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The relationship between the granulometric composition of grassland soils and their content of mineral nitrogen and organic carbon

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Abstract: The study analysed the relationship between the granulometric composition of grassland soils as determined by laser diffraction and their content of mineral forms of nitrogen and organic carbon. The content of mineral forms of nitrogen (NO_3-N and NH_4-N) in soil samples – after their extraction with 1% solution K_2SO_4, was determined by flow colourimetry. Soil organic carbon content was determined using the Tyurin method. The study examined soil samples collected from 169 control and measurement sites located in different regions of Poland in terms of conditions for agricultural production. Statistical analyses of the research results showed that the grain size of grassland soils had a significant effect on their ammonium nitrogen content but not on their nitrate nitrogen and organic carbon content. In this respect, it was found that there was a positive correlation between the share of the sand fraction and the content of ammonium nitrogen in soils and an opposite relation between the share of coarse silt, fine silt and clay and the content of the aforementioned component. Results of the analyses differ considerably from the results of studies by other authors on the influence of soil grain size distribution on the content of mineral nitrogen and organic carbon in soils based on classical methods of measurements of soil particle size distribution. There is a need to develop solutions to convert and compare results obtained by laser diffraction and standard methods.

Keywords: granulometric composition, grassland, mineral soils, mineral nitrogen content, organic carbon content

INTRODUCTION

Soil granulometric composition plays an important role in nutrient management as it determines nutrient transport and storage (retention) in the soil environment. Soils with a fine texture and a high clay fraction have a relatively high cation exchange capacity (*CEC*) and are therefore able to retain positively charged nutrients such as ammonium ions. Coarse-grained soils with a predominantly sandy texture have good permeability due to their large pores, which means that they have a low capacity to retain infiltrating water and plant nutrients, such as nitrate, as these are washed away by water. At the same time, the *CEC* of these soils is relatively low. Just like texture, soil organic matter (SOM) plays an important role in soil nutrient management. Organic matter has a very high *CEC* and therefore has a high capacity to retain cations of plant nutrients. Apart from contributing to the retention of nutrients in the soil, SOM is also a source of nutrients. Soil organic matter is a key integral indicator of soil quality. Both soil organic carbon (SOC) and soil organic nitrogen (SON) are attributes of SOM used to describe various SOM functions (Kunlani, Khwanchum and Vityakon, 2020).

The soil grain size directly affects the amount of organic carbon and total nitrogen it contains (Bechtold and Naiman, 2006; Pan *et al.*, 2013; Udom, Benwari and Osaro, 2015). Zhou *et al.* (2019) have showed that the total carbon (TOC) and nitrogen (TON) contents increase as the proportion of silt and clay fractions increases. On the other hand, Cui, Askari and Holden (2015) found that an increase in the level of SOC and TON in the soil occurs with an increase in the proportion of clay fraction (with grain diameter ≤0.002 mm) in the soil, according to the following pattern of granulometric groups: sandy loam < sandy clay loam < clay loam < silty clay loam. However, these authors observed that the differences in SOC and TON were small depending on these soil groups.

Soil granulometric composition is also a factor that affects nitrogen mineralisation in soil. Soils with a fine structure (with high content of clay parts) are characterised by a lower efficiency of nitrogen mineralisation compared to soils with a coarse structure (Bechtold and Naiman, 2006; Najmadeen, 2011; Soinne *et al.*, 2021). Soil nitrogen mineralisation, i.e. transformation of organically bound nitrogen in soil organic matter into its mineral forms – nitrate and ammonium, affects the nitrogen cycle and its resources in the soil, and thus the availability to plants and their yields.

The understanding of the relationship between soil texture and the amount of carbon and nitrogen it contains is important in terms of maintaining soil quality, shaping crop production, and protecting the environment (Zhou *et al.*, 2019). In practical terms, soil texture is a key soil property that should be taken into account when making recommendations for nitrogen fertilisation of crops (Shahandeh, Wright and Hons, 2011; Cambouris *et al.*, 2016), and the ratio of SOC content to the proportion of clay or other fine soil textural fraction can be a useful indicator in selecting the rate nitrogen is applied to a crop (Soinne *et al.*, 2021).

