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ORIGINAL PAPERS

CONTENT OF MINERAL NITROGEN IN SANDY SOILS AFTER AN APPLICATION OF SLOW-RELEASE FERTILISERS IN SWEET SORGHUM CULTIVATION*

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Abstract

In 2013-2014, field experiments were conducted at the Agricultural Research Station in Pawłowice (Department of Crop Production of the Wroclaw University of Environmental and Life Sciences), using sorghum as a test plant. The purpose was to determine the influence of the type of fertiliser on the content of mineral nitrogen (N-NO_3 and N-NH_4) in the top soil layer (0-60 cm). Soil samples were collected three times during the growing season: in the spring before sowing, during the phase of shoot formation (July), and after the harvest (October). The fertilisers used in the experiment were ammonium nitrate, urea and slow-release coated urea (Meister). Regardless of the weather conditions in 2013 and 2014, similar tendencies were found with respect to the differentiation of the nitrogen content in soil. The total nitrogen content was the highest in the middle of the growing season, and the amounts of nitrate form differed greatly among the treatments. The content of N-NO_3, measured in that period was 20-44% lower in the soil fertilised with coated urea than with standard urea. After the harvest, the stock of nitrogen in soil fertilised with ammonium nitrate was 58-61 kg ha^{-1}, which was classified as a medium-high level (posing a threat to water quality), while being on a low level of 31-46 kg ha^{-1} in soils fertilised with standard urea and coated urea, which is considered to be harmless for the ground- and surface waters under climate conditions of Poland. The stocks of N-NO_3 left in soil after sorghum harvest fell into the medium-high level according to the limits recommended for sandy soils in Poland after fertilisation with ammonium nitrate, and into the low level if fertilised with standard urea and coated urea, in both years.

Keywords: N-NO_3, N-NH_4, growing season, nitrogen fertilisation, mineral nitrogen stock.

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INTRODUCTION

One of the challenges for modern agriculture is to introduce into cultivation several new plant species that will adapt to changing environmental conditions (Lobell 2014). In Central Europe, sweet sorghum (*Sorghum bicolor* L. Moench) may provide an alternative for maize (Berenji, Dahlberg 2004). The possibility to use sorghum both as a fodder plant and as an energy source, for bioethanol production, determines potentially high economic value of this crop. Sweet sorghum is a species of high-yield potential, resistant to such stress factors as high temperature or drought (Zegada-Lizarazu, Monti 2012). It belongs to plants that have high photosynthetic efficiency (C4 photosynthesis cycle plant group), as well as a lower transpiration coefficient and better use of nitrogen than most other cultivated plants (Zhao et al. 2005). This species brings high yields, but similarly to maize, it takes up high amounts of nutrients during the growing season.

The main factors influencing the yields are the soil properties and fertilisation (especially with nitrogen). Moreover, nitrogen fertilisation determines the quality of crops. In soil, nitrogen is present mainly in the organic form, although it is subject to rapid biological transformation to mineral forms, easily available to plants (Fotyma et al. 2002). In temperate climate conditions, the lowest amount of soil mineral nitrogen is noted in winter. It increases gradually with rising temperature, as the mineralisation of organic matter is resumed. In the middle of a growing season, it decreases again as a result of nitrogen uptake by plants (Fotyma et al. 2010). Plant nutritional requirements are covered by mineral nitrogen uptake from soil; whereas, the plant-available nitrogen pools in soil are recovered by mineralisation of organic residues, organic and mineral fertilisation, as well as atmospheric precipitation.

The dose of nitrogen fertilisation should take into account the present soil fertility and the microbiological transformation processes in soil, and it should cover the uptake of nutrients with the yield. Depending on the soil type and moisture regime, the doses of nitrogen applied to sweet sorghum vary in the range 45-224 kg N ha^{-1} (Zhao et al. 2005, Barbanti et al. 2006, Sowiński, Liszka-Podkowa 2008, Marsalis et al. 2010).

