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MINERAL NITROGEN CONTENT IN THE 60-90 CM LAYER OF GRASSLAND SOILS RELATIVE TO OTHER FODDER CROPS, WAY OF MANAGING AGRICULTURAL LANDS AND FARMING INTENSITY*

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A b s t r a c t. Mineral nitrogen occurring at the depth of 60-90 cm of the soil profile, which is unavailable to the main root mass of grassland plants and arable land crops and which is located in this layer due to leaching to deeper soil layers, can pose a serious threat to water quality. This study attempted to evaluate N_{min} content in grassland soils depending on soil type, land use, and farming intensity (i.e. livestock density). Regardless of observation period and natural factors evaluated, both land use and grassland use had a significant effect on mineral nitrogen content in the 60-90 cm soil layer. The lowest nitrogen content was shown in grassland mineral soils, whereas the cultivation of both maize and mixed cereals promoted greater accumulation of this nutrient in the soil profile at the depth of 60-90 cm. Mineral nitrogen content also depended on the use of grassland ecosystems. In mineral soils, the highest amounts of N_{min} were found in hay grasslands, whereas in organic soils - in hay and pasture grasslands. The lowest amounts of nitrogen in the investigated soil layer were observed in alternate grasslands. It was also revealed that strong significant correlations exist between livestock density and the content of mineral nitrogen in the 60-90 cm soil layer. Calculated regression equation describing those relationships can help the farmer to plan sustainable fertilisation depending on livestock density of his farm.

K e y w o r d s: nitrogen losses, land use, mixed cereals, maize, grasslands, farming intensity

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INTRODUCTION

In Poland grasslands are an extremely important component of agricultural land. These are not only valuable meadows and pastures, a source of cheap fodder, but also areas with rich flora and fauna which diversify and beautify the landscape (Sawicki 2006), and their role in soil and water protection is stressed more and more frequently (Wasilewski 2009). Over the last dozen or so years, the area of arable land and grassland in Poland has declined substantially. During the period of 2000-2012, the cereal crop area decreased from 8.8 to 7.7 million ha, while the area of potato crops from 1.2 million ha to barely 360,000 ha. However, the rapeseed crop area increased from 437,000 to 720,000 ha, while that of maize from 162,000 to 508,000 ha. The grassland area decreased by almost 1.0 million ha. Grasslands now account for 19.7% of the agricultural land area and occupy 3,184,400 ha, with meadows making up 77% (2,450,300 ha) and pastures 23% (734,100 ha). A significant reduction in the crop area, both grassland and arable land, and a simultaneous increase in yield potential per unit area of agricultural land, make us ask questions concerning, among other things, the impact of plant production on the environment, including the impact of land use. The factors that are of significant importance in this respect undoubtedly include nitrogen which, in its mineral form in the soil, is a major nutrient for plants, but can also adversely affect production and the environment through its losses due to its being leached to deeper soil layers and groundwater (Koc *et al.* 1996, Rutkowska *et al.* 2002, Sapek 2010).

Grasslands that occur in areas intensively supplied with water perform an important function in determining water conditions (water retention and floodwater storage), while grasslands in undulating and mountainous areas protect the slopes from erosion, purify water, and reduce surface runoff. When grasslands are directly adjacent to rivers and other water bodies, they are an efficient filter preventing undesirable substances from getting into the aquatic environment. Hence, grassland communities, in particular meadows, pastures, and reed beds, are an important barrier to migration of biogenic elements.