Grassland soils are highly differentiated in terms of grain size and are characterised by a relatively high content of organic matter (Pietrzak and Hołaj-Krzak, 2022). The relationships occurring between the texture of these soils and their SOC and TON content as well as between texture and nitrogen mineralisation have been the subject of many studies (Hassink *et al.*, 1993; Hassink, 1997; Cui, Askari and Holden, 2015; Risch *et al.*, 2019; Matus, 2021). These studies have provided a better understanding of linkages and interactions between the aforementioned factors. Nevertheless, in order to increase the reliability and utilitarian nature of their results, it is reasonable that they should be further developed. An important related task is to solve the problem of investigating the granulometric composition of soils. Conventionally, sieve and sedimentation methods were used in these studies. Nowadays, a laser diffraction method is used increasingly frequently to determine the grain size distribution in soils. It has many advantages, such as short analysis time, high repeatability, small sample volume required, wide measurement range, and wide range of sorted fractions (Šinkoviová *et al.*, 2017). However, the results of particle size measurement by laser diffraction are not the same as the results of soil grain size determination by standard methods (Płaskonka, 2010; Šinkoviová *et al.*, 2017) (due to different physical principles on which they are based), which in practice creates difficulties in using the data obtained. Despite years of research work, this is a major inconvenience that has not been eliminated. It is necessary to continue the work.

In this study, the aim was to examine the relationship between the granulometric composition of grassland soils determined by laser diffraction and the content of mineral forms of nitrogen and organic carbon in these soils, and to determine the functionality of results obtained in comparison with results of similar studies obtained using standard methods for measuring soil grain size.

MATERIAL AND METHODS

DATA ORIGIN AND LOCATION OF SAMPLING SITES

Studies of the granulometric composition of grassland soils in Poland and the content of mineral nitrogen and organic carbon in them were carried out as part of the soil and water monitoring system operated by the National Chemical-Agricultural Station (Pol. Krajowa Stacja Chemiczno-Rolniczą, KSChR) and district chemical-agricultural stations, in cooperation with the Institute of Technology and Life Sciences – National Research Institute (Pol. Instytut Technologiczno-Przyrodniczy – Państwowy Instytut Badawczy, ITP–PIB). Within this system, 169 control and measurement sites of mineral grassland soils in different regions of Poland (Fig. 1), were selected and samples taken for laboratory analyses. The study was implemented in 2008–2020. Its scope included:

- at the beginning of the research in 2008, a single determination of granulometric composition and content of organic matter in the soil samples analysed (for three monitoring points, composition and content were determined in 2006);
- twice each year, determination of mineral nitrogen forms in soil samples taken in early spring, before the application of nitrogen fertilisers (i.e. before or immediately after the start of vegetation) and in autumn, after the harvest.

Fig. 1. Location of soil sampling sites in grasslands in Poland for the determination of grain size, mineral nitrogen and organic carbon; source: Nawalany (2022), unpublished

RESEARCH METHODS

Soil samples for the study were taken from the 30 cm topsoil, with a representative (composite) sample of approximately 100 g made from 15–20 individual samples taken from an area up to 100 m^2 (Watros *et al.*, 2019).

The granulometric composition was determined by the laser diffraction method using the Malvern Mastersizer 2000 particle analyser. On the basis of results, four fractions and granulometric sub-fractions were distinguished according to the classification of grain size distribution in soils and mineral formations by the Polish Soil Science Association, assigning to them individual codes of F1–F4 – Table 1.

Table 1. Classification of soil grain size

Name of granulometric fraction and sub-fraction	Grain diameter (d), mm	Code
Sand fraction	$0.05 < d \leq 2.0$	F1
Silt fraction	$0.002 < d \leq 0.05$	
– coarse silt	$0.02 < d \leq 0.05$	F2
– fine silt	$0.002 < d \leq 0.02$	F3
Clay fraction	$d \leq 0.002$	F4

Source: own elaboration based on: Skłodowski (2009).