In parallel to nitrogen uptake by higher plants and soil microorganisms, losses of nitrogen occur, mainly *via* nitrate leaching to the waters and emissions of gaseous compounds resulting from the transformation of the ammonium form (Fotyma et al. 2002, Sapek, Sapek 2007). It is possible to reduce the nitrogen losses and the environmental pollution by rational fertilisation methods, or the application of slow-release fertilisers. In the optimum nitrogen nutrition model, the availability of this nutrient should be synchronised with the plant requirements (Trenkel 2010). Fertilisation with split doses is a way to synchronise fertilisation with plant requirements. The disadvantages of this technology include the higher costs and the increased CO_2 emission to the atmosphere connected with multiple use of agricultural vehicles. An alternative is a use of slow-release fertilisers. They contain the same nutrients as commonly used fertilisers, but the release of nutrients is reduced by coating materials. Various substances are used as coatings, such as polyethylene, polyvinyl chloride, latex, sulphur compounds and other stuffs (Yan et al. 2008). Another methods is use of organic waste biomass like meat and bone meals contain nitrogen in the form of protein compounds, which is slowly released to soil (Nogalska 2013).

An example of slow-release fertiliser is Meister, which consists of polyolefin (a monomer of carbon and hydrogen) - coated urea - POCU (Trenkel 2010). The polymer is subject to slow degradation; first under the influence of solar radiation and then under alternating wetting and drying it undergoes mechanical destruction (cracking). Final products of its complete decomposition are water and carbon dioxide. During the ongoing mechanical and chemical degradation of the polymer coating, nitrogen fertiliser is gradually released to the soil solution.

The aim was to verify the hypothesis on the lower accumulation of mineral nitrogen forms, both during and after growing season, in soils fertilised with coated slow-released fertiliser as compared to conventional nitrogen fertilisers.

MATERIAL AND METHODS

The study presents the results of field experiments carried out in 2013-2014 in Wroclaw-Pawłowice (51°10′25″N, 17°07′02″E), on the experimental fields belonging to the Department of Crop Production of the Wroclaw University of Environmental and Life Sciences. The fields are located on the upper, non-flooded terrace of the Dobra river, developed of the Pleistocene alluvial sands and gravelly sands (Kabała et al. 2011). The experiment was conducted on sandy soils, originally classified as (IUSS working group WRB 2014) Brunic Arenosols (Gleyic), but currently transformed to Gleyic Phaeozems (Anthric, Arenic, Brunic) due to long-term and intense cultivation, including deep ploughing, liming and fertilisation (Labaz, Kabala 2016). Soils have a thick (28-32 cm) and structural humus horizon, neutral reaction and high base saturation throughout the profile (Table 1). Soils have sandy texture down to at least 100 cm, slightly differentiated within the upper 60 cm. The soils are drained at the depth of 75-80 cm that determines the highest level of groundwater table (in spring).

The plot experiment was conducted using the random block method, and the analysed variance factor was the fertiliser type: ammonium nitrate, standard urea and slow-release urea as the commercial preparation called Meister. The unified dose of nitrogen was 135 kg N ha^{-1} applied once at the beginning of a growing season. The impact of dose splitting was statistically

Table 1
Basic physicochemical properties of soils of the experimental field (Sowiński et al. 2016). Given values are arithmetic means from all experimental plots

Depth (cm)	Soil layer	Particle-size distribution			Bulk density	pH_{KCl}	TOC	Nt	C:N
		sand	silt	clay					
		(%)			(g cm^{-3})		(%)		
0-30	Ap	87	11	2	1.65	6.8	1.16	0.059	20
30-60	Bv	92	7	1	1.73	6.9	0.30	0.022	14

Key: TOC – total organic carbon, Nt – total nitrogen.

insignificant, thus the data for two variants were averaged. The control plots were not fertilised with nitrogen. The experiment was carried out in four replicates.

Before sorghum sowing, phosphorus and potassium fertilisers were applied in the following doses: 31 kg P ha^{-1} (as triple superphosphate) and 100 K ha^{-1} (as potassium salt), and mixed with topsoil with a combined cultivator. Due to technical reasons, determined by other simultaneous observations (that required installation of MicroRhizon samplers), nitrogen fertilisation was applied after plant emergency.