At the end of the 1990's in Poland, the Ministry of Agriculture and Rural Development commissioned to undertake research on soil mineral nitrogen. The effect of this research was the quantitative determination of the occurrence of nitrate and ammonium nitrogen in soils and the characteristics of factors affecting the occurrence of mineral nitrogen (Fotyma 2000, Igras and Lipiński 2006, Fotyma *et al.* 2010, Jadczyszyn *et al.* 2010b). The obtained results were used for fertilisation advice purposes (Lipiński *et al.* 2010, Jadczyszyn *et al.* 2010a) as well as for environmental purposes (MoE's Regulation 2002). Determination of macro- and micronutrient (especially nitrogen) levels and their relationships with physicochemical properties of soil and the applied cultivation measures is an actual issue and has not only practical significance (Tkaczyk *et al.* 2017a,b, 2018a,b), but it is also a research problem – the NPK balance is currently modelled by implementing the information on the interactions between the content of macro and microelements and the physicochemical properties of soil into the soil sub-models (Lamorski *et al.* 2013, Walczak *et al.* 1997) of the most advanced crop growth and yield models. This may constitute a new quality in research on crop production in the conditions of changing climate, taking into account various cultivation and fertilisation treatments (Fronzek *et al.* 2018, Pirttioja *et al.* 2015, Ruiz-Ramos *et al.* 2018). The content of mineral nitrogen in soil is also influenced by atmospheric conditions, therefore studies on spatio-temporal variability and forecasting of meteorological time series from different climate zones are extremely important (Baranowski *et al.* 2015, Hoffmann *et al.* 2017, Krzyszczak *et al.* 2017a,b, Murat *et al.* 2018). This allows to assess how climate change impacts not only agricultural production, but also the content of macro-elements in the soil.

This study attempted to identify factors determining nitrogen content in the 60-90 cm soil layer from which nitrogen can migrate to waters. The problems of nitrogen surface runoff and also its distribution in the soil profile and possible losses caused by its leaching to deeper layers of soil are of great importance for economic, production and environmental reasons (Soon *et al.* 2001). As a result of runoff and leaching, pollution of surface and ground waters is frequently observed (Fotyma *et al.* 2010). Therefore, frequent monitoring of nutrient status in the soil, and research concerning its dependence on soil properties and management should be performed, which can lead to an increase of farmers' awareness of environmental hazards related with improper dosing of fertilisers. The study hypothesised that there would be differences in the content of mineral nitrogen being beyond the reach of the main root mass of crop plants in grassland soils and in arable soils depending on soil type, land use and farming intensity (i.e. livestock density). The aim of this study was to evaluate mineral nitrogen content in the 60-90 cm soil layer in grassland soils relative to other selected agricultural fodder crops depending on grassland use and livestock density.

MATERIALS AND METHODS

Evaluation of soil mineral nitrogen content was performed based on the results of environmental investigations conducted by the Regional Chemical and Agricultural Stations in agricultural farms across Poland over the period of 2010-2012. Only those grassland sites were selected where the same land use was continued over the entire study period. Soil samples were taken in spring and autumn from three soil profile layers, 0-30, 30-60, and 60-90 cm, from fields with a total area of not more than 4 ha. Sampling sites were identified by geographical coordinates and these were fixed sites throughout the entire study period. The location of soil sampling points is shown in Figure 1. In order to verify the research hypothesis, the average mineral nitrogen content in the 60-90 cm soil layer for the period of 2010-2012 under grassland mineral (859 sites) and organic (167 sites) soils was evaluated. For comparison, 826 sites with maize crops and 951 sites with mixed cereals were chosen (Tab. 1). For each site selected, if the same crop was grown in successive years of the study, the average value for the respective period was calculated. The research material was grouped on the basis of questionnaires, in which farmers declared their farm livestock density in Livestock Units (LSU) as one of the three groups – <0.75, 0.75-1.5 and >1.5 LSU ha^{-1}. The information about the number of farms encompassing fields with grassland mineral and organic soils and fields with maize crops and with mixed cereals, divided into livestock density groups, is presented in Table 1.

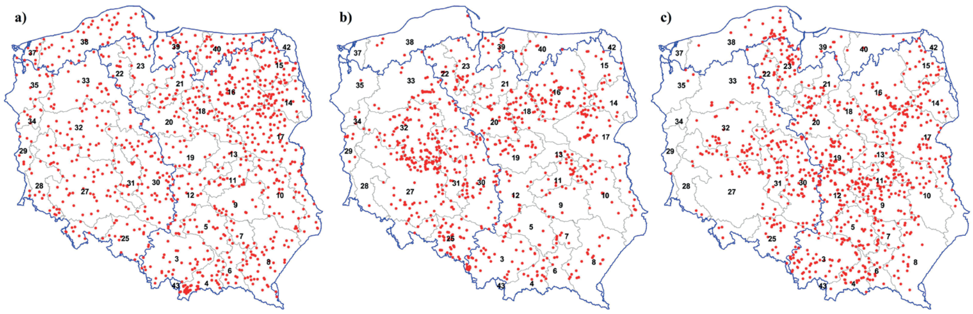

Fig. 1. Location of soil sampling points from a) grasslands, b) maize and c) mixed cereals