Soil analysis for mineral nitrogen content was conducted according to the PN-R-04028:1997 standard. The analytical procedure included determination of nitrate nitrogen (V) (NO_3-N) and ammoniacal nitrogen (NH_4-N) in soil samples at current moisture content after defrosting (until the start of the analysis, the soil material was stored at −18°C), after their extraction with a 1% solution of potassium sulphate (K_2SO_4) at a volume ratio of soil to solution as 1:10. The results of the determination of the mineral forms of nitrogen were expressed in mg·kg^{-1} of soil dry matter.

The soil organic carbon content was determined using the Tyurin method. Chemical analyses conducted in accordance with this method consisted in the oxidation of organic carbon of a soil sample using an oxidising agent – potassium dichromate ($K_2Cr_2O_7$), in the presence of sulphuric acid (H_2SO_4) and, back titration of the excess oxidant remaining in solution with Mohr salt ($(NH_4)_2Fe(SO_4)_2·6H_2O$). From the amount of potassium dichromate solution used, the soil organic carbon content was calculated. The Tyurin method was applied to soil samples with organic matter content up to 15%, because above this value of OM in the soil, the method does not give "reliable results due to the difficulty to completely burn large amounts of organic carbon" (Fajer, 2014, p. 87).

Research results obtained were subjected to statistical processing. In this respect:

– descriptive statistical analysis was performed on sets organic carbon determined in soil samples, while calculating their arithmetic means, medians, standard deviations, and smallest and largest values;
– Spearman correlation analysis was conducted involving the share of the clay fraction ($d \leq 0.002$ mm), fine silt ($002 < d \leq 0.02$ mm), coarse silt ($0.02 < d \leq 0.05$ mm), sand fraction ($0.05 < d \leq 2.0$ mm) and the fluvial fraction (grain diameter <0.02 mm) and spring and autumn averages in 2008–2020 and nitrate nitrogen and ammonium nitrogen contents in the 0–30 cm soil layer and the organic carbon content.

Sampling of grassland soils and their laboratory tests (own accredited laboratories) were carried out by the district chemical and agricultural stations. Results were collected in a database kept by the KSChR. Results of laboratory analyses were elaborated in the ITP–PIB Falenty on the basis of data provided by the KSChR.

RESULTS AND DISCUSSION

In terms of grain size, mineral soils from analysed grassland areas in Poland comprised on average 63.5% of sand fraction with 33.8% of silt fraction (including 17.3% coarse silt and 16.5% fine silt) and 2.7% of clay fraction in their top 30 cm layer – Table 2. In 2008–2020, in the profile up to 30 cm below the ground surface, the average mineral nitrogen content in grassland soils analysed was respectively 17.8 mg N·kg^{-1} in spring and 19.5 mg N·kg^{-1} in autumn. In spring, mineral nitrogen occurred mainly in the form of ammonium (65.7%), and in autumn in the form of nitrate (60.0%). The average content of organic carbon in soils examined was 2.77%.

It can be assumed that values that characterise the grain size of grassland soils and their organic carbon content were constant throughout the study period. The texture of grassland soils does not change easily, therefore it is considered a constant soil feature, according to Brady and Weil (2007) (as cited in Jaja, 2016, p. 1). With regard to organic carbon, it is concluded that its content in agriculturally used soils remains relatively constant provided

Table 2. Descriptive statistics of average 2008–2020 contents of nitrate nitrogen (NO_3-N) and ammonium nitrogen (NH_4-N), organic carbon content and percentage of fractions and granulometric sub-fractions (F1–F4) in grassland mineral soils in the 0–30 cm layer at all monitoring points (n = 169)

Factor	F1	F2	F3	F4	F3+F4	N_{NO3_S}	N_{NO3_A}	N_{NH4_S}	N_{NH4_A}	SOC (%)
	%					mg N·kg^{-1}				
$\bar{x}$	63.5	17.3	16.5	2.7	19.2	9.0	11.7	8.8	7.8	2.77
Me	69	15	14	2	16.0	8.0	10.4	7.2	5.9	2.37
SD	20.9	9.5	10.6	2.1	12.6	5.1	6.5	5.8	5.8	1.53
max.	95	42	48	10	58.0	27.9	35.8	41.5	39.3	7.49
min.	16	3	2	0	2.0	1.1	0.9	1.5	1.1	0.41