The hybrid of sweet sorghum Sucrosorgo 304, recommended for silage production, was used in the experiment as a test plant. This hybrid is characterised by a high efficiency of biomass production, elevated content of soluble sugars, and high resistance to droughts. Sorghum was sown in the first half of May using a Wintersteiger plot seed drill, in the amount of 20 seeds per 1 m^2, at the row spacing of 70 cm.

Soil samples were collected from the 0-30 and 30-60 cm layers with a steel probe (Eijkelkamp Agrisearch Equipment), in two replicates from each plot, three times a years: prior to sowing (early May), in middle of a growing season (early July), and after the harvest (early October). The soil samples were divided into two parts. Onw was weighed and then dried at a temperature of 50^o C to establish the moisture content. Mineral forms of nitrogen were determined after extraction of fresh soil (stored in a fridge until analysed at -20ºC temperature) with a 1% solution of K_2SO_4, at the solution to soil ratio of 5:1 and the shaking time of 1 hour. In the filtrate, the concentrations of mineral nitrogen forms were measured colorimetrically: $N\text{-}NO_3$ with phenol-disulphonic acid, and $N\text{-}NH_4$ with potassium sodium tartrate and Nessler's reagent. Finally, the content of nitrogen forms was converted to soil dry mass. The pools of mineral nitrogen were calculated based on the nitrogen content (in mg kg^{-1}) and soil bulk density, separately for 0-30 and 30-60 cm-thick layers and then summarized to obtain the pools in the 0-60 cm layer. The sampling and laboratory analyses were compliant with Polish reference standard (PNR 1997).

In both analysed years, the sums of temperatures during the growing season were similar and ranged from 1060 to 1110 degrees (Figure 1). However , the accumulated sums of precipitations varied considerably (Figure 2). In 2013, 30 days after sowing, total precipitation was higher than in 2014 by