Table 1. Number of analysed soil samples taken from the 60-90 cm layer from grasslands on mineral and organic soils, maize and mixed cereals and information about the number of farms encompassing fields from which soil samples were collected, divided into livestock density groups

Land use		Number of sampling points	Number of farms			
			LSU ha^{-1}			
		<0.75	0.75-1.5	>1.5	N.A.*	
Grasslands on mineral soils	total	859	368	310	118	63
	hay	519	232	167	68	52
	pasture	159	64	62	23	10
	hay and pasture	83	39	38	6	0
	alternate	98	33	43	21	1
Grasslands on organic soils	total	167	85	48	32	11
	hay	111	55	29	16	11
	pasture	17	11	4	2	0
	hay and pasture	39	19	15	5	0
	alternate	0	0	0	0	0
Maize		826	215	321	172	118
Mixed cereals		951	404	328	100	119

*N.A. – data not available, farmer did not respond to the questionnaire; LSU – Livestock Unit

In the laboratories of the Regional Chemical and Agricultural Stations, soil samples with natural moisture content (after defrosting) were subjected to extraction with a 1% potassium sulphate solution at a ratio of 1:10. In the extracts obtained, nitrate and ammonium nitrogen content was determined spectrophotometrically using a Skalar San Plus System auto-analyser (in accordance with PN-R-04028:1997). Dry matter content was also determined in the examined samples (in accordance with PN-ISO 11465:1999). Mineral nitrogen content, as total nitrate and ammonium nitrogen, was expressed in mg kg^{-1} of dry weight of the sample (soil). The study results were analysed using standard statistical methods. For each type of land use and livestock density group basic descriptive statistics, such as average value of mineral nitrogen content and standard deviation, were calculated and presented in respective figures. Then, the relations between the content of N_{min} and a given factor were characterised by Pearson correlation coefficients and by simple regression analysis calculated in the SAS v. 9.1 program.

RESULTS AND DISCUSSION

Mineral nitrogen content in the 60-90 cm soil layer is also largely modified by the use of agricultural land, including grasslands. The study showed that in mineral soils the lowest contents of this form of nitrogen were found in grasslands, whereas the highest ones in soils under maize crops. The effect of mixed cereals on the high content of the above-mentioned form of nitrogen was medium – it was greater than in grasslands and smaller compared to soils under maize (Fig. 2). The above-mentioned relationships were observed both in spring and in autumn (Fig. 3).

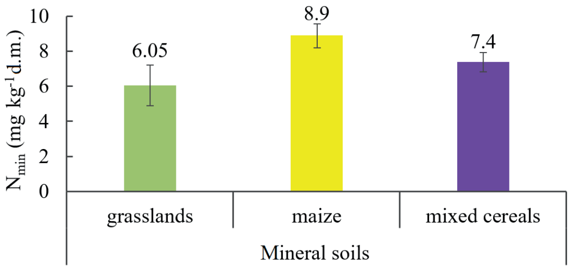

Fig. 2. Average mineral nitrogen content N_{min} in the 60-90 cm layer of mineral soils depending on land use

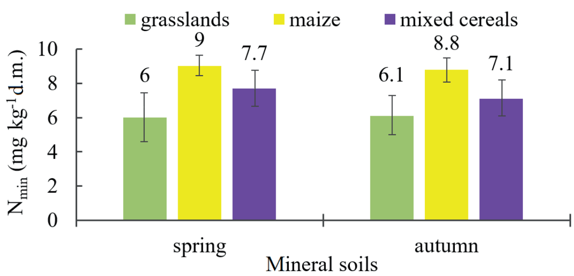

Fig. 3. Average mineral nitrogen content N_{min} in the 60-90 cm layer of mineral soils depending on land use and sampling date

The dependence of mineral nitrogen content in mineral soils on land use has been proven by many authors. According to Pecio *et al.* (2005), the highest mineral nitrogen content is found in soils under root crops, while the lowest in soils under winter crops. In the opinion of Rutkowska *et al.* (2002), the relationship between N_{min} and the place in crop rotation can result from crop residue and time distance from farmyard manure application. Kornas (2012) showed that the lowest mineral nitrogen losses are in soils under cereal crops, both in spring and in autumn, while the highest ones in soils under root crops in spring and in the other crops in autumn. In his opinion, crops characterised by the highest nitrogen uptake cause a decrease in N_{min} content in the 60-90 cm soil layer.

