

MINERAL NITROGEN CONTENT IN SOILS DEPENDING ON LAND USE AND AGRONOMIC CATEGORY

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Abstract. Evaluation of mineral nitrogen content ($N_{\min}$) was performed for the 60-90 cm layer of grassland soils relative to other selected agricultural fodder crops. Soil samples were collected two times per year, in spring and autumn, over the period 2010-2012 from fixed locations scattered across whole Poland territory. Additionally, particle-size distribution was assessed in the tested soil samples, which allowed to assign soil agronomic categories to them and assess the relationship between $N_{\min}$ content and assigned categories. Regardless of sampling date and land use, agronomic category had a significant effect on $N_{\min}$ content. Generally the relationships between the percentage of particles with dimensions below 0.02 mm and $N_{\min}$ content were characterized by a negative correlations, but in maize crops they were found to be positively correlated. Based on the obtained correlations, linear regression equations were developed. Calculated relations were less pronounced in spring, before fertilization, than in the autumn, after harvest. These equations can be very important from the practical point of view, as they may be used by farmer to plan a rational and sustainable fertilization based on forecasting of losses of mineral nitrogen content in the soil depending on the percentage of fine particles (agronomic category) of cultivated soil.

Keywords: mineral soils, organic soils, maize, mixed cereals, regression equations

Introduction

Nitrogen is one of the most important macronutrients, playing crucial role in crop growth process. The management of mineral nitrogen to ensure optimal level for plants is strongly dependent on physico-chemical properties of cultivated soil, such as particle-size distribution, bulk density, porosity or pH, crop management practices, as well as climatic conditions, which not only are a subject of constant changes, but also experienced a sudden shift related to climate change resulting in temperature increase (Swanson and Tsonis, 2009) and variation in precipitation structure. Increasing global food demand and gradually diminishing arable land area put new challenges for crop

production, which can be fulfilled by precision agriculture and sustainable soil management. For example, in Poland arable land as a share of land area fell gradually from 45.6 % in 2000 to 35.6 % in 2015 (The World Bank, 2015), but yields per hectare are increasing, which is related to the intensification of plant production. Usually it involves the use of higher doses of fertilizers, what results in the stronger impact of agriculture on the environment, as about 40 to 70% of nitrogen applied as normal fertilizer is either chemically bound in the soil and becomes unavailable to plants or is lost to the environment due to leaching (Jarosiewicz and Tomaszewska, 2003). In terms of sustainable agriculture, intensification should be strongly connected with optimization of efficiency of fertilizers use by modifications leading to graduation of their release time and biochemical activity. Also, the application of fertilizers for specific location should take into account soil bio-physico-chemical status, expressed through particle size distribution, mineralogical composition, soil pH, water retention properties and hydraulic conductivity, organic matter content or soil microbial community composition, activity of which can depend not only on N fertilization (Gleń-Karolczyk et al., 2018; Walkiewicz et al., 2018), but also on contamination (Walkiewicz et al., 2016; Wnuk et al., 2017). Poland is a region characterized by a significant diversification of soils and thus, the agricultural production conditions. Therefore, regular monitoring of soil properties and analysis of their relations with macro and micronutrients status (Tkaczyk et al., 2017; 2018a; 2018b) that is taking into account the diversity of soils is necessary for appropriate distribution and application of NPK fertilizers and their sustainable management (Tunbare et al., 2005; Watros et al., 2018). This can be done by precise prediction of soil properties variations in space and time using physical-mathematical modelling (Lamorski et al., 2013), which consider spatio-temporal variations of soil and climate conditions. To consider crop production in the conditions of a changing climate, various approaches can be applied. They capture projections of future climate from climatic models, which take into account various climate change scenarios, by either modification of amplitudes of partial density functions of measured time series to be in accordance with predicted climate change (Pirttioja et al., 2015; Fronzek et al., 2018) and consider adaptation measures (Ruiz-Ramos et al., 2018; Rodríguez et al., 2019), or take into account various statistical models (Murat et al., 2018) to forecast hourly or daily courses of future time series. It was shown that modifications of the weather time series structure (either by changing amplitudes or by an spatio-temporal aggregation) interfere with their inherent properties, such as long distance power-law correlations (Baranowski et al., 2015; Hoffmann et al., 2017; Krzyszczak et al., 2017a; 2017b; Krzyszczak et al., 2018) and therefore should be done with appropriate caution, as it may highly influence the results of modelling.