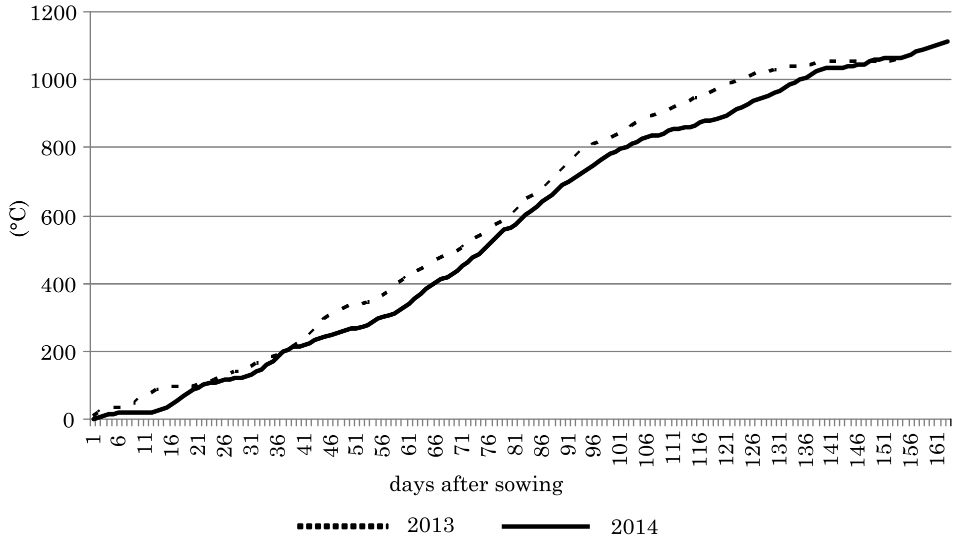

Fig. 1. Cumulative sum of effective temperatures during the growing periods

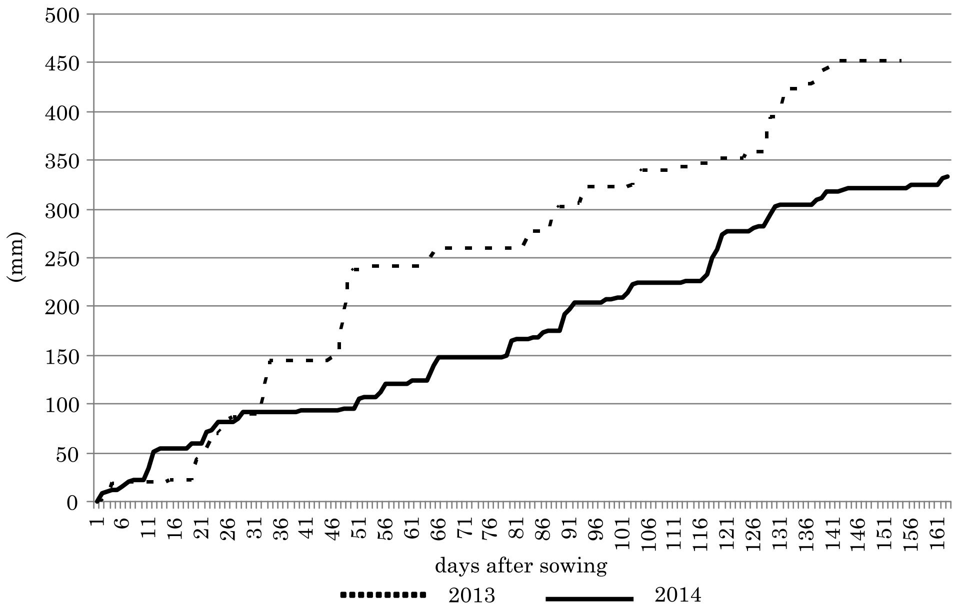

Fig. 2. Cumulative sum of rainfall during the growing period

approx. 50 mm, and starting from day 50, by another 100 mm. Later in the growing season, the lines of accumulated precipitations for both years were parallel and the difference arisen in the first part of the growing season remained constant until the harvest.

The experimental results were analysed using Statistica 10 software and presented as box-whiskers diagrams, grouped by a fertiliser type. The statistical significance of differences between the experimental variants was tested using the LSD test and the homogeneous groups of means were displayed in the graphs. Statistical analysis was conducted separately for the data obtained in middle of growing season, and after the sorghum harvest.

Box whiskers are a statistical tool for detecting and presenting the location and variation changes between different data groups (Chambers et al. 1983). Box whiskers help determine whether a factor has a significant effect on the response with respect to either the location or variation.

RESULTS AND DISCUSSION

Sorghum is a thermophilic species, and the course of its growth depends on the sum of effective temperatures. According to the findings of Vanderlip and Reeves (1972), as soon as the sum of effective temperatures accumulates to 1000-1100 degrees (depending on the variety), sorghum enters the phase of forming panicles and grain filling. In both years, sorghum reached this growth stage (at similar sums of temperatures).

Sorghum is resistant to the deficit of precipitation (Lobell 2014, Zegada-Lizarazu, Monti 2012) but, due to high yield potential, water requirement by this species is quite high. In the study of Yimam et al. (2015), the evapotranspiration during the growing season of sorghum ranged from 446 to 683 mm with yield from 4.4 to 32 t DM ha^{-1}. In 2013, the total precipitation was close to the optimum, but periodical excess of moisture might have affected the transformations of nitrogen forms in soil and their translocation in the soil profile.

In 2013, prior to sorghum sowing, the content of the ammonium and nitrate forms in soils (averaged from all experimental plots) was similar (Figure 3), while in 2014 the content of the nitrate form was by average 2.7-fold higher than that of the ammonium one (Figure 4). In the beginning of July, in both analysed years, the content of the ammonium and nitrate forms was on a similar level of approx. 4 and 6 mg kg^{-1}, respectively (Figures 3 and 4). After the harvest, the content of the nitrate form was higher than that of the ammonium form, especially in the first year (the differences were statistically significant), which might have potentially influenced the higher content of this form in the subsequent year. After the harvest, the average content of the $N\text{-}NO_3$ form should be considered as low (4.2 in 2013 and 5.0 mg kg^{-1} in