Analysing the effect of grassland use on mineral nitrogen content in the 60-90 cm soil layer, evaluation was performed separately for mineral soils and organic soils due to the significant differences in physicochemical properties between them. The obtained results for mineral soils showed the highest content of the investigated form of nitrogen for hay grasslands, while it was the lowest in alternate grasslands (Fig. 4).

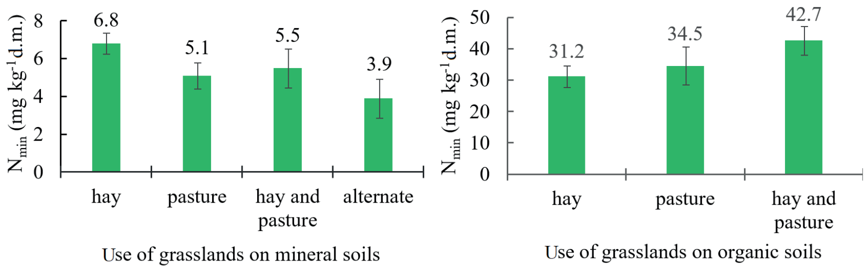

Fig. 4. Average mineral nitrogen content N_{min} in the 60-90 cm layer of mineral and organic grassland soils depending on grassland use

In soils of hay grasslands, as well as in hay and pasture grasslands, N_{min} contents in the investigated layer were similar. A study by Sapek and Kalińska (2004, 2007) also proves the different uses of grassland communities to have an effect on increased mineralisation of nitrogen compounds in the soil. They found N-NO_3 released under hay meadow conditions to be about three times higher and N-NH_4 to be twice higher compared to the amounts released from grass crops in arable land (alternate grasslands). In the present study, the variable use, i.e. hay and pasture use, contributed to the highest mineral nitrogen content in the non-root layer in organic soils. On the other hand, hay use had the most beneficial effect. In most cases, mineral nitrogen content in grassland soils did not differ significantly depending on grassland use and sampling date. Nevertheless, in spring its lower contents were observed in meadows and pastures, both in mineral and organic soils (Fig. 5). Greater differences in soil nitrogen content in spring and autumn were found in hay and pasture grasslands, where higher N_{min} contents were recorded in spring than in autumn, in particular in organic soils.

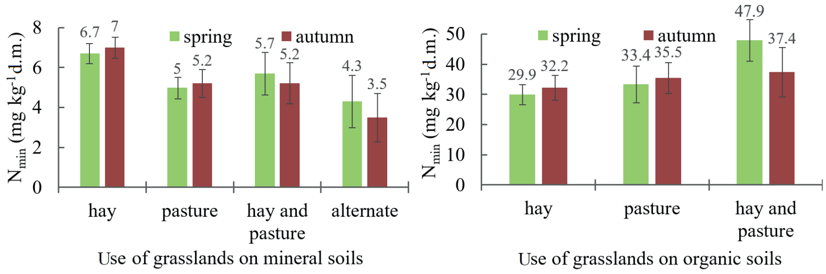

Fig. 5. Average mineral nitrogen content N_{min} in the 60-90 cm layer of mineral and organic grassland soils depending on grassland use and sampling date

In spring, higher contents of the mineral form of nitrogen in the 60-90 cm soil layer were also found in alternate grasslands on mineral soils. Sapek and Sapek (2007) also conducted research on mineral nitrogen content in grassland soils. They observed the lowest $N\text{-}NO_3$ contents in samples collected in spring, before the start of the growing season, while the highest ones in samples taken after the second regrowth when the soil temperature was already high. In summer and early autumn, these contents decreased despite the soil moisture content being maintained at a similar level. In the opinion of those authors, $N\text{-}NO_3$ content in meadow soil is proportional to the rate of nitrogen uptake by meadow vegetation, which may suggest that mineralisation efficiency has the same rhythm as plant growth. Sapek and Sapek (2007) also explain the small differences between meadows and short-term alternate grasslands regarding the average mineral nitrogen content in the soil before and after the growing season by significantly lower leaching of nitrates from permanent grasslands compared to grasslands on arable land.