The most general form of presenting soil properties and analyzing their impact on crop production is the use of agronomic category. The studies on impact of agronomic category on mineral nitrogen in soil makes it possible for farmers to easily evaluate fertilization needs for a specific soil type. Up to this moment there are not many studies regarding the relation agronomic category on soil mineral nitrogen performed in large scale covering whole country area, which consider sampling date and land use. For example, it was already shown that, in general, soil mineral nitrogen content is affected by soil agronomic category (Paz and Ramos, 2004). Differences in soil mineral nitrogen content in spring and autumn sampling dates, as well as the assessment of percentage of nitrate and ammonium nitrogen in mineral nitrogen content were assessed by Fotyma

and Pietruch (2000) and Pietrzak (2014). Fotyma and Pietruch (2000) showed that in the 0-60 cm layer, the greatest variations in this respect were found in very light and light soils, whereas in the 60-90 cm layer heavy soils exhibited the largest differences. In medium and heavy soils, the percentage of ammonium nitrogen is about 30% of the total amount of mineral nitrogen, while in light soils this percentage is substantially higher, standing at 50%. It can be explained by greater denitrification intensity in heavy soils (Mosier et al., 2002). Pietrzak (2014) stated that in the topsoil (0-30cm) the highest content of mineral nitrogen are found in meadow soils with high permeability, i.e. light and very light soils, and that the amount of mineral nitrogen in meadow soils generally increases during growing season and decreases in the off-season.

Mineral nitrogen located in the 0-30 cm layer can migrate to deeper layers of the soil profile due to leaching (Powelson, 1988; Coyne and Frye, 2005). In the Soon et al. (2001) opinion, nitrogen losses in agriculture caused by nitrogen leaching are of significant importance for economic, production and environmental reasons. A direct consequence of mineral nitrogen leaching is pollution of ground and surface waters (Fotyma et al., 2010). In Poland monitoring of soil mineral nitrogen has been conducted for many years (Fotyma and Pietruch, 2000; Regulation, 2002; Jadczyński et al., 2010; Pietrzak, 2014). Based on this monitoring, the impact of soil N_{min} content on water quality can be predicted. This study attempted to identify factors determining nitrogen content in the 60-90 cm soil layer from which nitrogen can migrate to waters. As soil mineral nitrogen content is expected to be highly varied in time (Yu et al., 2003), with higher content during the spring and lower at the turn of August and September, which is a result of changes in the intensity of nitrification and enhanced nitrogen uptake by plants (Łoginow et al., 1987), therefore the analysis was carried out for two sampling dates – spring and autumn.

The study hypothesis is that, depending on selected soil properties, land use and sampling dates, significant differences exist in the content of mineral nitrogen in the soil layer beneath 60 cm, which is beyond the reach of the main root mass of crop plants in grassland soils (Mezhunts et al., 2005; Bonin et al., 2013) and in arable soils (Fan et al., 2016). The aim of this study was to evaluate mineral nitrogen content in grassland soils relative to other selected agricultural fodder crops in 60-90 cm layer depending on soil agronomic category.

Material and methods

Sampling sites

The results of environmental investigations conducted by the Regional Chemical and Agricultural Stations in agricultural farms across Poland over the period 2010-2012 were used to evaluate soil mineral nitrogen content for Polish soils under different land uses. The number of analyzed soil samples with the specified land use is presented in *Table 1*. Soil sampling sites, scattered over whole Poland territory, were identified by their geographical coordinates using GPS Pathfinder ProXT by Trimble (Westminster, CO 80021, USA, www.trimble.com) and were fixed for the entire study period. Locations of soil sampling points are presented in *Fig. 1*.