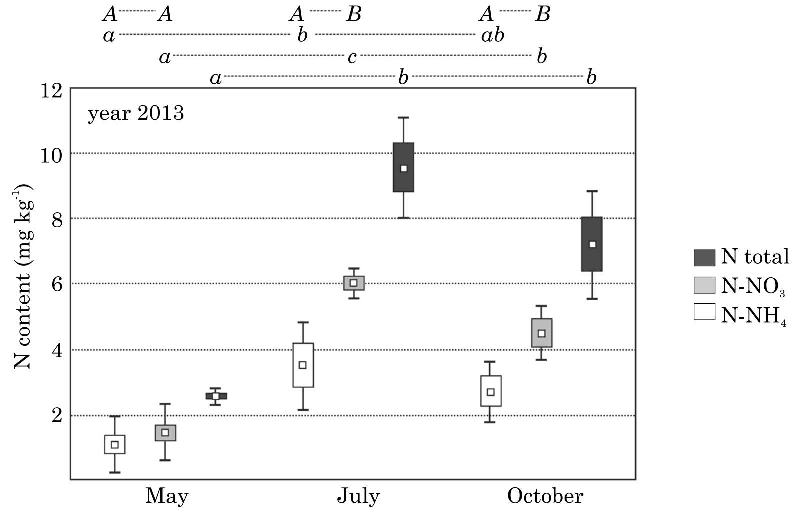

Fig. 3. N_{min} changes in the growing season 2013 in the 0-60 cm soil layer. Values for three sampling periods averaged for all fertilisers. Average value (point), standard deviation (box) and interval of confidence 95% (whiskers). *A*, *B* - homogeneous groups of N form content within terms of soil sampling, *a*, *b*, *c* - homogeneous groups of N form content across terms of soil sampling

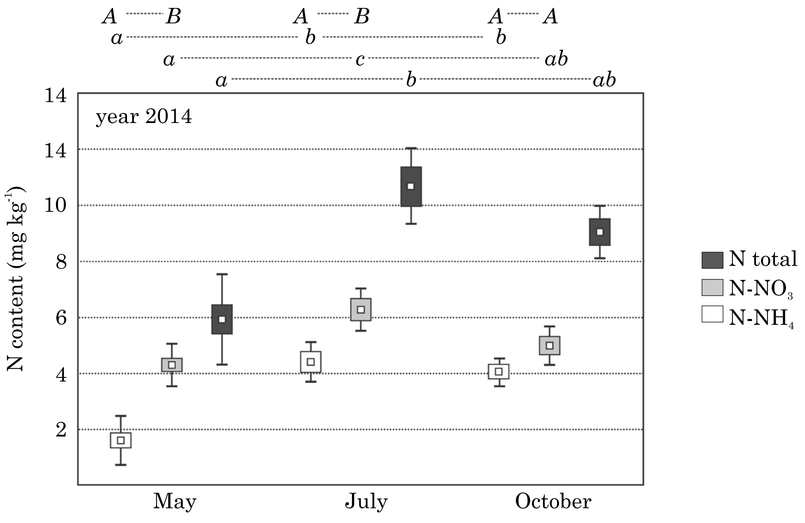

Fig. 4. N_{min} changes in the growing season 2014 in the 0-60 cm soil layer. All explanations as in Fig. 3

2014), as compared to 5.5 mg kg[-1], which is equivalent to nitrate nitrogen pools of 50 kg ha[-1] assumed as a mean value for sandy soils (FOTYMA et al. 2010).

In comparison, in the study by Guan et al. (2014), the content of mineral nitrogen in soil increased until day 120-150 after fertilisation, and a decreasing tendency was noted only in the final period (last 20-30 days of vegetation). Peng et al. (2013) obtained the highest mineral nitrogen content (ca. 80 mg kg^{-1}) in day 80 of maize growth.