Mineral nitrogen content in the 60-90 cm soil layer was also examined taking into account the livestock density expressed in LSU (livestock unit). It was already shown that the livestock density can significantly influence nitrogen supply to the soil (Baryła and Kulik 2006, Kornas 2012). Irrespective of the sampling date and land use, the largest content of mineral nitrogen in the assessed soil layer was observed for densities not exceeding 0.75 LSU, whereas the smallest amounts of N_{min} were observed for soils located in the vicinity of farms with animal density in the range between 0.75 and 1.5 LSU (Fig. 6).

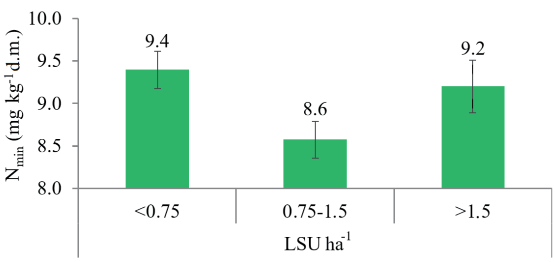

Fig. 6. Average mineral nitrogen content N_{min} in the 60-90 cm soil layer depending on livestock density

However, after further assessment of the studied soils performed separately for mineral soils and organic soils, it was revealed that on mineral soils the content of mineral nitrogen increases with livestock density increase, while for organic soils it is the highest for LSU lower than 0.75 (Fig. 7). It was also revealed that the content of N_{min} was significantly higher for organic soils compared to mineral soils, regardless of livestock density. This may be related to fertilisation, as greater impact of organic fertilisers use than of mineral fertilizers use on the content of mineral nitrogen in the soil was emphasised by Sosulski et al. (2005), Mazur and Mazur (2006) and Żabikowska (2002).

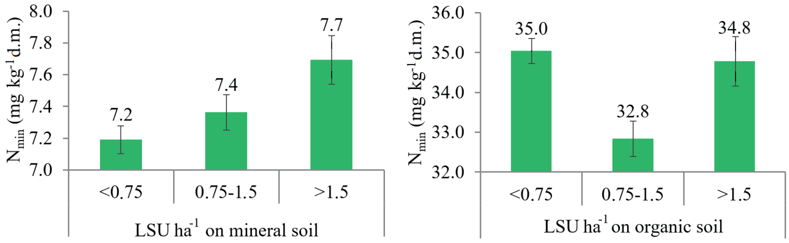

Fig. 7. Average mineral nitrogen content N_{min} in the 60-90 cm layer of mineral and organic soils depending on livestock density

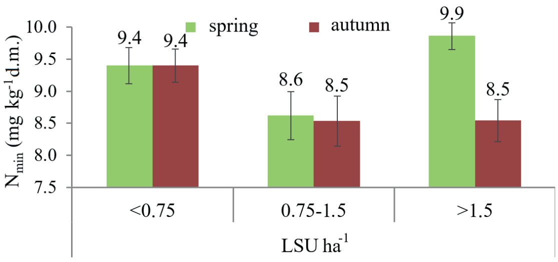

Fig. 8. Average mineral nitrogen content N_{min} in the 60-90 cm soil layer depending on livestock density and sampling date

Regardless of the type of soil, the content of mineral nitrogen in the 60-90 cm layer did not differ significantly on the spring and autumn sampling dates only for soils located in the vicinity of farms with livestock density lower than 1.5 LSU. With higher densities (LSU > 1.5), significantly higher N_{min} contents were observed in spring than on the autumn sampling date (Fig. 8).