Soil samples were collected twice a year, in spring and autumn dates, from fields with a total area of not more than 4 ha. Soil sampling in spring were conducted in the period from February to April (before applying fertilizers), whereas in autumn in the period from September to October (after harvesting). Sampling done for 3 consecutive

years diverse in terms of meteorological conditions (*Tab. 2*), with 2010 being cold and wet, 2011 – very warm and dry and 2012 – warm and moderate (Statistical yearbook, 2011; 2012; 2013), two times per year, allow to average out the influence of year-by-year variations of these conditions and reveal more the influence of agronomic categories on N content. Each sample, weighing about 200 g, consisted of 15-20 primary soil samples collected from 60-90 cm layer using Egner stick from an area no larger than 100 m².

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. In the case of sites located in grasslands, the same land use was continued over the entire study period and the average N_{min} content for the period 2010-2012 was considered.

Table 1. Number of analyzed soil samples taken from the 60-90 cm soil layer in grasslands on mineral soils, maize and mixed cereal (mostly oat and barley) crops

Crop type/land use		Number of samples
Grasslands (on mineral soils)	Total	859
	Meadows	521
	Pastures	160
	Hay and pasture	84
	Alternate	98
Maize		826
Mixed cereal (mostly oat and barley)		951

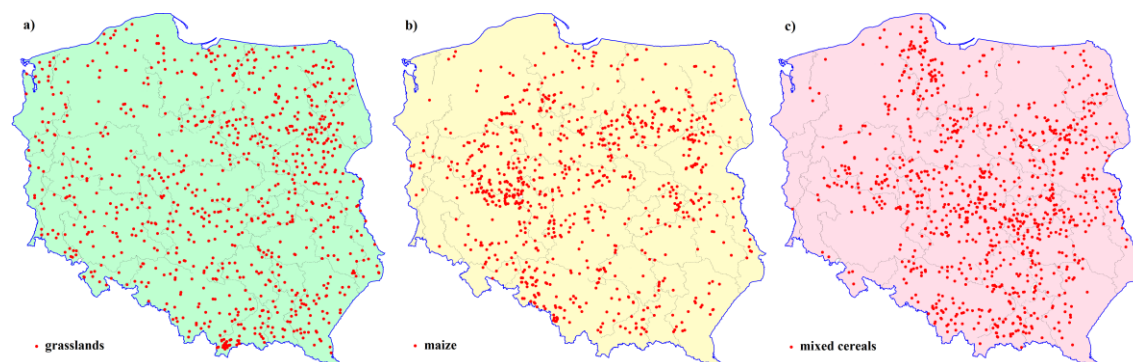


Figure 1. Location of soil sampling points from a) grasslands, b) maize and c) mixed cereals

Table 2. Basic meteorological conditions (on average) of the experimental years

Meteorological parameter	Year		
	2010	2011	2012
Temperature [°C]	7.1	8.5	8.1
Maximum temperature [°C]	36.6	34.3	36.5
Minimum temperature [°C]	-29.0	-25.1	-29.9
Precipitation [mm]	869.3	598.3	643.1
1 day maximum precipitation [mm]	186.2	140.5	66.2
Wind speed [m/s]	3.34	3.43	3.35
Sunshine hours [h]	1706.7	1973.7	1850.9