Explanations: $\bar{x}$ = arithmetic mean, *Me* = median, *SD* = standard deviation, max. = maximum value, min. = minimum value, F1 = percentage of soil particles with diameter $0.05 < d \leq 2.0$ mm, F2 = percentage of soil particles with diameter $0.02 < d \leq 0.05$ mm, F3 = percentage of soil particles with diameter $0.002 < d \leq 0.02$ mm, F4 = percentage of soil particles with diameter ≤0.002 mm (%), (F3 + F4) = percentage of floatable fraction with grain diameter <0.02 mm (floatables include soil mineral particles which are floated with the solution during flow or sediment grain size analyses); N_{NO3_S} = average 2008–2020 spring soil NO_3-N content (mg N·kg^{-1}), N_{NO3_A} = average 2008–2020 autumn soil N-NO_3 content (mg N·kg^{-1}), N_{NH4_S} = average 2008–2020 spring soil N-NH_4 content (mg N·kg^{-1}), N_{NH4_A} = average 2008–2020 autumn soil NH_4-N content (mg N·kg^{-1}), C_{org} = soil organic carbon content (%).
Source: own elaboration based on KSChR results.

management and environmental conditions do not change (Allison, 1973; Kuś, 2015; Wiesmeier *et al.*, 2016). Therefore, it can be assumed that in grassland soils, which are permanently overgrown with grass vegetation, homogeneously used, and which are not subject to mechanical treatment, organic carbon levels do not undergo major fluctuations in time if they are not disturbed by environmental factors. At the same time, it is worth noting that, as shown by results of the IUNG–PIB research (IUNG–PIB, 2017), even in arable soils the quantity of organic carbon does not undergo significant changes over a long period.

In the case of mineral nitrogen, its content in grassland soils varied in 2008–2020. In this period, the average content of mineral nitrogen (N_{min}) in soils examined ranged from 15.1 to 20.5 mg N·kg^{-1} in spring and from 17.2.1 to 23.0 mg N·kg^{-1} in autumn (Fig. 2). In the analysed 13-year period changes in nitrate nitrogen content showed an increasing trend both in spring and autumn (Fig. 3). As for ammonium nitrogen, its changes showed an increasing trend in spring and a decreasing trend in autumn.

The changes in mineral nitrogen content in grassland soils observed in the time series could be largely due to the fact that each year of the research had different precipitation and air temperature. Obviously, these factors directly affect the quantitative status of nitrogen in soils and the yield of plants, thus influencing the amount of nitrogen taken up by them from soil. In the 13-year period of 2008–2020, mean annual precipitation and mean annual air temperature ranged from 481.0 to 830.0 mm and from 7.5 to 10.5°C, respectively (Tab. 3). During this period, meadow sward yields converted to hay ranged from 40.1 to

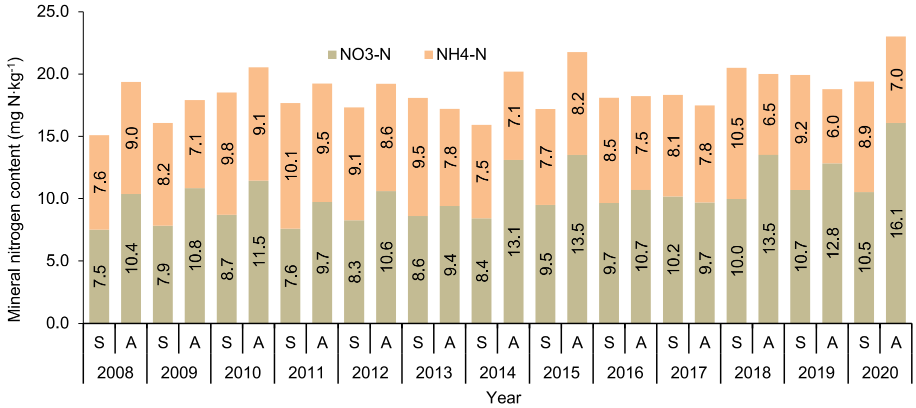

Fig. 2. Changes in mineral nitrogen content in the 0–30 cm layer of grasslands mineral soils in 2008–2020 during spring and autumn periods; source: own study based on KSChR data