The increase in livestock density clearly contributed to the higher content of N_{min} in mineral soils, however on the autumn sampling date no dependence between LSU and the amount of N_{min} in the assessed soil layer was observed (Fig. 9). In turn, in the organic soils at the spring sampling date the lowest content was found for the range between 0.75 and 1.5 LSU, and the highest for LSU larger than 1.5. On the contrary, for the autumn sampling date a decrease in the average mineral nitrogen content was noted along with the increase in livestock density. In mineral soils under grasslands the density of livestock (in the assessed range of LSU) did not cause any differences in mineral nitrogen content in the 60-90 cm layer, both in spring and autumn

(Fig. 10). On the contrary, the impact of livestock density on N_{min} content appeared in soils under maize, with a higher level of this element for lowest densities. In the case of soils under mixed cereals an increase in the value of LSU caused higher N_{min} contents in the 60-90 cm soil layer. For each of the defined LSU ranges and regardless of the sampling date, N_{min} content in soils under grasslands was lower compared to the content of this nutrient in the soils under maize or mixed cereals.

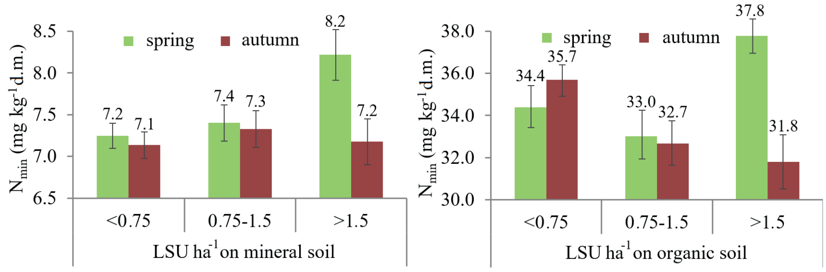

Fig. 9. Average mineral nitrogen content N_{min} in the 60-90 cm layer of mineral and organic soils depending on livestock density and sampling date

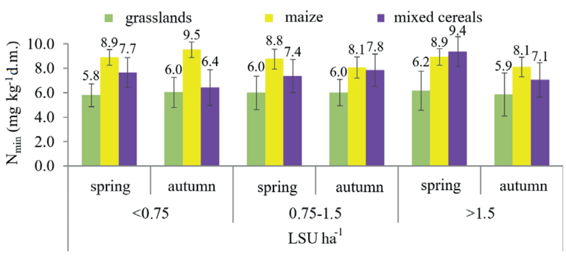

Fig. 10. Average mineral nitrogen content N_{min} in the 60-90 cm layer of mineral soils depending on livestock density, land use and sampling date

Statistical analysis confirmed the results of the observations (Tab. 2, Figs 11-14). It was shown that strong significant relationship exists between livestock density and the content of N_{min} in the 60-90 cm layer of mineral soils, regardless of the land use (correlation coefficient R equal to 0.98). High correlation was also confirmed for the spring sampling date, whereas this relationship was low and insignificant for the autumn sampling date. For organic soils, sampling made in autumn revealed a significant and negative correlation between livestock density and the content of N_{min} in the 60-90 cm layer (R = –0.95). On the spring sampling date an increase in the number of animals could promote the outflow of mineral nitrogen beyond the reach of the main root mass of grasslands on mineral soils (R = 0.99), especially in the case of alternate grasslands and pastures. This was also confirmed for the autumn sampling date. The calculated correlation coefficients indicate that livestock density can have a significant impact on N_{min} content in the soil, which was manifested by an increase in the content of this nutrient mainly in mineral soils in spring and by a decrease in organic soils in autumn and in mineral soils under maize.

Table 2. Relationships between livestock density and mineral nitrogen content N_{min} in the 60-90 cm soil layer from grasslands on mineral and organic soils, maize and mixed cereals, expressed in terms of correlation coefficients taking into account both the land use and the date of soil samples collection

Land use	Date of soil samples collection	
	spring	autumn
Grasslands on mineral soils	1.00	–0.97
Hay on mineral soils	0.27	–0.37
Pasture on mineral soils	0.63	0.70
Hay and pasture on mineral soils	–0.14	–0.51
Alternate grasslands on mineral soils	0.95	0.96
Grasslands on organic soils	0.69	–0.95
Hay on organic soils	0.84	–0.92
Pasture on organic soils	–0.92	–0.17
Hay and pasture on organic soils	0.91	0.89
Maize	0.11	–0.86
Mixed cereals	0.79	0.45
Soils in total	0.37	–0.86
Mineral soils in total	0.93	0.19
Organic soils in total	0.69	–0.95
Soils in total – annualised	–0.23	
Mineral soils in total – annualised	0.98	
Organic soils in total – annualised	–0.11	