Soil samples analysis

Collected samples were delivered to the respective laboratory in tightly sealed containers and kept at a temperature of -18°C until an analysis of mineral nitrogen was performed. The soil samples with natural moisture content (after defrosting) were subjected to extraction with a 1% potassium sulfate 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-analyzer (in accordance with the PN-R-04028:1997 norm, which is slightly modified, but equivalent to International Standard ISO 14256). Mineral nitrogen content (a sum of nitrate and ammonium nitrogen) was expressed in $\text{mg}\cdot\text{kg}^{-1}$ of dry matter of the soil sample (DM). Determination of dry matter was made using the gravimetric method after drying at 105°C (according to PN-ISO 11465:1999). In the air-dried samples, particle size distribution was determined using the laser diffraction method. As the extraction of nitrate and ammonium is carried out in a sample with natural moisture content, therefore obtained results were recalculated to the dry matter content using the empirical coefficient suitable for the soil of specific granulometric composition. Based on the content of particles with a diameter of $<0.02\text{ mm}$, one of four soil agronomic categories has been assigned to each soil sample (IUNG, 1990): very light soils ($< 10\%$ of fine particles), light soils (11-20%), medium soils (21-35%), and heavy soils ($> 35\%$ of fine particles).

Statistical analysis

To assess the relationship between soil agronomic category and content of mineral nitrogen in layer beyond the reach of roots of crop plants, $N_{\min}$ content in the 60-90 cm soil layer beneath ground surface in grasslands, as well as in soils under maize and mixed cereals was calculated as an annual average. Separately, averages were calculated for the spring and autumn sampling dates, depending on the assigned agronomic category and land use. Beside average values, standard deviations (SD) of mineral nitrogen content were calculated and presented on the figures. The relationships between $N_{\min}$ content and agronomic category were characterized by Pearson's correlation coefficients and assessed statistically using the one-way non-orthogonal analysis of variance classification with Tukey confidence intervals ($p = 0.05$). Additionally, simple regression analysis performed in SAS v. 9.1 software was carried out to obtain linear equations describing the relationship between the soil agronomic category and the $N_{\min}$ content in the 60-90 cm soil layer for varying land use. The goodness of fit of linear regression was evaluated using determination coefficients (R^2).

Results and discussion

The analyses show that indeed mineral nitrogen content in the 60-90 cm soil layer depends on agronomic category (*Fig. 2*). The highest mineral nitrogen content was observed in light soils, whereas a slightly lower one in very light soils. This trend persisted both in spring and in autumn, except for very light soils for which a higher content of this form of nitrogen was noted in spring than in autumn (*Fig. 3*). The effect of seasonality on nitrogen mineralization in soils of peatland ecosystems is discussed by Pawluczuk and Gotkiewicz (2003). They showed much higher amounts of soil $N_{\min}$ in spring than in summer and autumn. In their opinion, the reason for this is that in muck

and peat soils enhanced mineralization occurs also in winter and the quantities of nitrogen unused by plants (because of the non-growing period) are lost. Also, Arbačiauskas et al. (2014) obtained similar tendencies for the 60-90 cm soil layer of Lithuanian agricultural lands, irrespective of soil texture or nitrogen fertilisation rate.

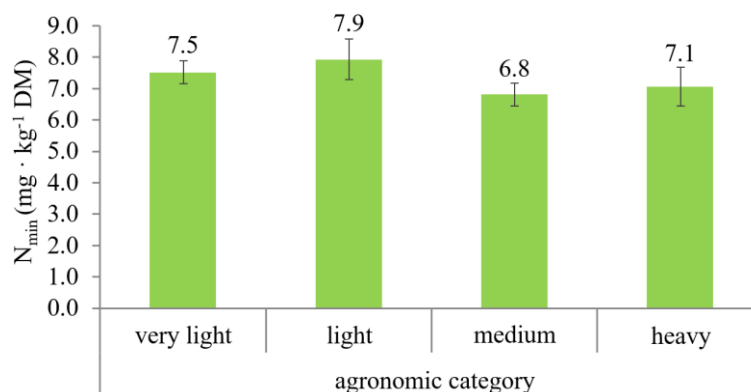


Figure 2. Average mineral nitrogen N_{min} content in the 60-90 cm soil layer with its standard deviation depending on soil agronomic category. DM stands for dry matter of the soil sample