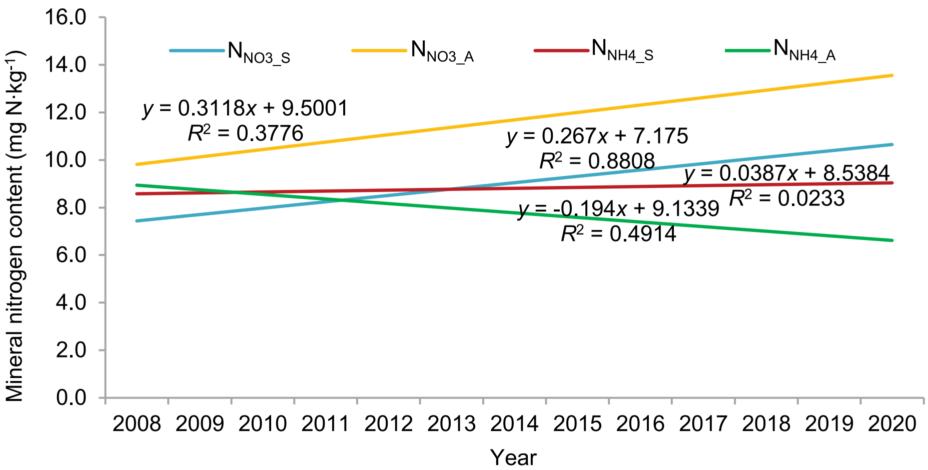

Fig. 3. Trend of changes nitrate and ammonium nitrogen in grasslands mineral soils from 2008 to 2020; explanations: N_{NO3_S}, N_{NO3_A}, N_{NH4_S}, N_{NH4_A} – as under Table 2; source: own study based on KSChR data

Table 3. Annual average precipitation and annual average air temperature in 2008–2020

Parameter	Value in												
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
P (mm)	609	692	830	567	617	641	626	481	660	740	490	550	645
T (°C)	9.4	8.6	7.5	8.9	8.5	7.5	9.6	9.8	9.2	9.0	9.8	10.5	9.9

Explanations: *P* = mean annual precipitation (mm), *T* = annual average air temperature (°C).
Source: own study based on: GUS (2021) and IMGW–PIB (2021).

52.1 dt·ha^{-1} (GUS, 2021), with the lowest yields in 2015, 2018 and 2019, when the most unfavourable thermal and water conditions occurred, i.e. high air temperatures and relatively low precipitation (Gabryszuk, Barszczewski and Wróbel, 2021).

In contrast to yearly changes in mineral nitrogen content in grassland soils in the thirteen-year period analysed, the granulometric composition of these soils was constant and their organic carbon content was relatively constant. Therefore, in order to investigate statistical relationship between the above-mentioned factors, the average values for the 2008–2020 period were used in the case of mineral nitrogen. This solution was adopted in order to generalise the character of the relationship in the system and to make results representative, while taking into account fluctuating atmospheric conditions and other factors affecting the state of N_{min} in soil over a long period. The statistical analysis of the relationship between the variables based on Spearman correlation coefficients – Table 4, provided according to the assumptions given above, showed in the 0–30 cm layer of mineral grassland soils in spring and autumn that:

- proportion of sand fraction had a significantly positive correlation with NH_4-N content;
- there was a significant negative correlation between the share of the clay fraction, fine silt, coarse silt, and floatables, and the NH_4-N content;
- proportion of different size classes of soil mineral particles in the earthy part (<2 mm) had no significant effect on NO_3-N and SOC content.