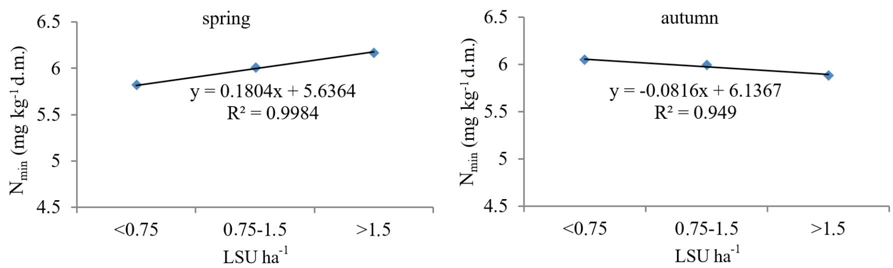

Fig. 11. Relationship between livestock density and average mineral nitrogen content N_{min} in the 60-90 cm layer of grassland mineral soils on both spring and autumn soil sampling dates

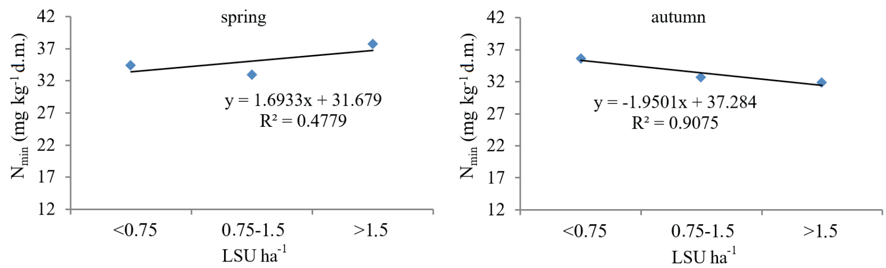

Fig. 12. Relationship between livestock density and average mineral nitrogen content N_{min} in the 60-90 cm layer of grassland organic soils on both spring and autumn soil sampling dates

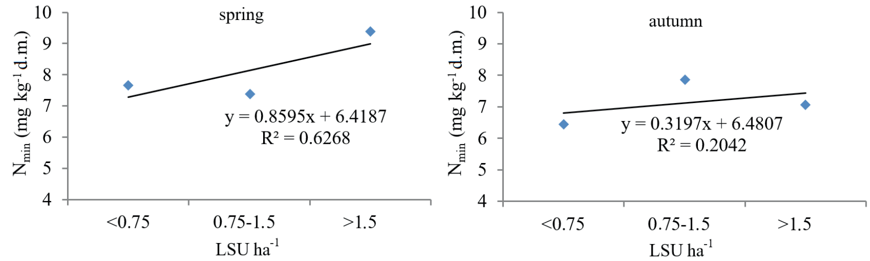

Fig. 13. Relationship between livestock density and average mineral nitrogen content N_{min} in the 60-90 cm layer of mineral soils under mixed cereals on both spring and autumn soil sampling dates

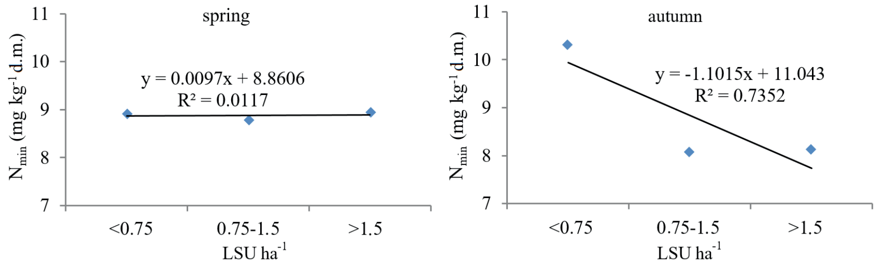

Fig. 14. Relationship between livestock density and average mineral nitrogen content N_{min} in the 60-90 cm layer of mineral soils under maize on both spring and autumn soil sampling dates

CONCLUSIONS

1. Monitoring of soil mineral nitrogen content, especially in the 60-90 cm layer, is an important indicator for the impact of nitrogen on water quality. This study assumed that mineral nitrogen occurring at a depth of 60-90 cm of the soil profile is beyond the reach of the main root mass of grassland plants, maize, and mixed cereals. Therefore, this content is a potential loss of this plant nutrient important from the production point of view and, as a consequence, it is a serious threat to water quality (especially outside of the growing season).