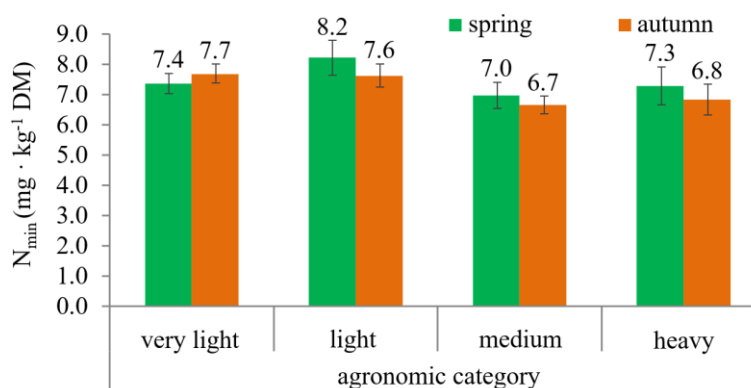


Figure 3. Average mineral nitrogen N_{min} content in the 60-90 cm layer of mineral soil with its standard deviation depending on agronomic category and soil sampling date. DM stands for dry matter of the soil sample

Higher mineral nitrogen contents in the 60-90 cm layer of very light and light soils relative to medium or heavy soils were also found in soil material taken from grassland soils and soils under mixed cereals. On the other hand, this relationship was opposite in the investigated layer in soils under maize because the highest N_{min} content was found in heavy soils (Fig. 4). A much higher N_{min} content in heavy soils relative to light soils was also found by Fotyma and Pietruch (2000). It was also shown that grassland soils accumulate less mineral nitrogen in the 60-90 cm layer than soils under mixed cereals or, which was even more evident, maize. Strong dependence of runoff and dissolved mineral nitrogen losses, and therefore differentiation of N_{min} content in the deeper soil layers, on vegetation cover was noticed by García-Díaz et al. (2017) for vineyards. Also De Notaris et al. (2017) showed that N leaching is influenced by vegetation cover, with spring wheat and potatoes being the two crops with highest N leaching.

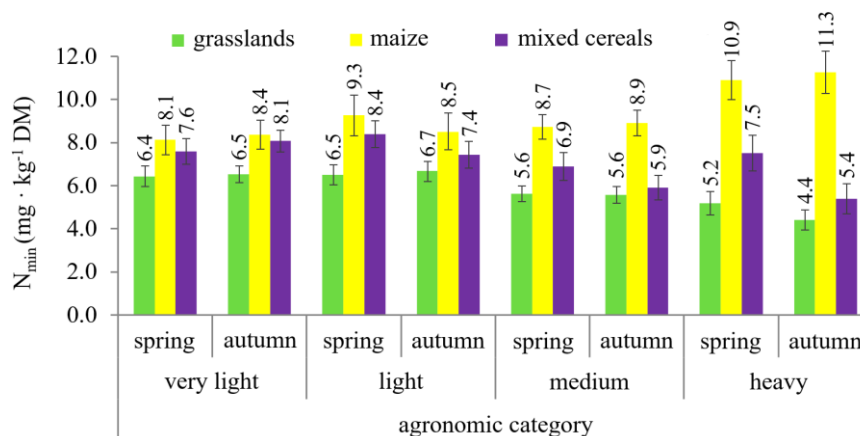


Figure 4. Average mineral nitrogen N_{min} content in the 60-90 cm layer of grassland soils and soils under maize and mixed cereals with its standard deviation depending on agronomic category and sampling date. DM stands for dry matter of the soil sample