There was no statistical impact of a fertiliser type on the ammonium nitrogen content in soil in the middle of a growing season, neither in 2013 nor 2014 (Figures 5 and 6). At the same time, however, the kind of fertiliser

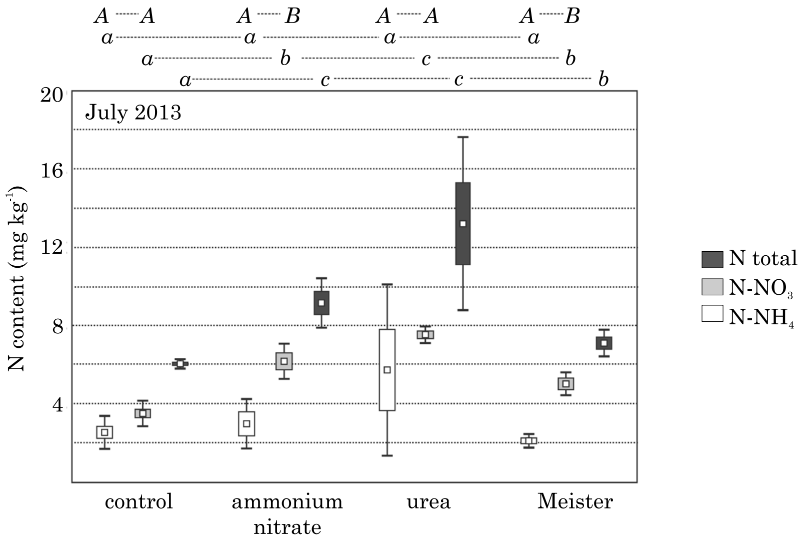

Fig. 5. N_{min} content in the 0-60 cm soil layer, in the middle of growing period 2013, as related to fertiliser type. Average value (point), standard deviation (box) and interval of confidence 95% (whiskers). *A*, *B* - homogeneous groups of N form content within each fertilisation variant, *a*, *b*, *c* - homogeneous groups of N form content across fertilisation variants

influenced significantly the content of nitrate form, which in July 2013 was the highest in soil fertilised with standard urea, on average 7.5 mg kg^{-1}. In soil fertilised with ammonium nitrate, the content of nitrate nitrogen was by 17.3% lower, and in soil fertilised with Meister – by 33% lower than in soil fertilised with standard urea. In July 2014, fertilisation with polymer-coated urea resulted in a reduction of the $N\text{-}NO_3$ content by 44% (statistically significant difference) in comparison to the plots fertilised with standard urea (Figure 6).

Different results were obtained in the experiments carried out by Zvomuya et al. (2003) and Nelson et al. (2009). The application of coated urea in their studies led to an increase in the nitrate nitrogen content in soils at the end of the growing season in comparison to non-coated urea. All these results are in accord with the opinon of Dechnik and Wiater (1996), who em-

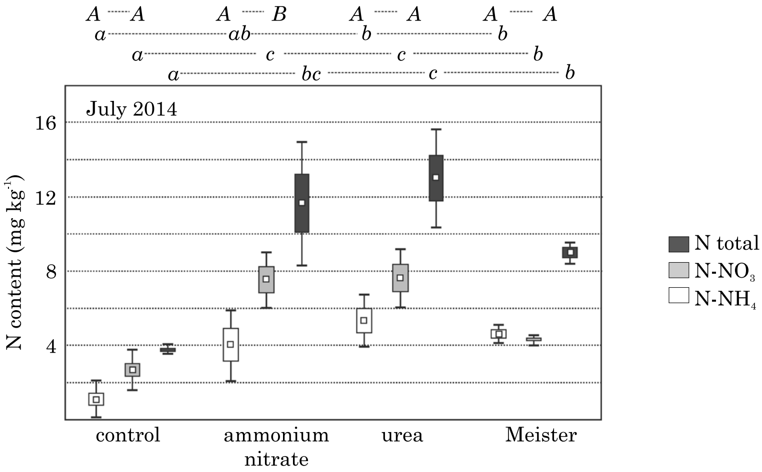

Fig. 6. N_{min} content in the 0-60 cm soil layer, in the middle of the growing period 2014, as related to fertiliser type. All explanations as in Fig. 5

phasised that the dynamics of nitrates in soil is determined by the course of weather conditions and, to a lesser extent, by the applied fertilisers and their dosage.