The obtained results of statistical analysis show that with an increase in the proportion of grains with a diameter ≤0.05 mm, including the clay fraction with a diameter ≤0.002 mm, there is a decrease in N_{NH4} content in mineral soils both in spring and autumn. This relationship is surprising, as it is known that the sorption capacity of soils in relation to cations, including NH_4^+, increases with an increase in the content of clay minerals in the soil (clay minerals as well as components of soil organic matter have negatively charged sites on their surfaces, which adsorb and retain positively charged ions by electrostatic force). In general, as demonstrated in their study by Fan *et al.* (2021), comparing soil fractions with grain diameters of 2.0–1.0, 1.0–0.5, 0.5–0.25, 0.25–0.1, 0.1–0.075 and <0.075 mm, determined using the sieve method – the level of ammonium nitrogen in the soil increases with decreasing soil particle size (there is increase in both specific surface area of soil and its clay particle content). This regularity was also confirmed by Podlasek, Koda and Vaverková (2021) who demonstrated a positive relationship between the amount of NH_4-N and the content of silt and clay particles in the 0–30 cm arable soil layer – from three regions of Poland. It was determined using sieve and hydrometric methods (it was interpreted as effect of sorption of positively charged ammonium on negatively charged soil particles). Considering the above, the relationship for grassland soils indicating that the content of ammonium nitrogen in the soil increased with an increase in the sandy fraction should also be regarded as unexpected.

Table 4. Spearman rank correlation coefficients between the share in the 0–30 cm layer of mineral grassland soils of soil particles of different diameters and the parameters of nitrogen quantitative status in these soils and the content of organic carbon in them at the number of correlated pairs n = 169

Parameter	F2	F3	F4	(F3+F4)	N_{NO3_S}	N_{NO3_A}	N_{NH4_S}	N_{NH4_A}	C_{org}
F1	−0.941***	−0.976***	−0.949***	−0.976***	−0.085	−0.022	0.268***	0.214**	−0.073
F2		0.855***	0.824***	0.854***	0.119	0.024	−0.224**	−0.162*	0.122
F3			0.965***	0.999***	0.049	0.014	−0.280***	−0.223**	0.034
F4				0.975***	0.053	0.005	−0.241**	−0.200**	0.037
F3+F4					0.049	0.012	−0.274***	−0.219**	0.033
N_{NO3_S}						0.689***	−0.148	−0.069	0.107
N_{NO3_A}							−0.104	0.000	0.129
N_{NH4_S}								0.704***	0.215**
N_{NH4_A}									0.197**

Explanations: F1, F2, F3, F4, (F3+F4), N_{NO3_S}, N_{NO3_A}, N_{NH4_S}, N_{NH4_A}, – as under Table 2, C_{org} = organic carbon, * correlation significant for level a = 0.05, ** correlation significant for level a = 0.01, *** correlation significant level a = 0.001.
Source: own elaboration.

Among significantly correlated variables, their dependence expressed by the value of Spearman's rho coefficient was at a weak level (although correlation was clear). It should be borne in mind, however, that the value of the correlation coefficient alone does not yet determine the magnitude of the link between the variables, as it still depends, among other things, on the sample size (Stupnicki, 2015), as well as on the degree of variability of data (Goodwin and Leech, 2006). In the case of small data sets, there is a relatively high probability of a strong relationship between them. With a large data sets – as is the case here – even a small value of the correlation coefficient is sufficient to consider the correlation reliable.

In the case of nitrate nitrogen, no significant relationship was found between the content of this component in grassland soils and the grain size distribution (especially share of finest soil fractions – silt and clay). Results of other studies carried out using conventional methods to determine the granulometric composition of soils show ambiguous relations in this respect. In one variant of the experiment, Podlasek, Koda and Vaverková (2021) showed a positive correlation of the content of the sand fraction and a negative correlation of the content of the silt fraction with the amount of NO_3-N, while in another variant they observed the lack of correlation between these factors. Depending on the stage and focus of their study, Shahandeh, Wright and Hons (2011) found that in the soils studied, clay content was not significantly related to N-NO_3, or it showed a reverse relation to the content of residual NO_3-N (i.e. its amount in soil that remained after harvest). In their research, Arbačauskas *et al.* (2018) determined that the NO_3-N content in light soils was lower than in heavier soils.