2. In evaluating (in spring and autumn) mineral nitrogen content in the 60-90 cm layer of grassland soils relative to other selected agricultural crops, this study confirmed the research hypothesis that there would be differences in the content of this form of nitrogen in that soil layer, depending on land use. Regardless of the observation period and the natural factors evaluated, grassland use also had a significant effect on mineral nitrogen content in the 60-90 cm soil layer. The lowest content of this form of nitrogen was shown in grassland mineral soils, whereas the cultivation of both maize and mixed cereals promoted greater accumulation of this nutrient in the soil profile at the depth of 60-90 cm. N_{min} content also depended on the use of

grassland ecosystems. In mineral soils, its highest amounts were found in hay grasslands, whereas in organic soils in hay and pasture grasslands. The lowest amounts of nitrogen in the investigated soil layer were observed in alternate grasslands.

3. It was also revealed that livestock density and the content of N_{min} in the 60-90 cm soil layer, regardless of the land use or sampling date, are strongly correlated. Equations describing those relationships, presented in Figures 11-14, can be of great importance from the practical point of view, because they may be used to predict nitrogen loses and thus help the farmer to identify the optimal dose of mineral nitrogen in soils with different livestock densities.

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ZAWARTOŚĆ AZOTU MINERALNEGO W WARSTWIE 60-90 CM GLEB UŻYTKÓW ZIELONYCH NA TLE INNYCH UPRAW O PRZEZNACZENIU PASZOWYM, SPOSOBÓW ZAGOSPODAROWANIA UŻYTKÓW ROLNYCH ORAZ INTENSYWNOŚCI GOSPODAROWANIA

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S t r e s z c z e n i e. Azot mineralny występujący na głębokości 60-90 cm profilu glebowego, niedostępny dla głównej masy korzeniowej roślin użytków zielonych i gruntów ornych, a znajdujący się w tej warstwie w wyniku wymywania do głębszych warstw gleby, może stanowić poważne zagrożenie dla jakości wód. W pracy podjęto próbę oceny zawartości N_{min} w glebach użytków zielonych w zależności od typów gleby, sposobów jej użytkowania oraz intensywności gospodarowania (np. rozmiary produkcji zwierzęcej). Niezależnie od okresu prowadzonych obserwacji i ocenianych czynników naturalnych istotny wpływ na zawartość azotu mineralnego w warstwie gleby 60-90 cm miały zarówno sposób użytkowania gleby, jak i sposób zagospodarowania użytków rolnych. Najniższą zawartość azotu wykazano w glebach mineralnych użytków zielonych, natomiast zarówno uprawa kukurydzy, jak i mieszanek zbożowych sprzyjała większemu nagromadzeniu tego składnika w profilu glebowym na głębokości 60-90 cm. Zawartość azotu mineralnego zależała także od sposobu użytkowania ekosystemów trawiastych. W glebach mineralnych najwyższe ilości N_{min} stwierdzano pod wpływem użytkowania kośnego, zaś na organicznych – kośno-pastwiskowego. Najmniejsze ilości azotu w ocenianej warstwie gleby notowano pod przemiennymi użytkami zielonymi. Wykazano także istnienie znaczącej zależności pomiędzy rozmiarami produkcji zwierzęcej a zawartością azotu mineralnego na głębokości 60-90 cm profilu glebowego. Otrzymane równania regresji mogą ułatwić rolnikom planowanie zrównoważonego nawożenia w zależności od obsady zwierzęcej w ich gospodarstwach.

Słowa kluczowe: straty azotu, sposób użytkowania, mieszanka zbożowa, kukurydza, użytki zielone, intensywność gospodarowania