After the sorghum harvest in 2013, no statistically significant influence of the type of fertiliser on the content of mineral nitrogen in soil was found (Figure 7). Moreover, the content of mineral forms of nitrogen in soil in that

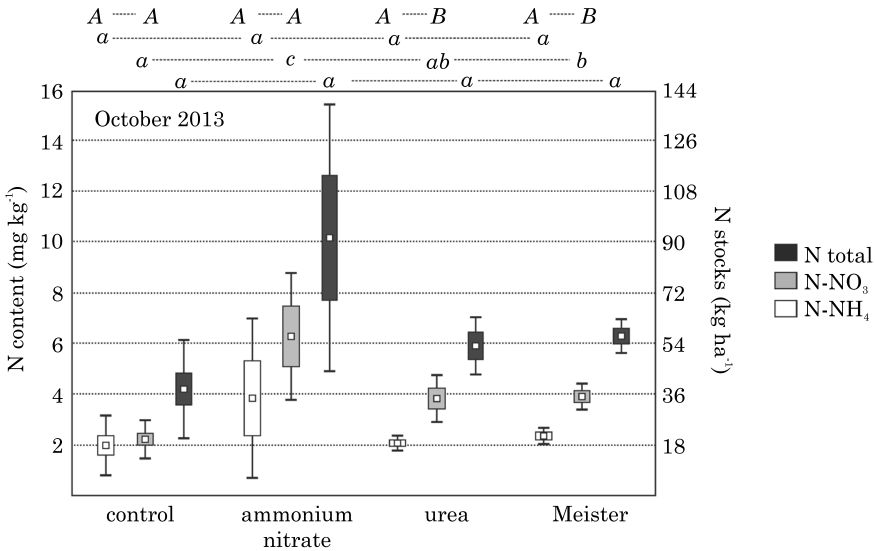

Fig. 7. N_{min} content in the 0-60 cm soil layer, after sorghum harvest and N stock depending on a fertiliser type in 2013. All explanations as in Fig. 5

period did not differ statistically from those in the control plots; only the content of nitrate form after the application of ammonium nitrate was significantly higher than in unfertilised soil. Similarly, in 2014, the type of nitrogen fertiliser did not have a significant effect on the content of the ammonium form in soil at the end of the plant growing season (Figure 8), and the

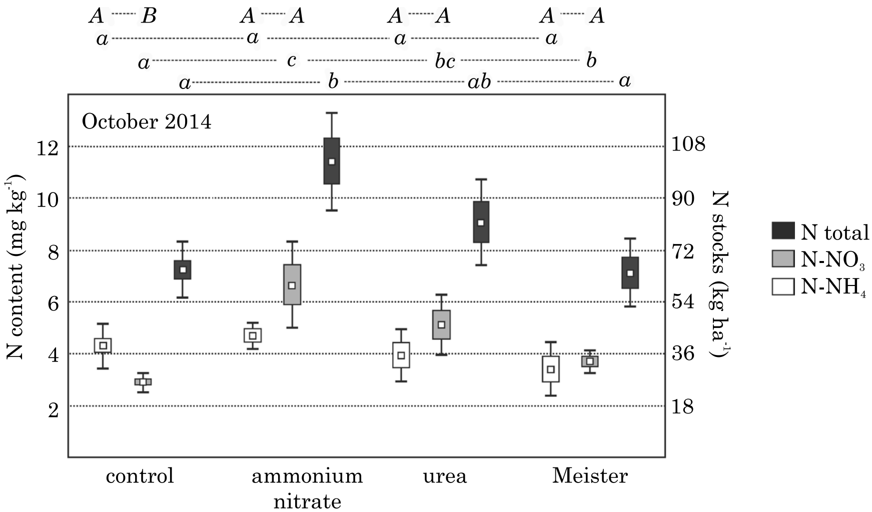

Fig. 8. N_{min} content in the 0-60 cm soil layer, after sorghum harvest and N stock depending on a fertiliser type in 2014 year. All explanations as in Fig. 5

noted values of this form were similar to those obtained in control plots. As far as the nitrate form is concerned, fertilisation with Meister decreased its content by 44.8% and 27.5% compared to fertilisation with ammonium nitrate and urea, respectively. The difference in the $N\text{-}NO_3$ content after fertilisation with Meister and ammonium nitrate was statistically significant.