Considering in turn mineral nitrogen content under different agronomic categories of grassland soils depending on land use, it was found that in most cases the highest content of this form of nitrogen at a depth of 60-90 cm was found in meadows (Fig. 5). The N_{min} contents in pasture grasslands as well as in hay and pastures grasslands were at a similar level, whereas the lowest amount of nitrogen was detected in alternate grasslands, which was particularly visible in heavy soils. Under the specific soil agronomic categories, greater differences in mineral nitrogen content between particular grassland uses were noted in autumn than in spring. Pawluczuk and Szymczyk (2008) obtained similar results. They found a lower mineral nitrogen content in muck and peat soils in extensively used meadows compared to this content in muck and peat soils in pastures. In the case of extensive grassland use, they found a higher nitrate content in groundwater under meadows than under pastures. These authors substantiate this fact by greater phytosorption of nitrogen by pasture vegetation and a low groundwater level. Above factors adversely affect the movement of the nitrate form of nitrogen deeper into the soil profile.

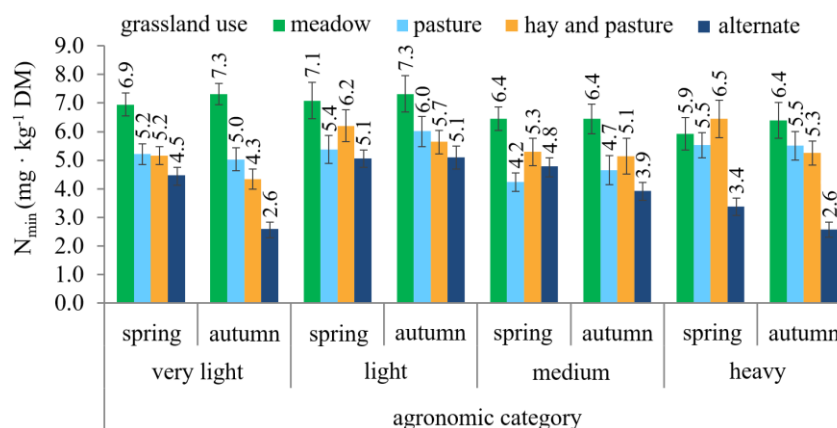


Figure 5. Average mineral nitrogen N_{min} content in the 60-90 cm layer of grassland soils with its standard deviation depending on grassland land use, sampling date and agronomic category. DM stands for dry matter of the soil sample

Observed relationships between soil agronomic category and mineral nitrogen content in the 60-90 cm soil layer (below the main root mass of the crops under investigation) were statistically confirmed (*Table 3*). Regardless of sampling date and land use, soil agronomic category had a significant effect on $N_{\min}$ content ($R = -0.68$), but this relationship was weaker in spring ($R = -0.42$) and stronger in autumn ($R = -0.86$). It means that the $N_{\min}$ losses decreased with the increase of percentage of fine particles with dimensions below 0.02 mm in soil, which is probably connected with lower permeability of heavier soils and therefore – reduced leaching. The dependence of N content on clay fraction (and, therefore, on agronomic category) was observed for USA, Australian rainforest, Denmark and the Netherlands, but those relations are not universal, however (Homann et al., 2007). According to Sapek and Kalińska (2004) the release of mineral forms during and after the growing season is increased due to the more intensive mineralization of nitrogen in the early summer months (May to July), which results in increased leaching in autumn and more pronounced relationships. The highest negative correlation was obtained for the relationship between the percentage of fine particles with dimensions below 0.02 mm and $N_{\min}$ content for meadows ($R = -0.94$). In turn, a positive relationship was demonstrated for hay and pasture use. A negative correlation was also obtained for alternate grasslands, but for autumn sampling date this correlation was statistically insignificant. As far as the field crop plants in question are concerned, a positive relationship between $N_{\min}$ content in the 60-90 cm layer and soil agronomic category was confirmed for maize crops. Opposite relationships were revealed for mixed cereal crops for both sampling dates and though for spring sampling these relationships are insignificant from the statistical point of view, a high and statistically significant correlation coefficient in the case of the autumn sampling date was obtained.

