimo metu. Nepakankama kukurūzų mityba azotu patręšus granuliuotu galvijų mėšlu ir žaliųjų atliekų kompostu lėmė mažesnį grūdų derlių ir N_{min} kiekį dirvožemyje. Kukurūzus auginant grūdams, granuliuotas paukščių mėšlas gali būti naudojamas kaip pagrindinis azoto šaltinis, o granuliuotas galvijų mėšlas ir žaliųjų atliekų kompostas turėtų būti naudojami kartu su mineralinėmis trąšomis.

Reikšminiai žodžiai: azoto įsisavinimas, azoto mitybos indeksas, dirvožemio mineralinis azotas, granuliuotas mėšlas, žaliųjų atliekų kompostas.