The mean stocks of mineral nitrogen after sorghum harvest in the 0-60 cm soil layer were calculated based on averaged soil bulk density and nitrogen concentrations. In the year 2013, N stock was the highest in soil fertilised with ammonium nitrate, where it reached 91.5 kg ha^{-1} (Figure 7). The application of standard urea resulted in a nitrogen content being lower by 38%, and the use of coated urea (Meister) meant a 42% decrease (the differences between coated and standard urea were statistically insignificant). In 2014, the highest stock of mineral nitrogen (102.8 kg ha^{-1}) remained in the soil fertilised with ammonium nitrate (Figure 8). The stocks of nitrogen noted in soils fertilised with standard urea were lower by 20.3%, and in soils fertilised with Meister – lower by 37.5%, in comparison to those in soil fertilised with ammonium nitrate.

Jadczyszyn et al. (2010) pointed out that the content of mineral nitrogen in soil, including its nitrate form, depends on the time (season) of sampling, which has been confirmed by numerous other researchers (Peng et al. 2013, Zvomuya et al. 2003, Nelson et al. 2009), and has also been proven in the experiment discussed here. Therefore, it is hardly possible to indicate one reference period of soil sampling and the analysis of the content of various nitrogen forms for a risk assessment regarding groundwater. According to Fotyma et al. (2010), the risk of nitrogen loss to groundwater should be assessed based on the content of mineral and nitrate nitrogen that remains in soil after a crop harvest (or at the end of a growing period), when the nitrogen uptake by plants is ceased. In autumn and winter, nitrates are particularly exposed to leaching, thus the content of nitrate nitrogen in soil in this season should be as low as possible. The acceptable level for sandy soils is less than 50 kg $N\text{-}NO_3$ ha^{-1} (Fotyma et al., 2010). In the soils in our experiment with three fertilisers, this level was not exceeded under fertilisation with urea, and in particular with coated urea (Meister), while fertilisation with ammonium nitrate did not ensure the acceptable level of nitrate nitrogen in soil in autumn.

CONCLUSIONS

The content of mineral nitrogen evaluated in soil in spring may provide a basis for the determination of fertilisation needs. In this experiment, the total content of mineral nitrogen in the 60-cm-thick layer of soil, determined prior to sorghum sowing, was 40.6 and 66.2 kg ha ^{1} in 2013 and 2014, respectively. It was therefore relatively low compared to nutritional requirements of sweet sorghum. Therefore, fertilisation with nitrogen was necessary.

The amount of mineral nitrogen, in particular its nitrate form, determined after the end of the plant growing season, allows us to evaluate the leaching potential of this element (Fotyma et al. 2010). In both years, regardless of the weather conditions (distribution and total precipitation, average and cumulative daily temperatures), similar trends of changes in the nitrogen content in soil were noted. In the middle of the growing season, the mineral nitrogen content reached the maximum, although it was highly differentiated, particularly in terms of the nitrate form. Fertilisation with polyolefin coated urea resulted in a lower content of mineral nitrogen content in soil, in particular compared to soils fertilised with ammonium nitrate, both in the middle and at the end of the growing season. In both experimental years, the content of total mineral nitrogen (and its ammonium form) that remained in soil after the crop harvest, was higher in soil fertilised with ammonium nitrate than in soil fertilised with standard urea and coated urea. The stocks of $N\text{-}NO_3$ left in soil after sorghum harvest fell into the medium-high level (according to the limits recommended for sandy soils in Poland by Fotyma et al. (1990)) after the fertilisation with ammonium nitrate, and into the low level if fertilised with standard urea and coated urea. This result was observed both in 2013, characterised by higher total precipitation during the growing season, and in the much drier year 2014. Fertilisation with Meister or standard urea did not result in an excessive content of mineral nitrogen in soil after the sorghum harvest, and therefore it was considered to be safer for soil-water environment than fertilisation with ammonium nitrate.

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