Table 3. Correlation coefficients between soil agronomic categories and mineral nitrogen $N_{\min}$ content in the 60-90 cm soil layer with a breakdown into both land use and sampling date

Land use	Sampling date	
	spring	autumn
Grasslands (on mineral soils)	-0.96*	-0.95*
Meadows (on mineral soils)	-0.94*	-0.92*
Pastures (on mineral soils)	-0.02	-0.02
Hay and pasture grasslands (on mineral soils)	0.57*	0.45*
Alternate grasslands (on mineral soils)	-0.69*	-0.22
Maize	0.84*	0.89*
Mixed cereals	-0.40	-0.98*
Total soils	-0.42*	-0.86*
Total soils (on an annual basis)	-0.68*	

* correlation significant at significance level $p = 0.05$

After confirming that the relationship between soil agronomic category and content of mineral nitrogen in 60-90 cm soil layer exists, equations describing those relations were elaborated (*Figs 6-8*). The determined linear regression equations can be of great importance from the practical point of view, as they may be used to forecast changes in mineral nitrogen content depending on the percentage of fine particles in mineral soil. Therefore they may help the farmer to identify the optimal dose of mineral nitrogen in soils with different agronomic category and suppress nitrogen losses and thus adverse

impact on the environment. Significance of relationships described by obtained equations was confirmed by the high coefficients of determination.

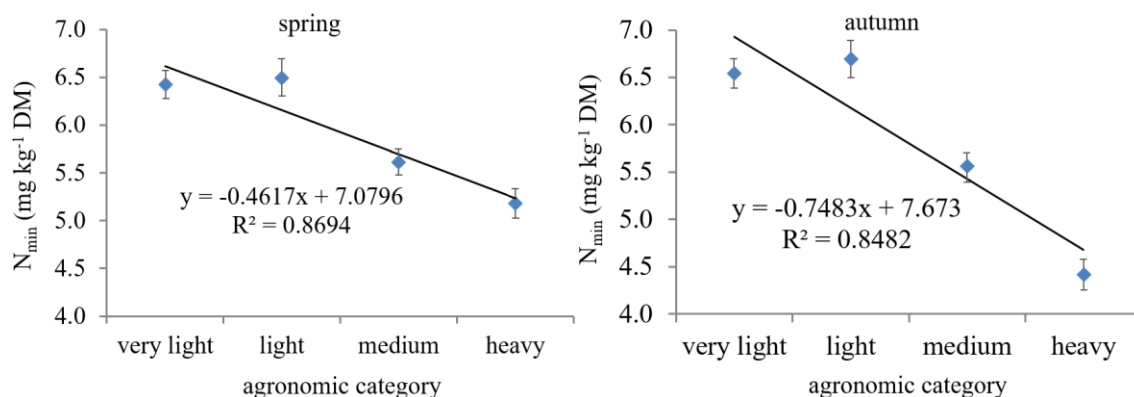


Figure 6. Relationship between agronomic category and average mineral nitrogen N_{min} content in the 60-90 cm layer of mineral soils under grasslands with its standard deviation for spring and autumn soil sampling dates. DM stands for dry matter of the soil sample