In particular, the nature of the relationship between the granulometric composition of soil and the content of mineral forms of nitrogen is well represented for comparative purposes by the results of monitoring of arable soils (comprising about 5100 permanent measurement and control points) carried out throughout Poland in 1997–2006 (Fotyma, Kęsik and Pietruch, 2010) – Table 5. These results indicate that the content of ammonium nitrogen in spring and autumn decreases with increasing share of fine silt and clay, i.e. fluvial components determined by a hydrometric method, and at the same time the content of nitrate nitrogen increases. This direction of dependence, indicated by the sign of correlation coefficients between the above mentioned factors was also observed in the case of grassland soils investigated. It should be stressed, however, that the statistically significant character of these relations was proved only in relation to the exchange of NH_4-N in these grassland soils. Changes in NO_3-N concurrent with changes in the proportion of grains with a diameter <0.02 mm were negligible only, and practically did not exist. In general, however, it is possible to mention a certain similarity of correlations when we compare arable and grassland soils.

In another set of correlations involving different grain size classes of grassland soils and their organic carbon content, no statistically significant cause and effect relationship was found. This deviates from commonly expressed assessments in the literature that soil texture influences the state of organic carbon content in the soil (Augustin and Cihacek, 2016). In particular, results of studies by different authors (Azlan *et al.*, 2012; Sarkar, Khan and Hanif, 2019) generally support that the organic carbon content of a soil increases with an increase in its silt and clay content and decreases with an increase in the proportion of sand.

As can be seen from the comparisons made, the relationships between soil grain size distribution and the amount of nitrogen and organic carbon determined on the basis of own studies are to a large extent different from those established within the framework of research by other authors, which is a factor hampering their interpretation. It may be presumed that this differentiation was largely influenced by soil granulation measurement techniques used in individual research: laser diffraction vs. sieve and sedimentation. Numerous comparative tests involving laser and conventional methods of determining the granulometric composition of soils (soils, sediments) have shown that their results are often inconsistent. There is a consensus in the literature that using the laser method always underestimates the proportion of clay fraction in the soil (Campbell, 2003; Gorączko and Topoliński, 2018). On the other hand, results of different research indicate that laser analysis tends to overestimate the contribution of sand and silt (Płoskonka, 2010; Yang *et al.*, 2019) compared to traditional methods. However, some studies indicate that it is possible to underestimate the contribution of sand (Kun *et al.*, 2013) or to determine it in a comparable way (Qiu *et al.*, 2021), as well as to overestimate the silt fraction (Bai *et al.*, 2021). Because results determined by laser diffraction cannot be compared with standard methods in a 1:1 ratio (Šinkoviová *et al.*, 2017), existing limit numbers for soil grain size classification (Taubner, Roth and Tippkötter, 2000) cannot be applied. To make it possible, it is necessary transform results obtained by the abovementioned methods (so far, no systematic approach has been developed). According to Igaz *et al.* (2020), this should be done at the level of laboratories using the laser diffraction method to measure the particle size distribution in soil samples.

In the light of the discussed research results with reference to grassland soils, it should also be pointed out that the specific "hermetic" character of results obtained using laser diffraction creates an obstacle of great practical importance; namely, it limits the possibility of using these results to determine the mineral nitrogen abundance in soils. The mineral nitrogen abundance (i.e. amount of mineral nitrogen accumulated on 1 ha of agricultural land in kg N·ha^{-1}) in a given soil profile is determined for sustainable plant nitrogen fertilisation (data on soil abundance N_{min} are used in particular for developing nitrogen fertilisation

Table 5. Average contents of nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N) and mineral nitrogen N_{min} (NO_3-N + NH_4-N) in the 0–30 cm layer of agricultural soils in Poland in 1997–2006

Parameter	Average value in							
	spring				autumn			
	soil agronomic category[1)]							
	very light	light	mean	severe	very light	light	mean	severe
Nitrate nitrogen (NO_3-N) content (mg N·kg^{-1})	4.24	5.53	6.59	7.53	6.89	8.35	9.02	9.64
Ammonium nitrogen (NH_4-N) content (mg N·kg^{-1})	3.12	2.98	2.74	2.36	2.83	2.67	2.57	2.24
Mineral nitrogen stock N_{min} (NO_3-N + NH_4-N) (kg N·ha^{-1})	33.9	38.3	40.4	40.3	45.8	51.5	52.2	51.0