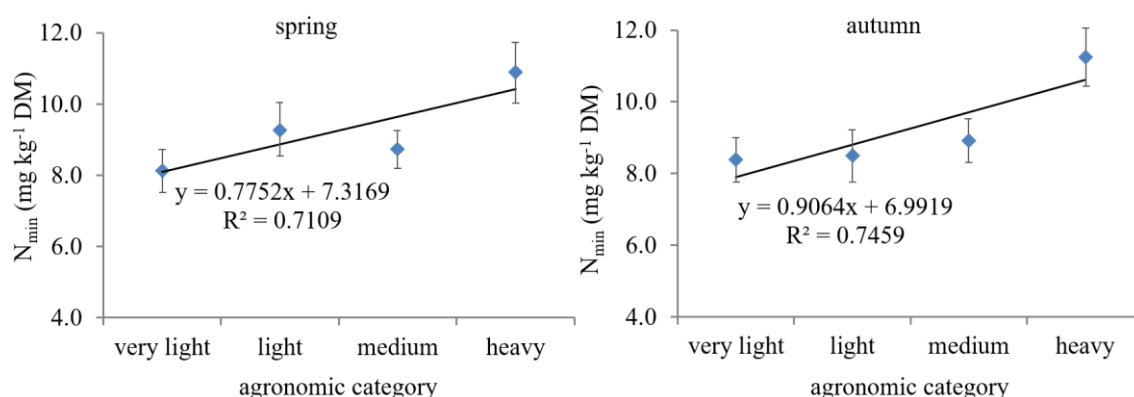


Figure 7. Relationship between agronomic category and average mineral nitrogen N_{min} content in the 60-90 cm layer of mineral soils under maize with its standard deviation for spring and autumn soil sampling dates. DM stands for dry matter of the soil sample

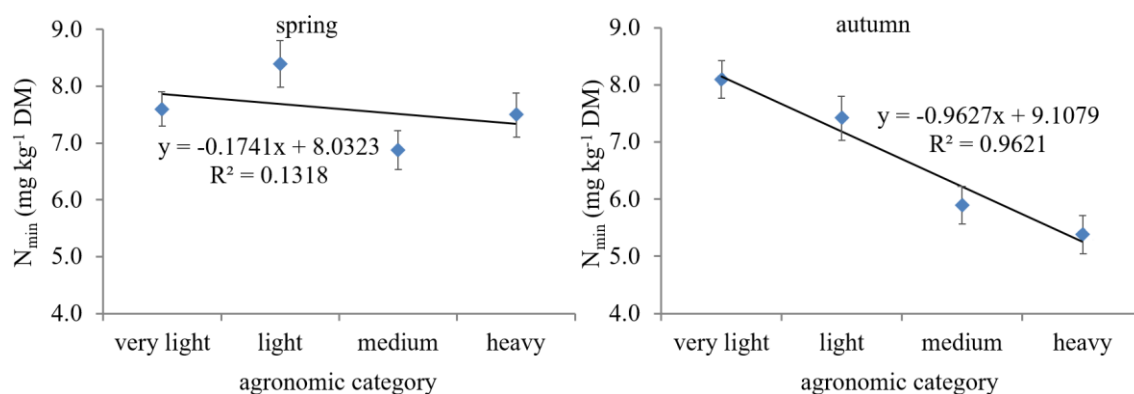


Figure 8. Relationship between agronomic category and average mineral nitrogen N_{min} content in the 60-90 cm layer of mineral soils under mixed cereals with its standard deviation for spring and autumn soil sampling dates. DM stands for dry matter of the soil sample

Conclusions

The results of this study confirm that significant differences in the content of mineral nitrogen can be observed in the soil layer beneath 60 cm, which is beyond the reach of the main root mass of crop plants in grassland soils and in arable soils, depending on agronomic categories and sampling date. It speaks for the fact that the leaching into deeper layers of soil occurs, which can have significant environmental consequences. Therefore, fertilization doses should take into account agronomic soil categories and type of land use. Regardless of observation period and the percentage of fine particles in mineral soils, the lowest content of $N_{\min}$ was shown in grassland soils, whereas greater accumulation of this nutrient in the soil profile at a depth of 60-90 cm was observed in the soils under both maize and mixed cereals. This was especially evident for soils under maize. It was revealed that agronomic category and the content of $N_{\min}$ in the 60-90 cm soil layer, regardless of the land use or sampling date, are strongly correlated. Elaborated equations describing those relationships for different land uses and sampling dates are characterized by very high coefficients of determination R^2 , which suggest that they may be successfully used in precision agriculture and contribute to sustainable management of fertilizers usage leading to reduction of nitrogen leaching from topsoil to groundwater, thus decreasing the negative impact of agricultural land use on environment.

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