[1)] Depending on the share of the soil fluvial fraction (FF) determined by the Boyuocos–Casagrande areometric method modified by Prószynski, four agronomic categories of soils: very light – FF ≤ 10%, light – 10 < FF ≤ 20%, medium – 20 < FF ≤ 35%, and heavy – FF > 35%, based on: Fotyma, Kęsik and Pietruch (2010), Strączyński and Wróbel (2000).
Source: own study based on: Fotyma, Kęsik and Pietruch (2010).

plans). The soil abundance index N_{min} can be calculated using the Equation (1):

$$Z_N = y \cdot N_{\min} \cdot h \cdot 10 \qquad (1)$$

where: Z_N = mineral nitrogen resources in soil layer 0–30 ($kg \cdot ha^{-1}$), y = soil bulk density ($kg\ DM \cdot dm^{-3}$, $Mg\ DM \cdot m^{-3}$); N_{min} = content of mineral nitrogen N_{min} in soil layer 0–30 (NO_3-N content + N-NH_4 content in 0–30 soil layer) (mg $N_{min} \cdot kg^{-1}$ DM), h = soil layer thickness (m).

In the context of the discussed limitation to the laser method, it is crucial that the value of "soil density" in the equation depends on its granulometric composition. For the calculation of the N_{min} in different agronomic categories of arable soils in Poland – Table 5, we use data on density of different soil types. These data should not be used to calculate N_{min} in soils whose type was determined by measurements of the grain size distribution using the laser diffraction method, e.g. as obtained within the framework of the study carried out for grassland soils. Otherwise, the calculated N_{min} values can be false. The range of calculation error can be indirectly deduced from comparative analyses carried out by different authors on the results of granulometric composition of soils determined by laser and sedimentation methods. In this respect, we can find data indicating that the agreement between the distribution of different particle sizes measured by methods compared can range from 95% (Šinkoviová *et al.*, 2017) to 40% or even less (Lopez, Gustavsson and Korkiala-Tanttu, 2021). In their comparative study of the state of soil granulation by laser diffraction and hydrometric methods, Ryżak and Bieganowski (2010) obtained a concordance of results at the level of 80–90%. In the opinion of these authors, the level of agreement is sufficient for the majority of practical laser method applications, e.g. for determining the soil category or recommendation of fertilisers.

CONCLUSIONS

Laser diffraction data pertaining to the impact of grassland soil texture on mineral nitrogen and organic carbon content suggest that:
– as the proportion of silt and clay decreases in grassland soils and the sand fraction increases, the content of ammonium nitrogen increases (in spring and autumn);
– granulometric composition of grassland soils does not affect their nitrate nitrogen or organic carbon content.

To a large extent, these findings do not correspond with results of similar studies presented in the literature, although these have been conducted using sieve and sedimentation methods for determining the grain size.

At present, the knowledge derived from the research cannot be fully exploited because the results of measurements of soil particle size distribution using the laser diffraction method and standard methods cannot be directly, as well as indirectly (e.g. based on regression equations) compared. Additional factor is the lack of appropriate norms regarding the classification of research results obtained with the laser particle size analyser. This indicates the need to look for solutions to make the knowledge more practicable.

REFERENCES

Allison, F.E. (ed.) (1973) "The organic matter content of soils," in *Soil organic matter and its role in crop production. Ser. Developments in Soil Science*. Amsterdam-London-New York: Elsevier Scientific Publishing Company, pp. 120–138. Available at: https://doi.org/10.1016/S0166-2481(08)70565-8.

Arbačauskas, J. *et al.* (2018) "Mineral nitrogen in soils of Lithuania's agricultural land: Comparison of oven-dried and field-moist samples," *Zemdirbyste-Agriculture*, 105(2), pp. 99-104. Available at: https://doi.org/10.13080/z-a.2018.105.013.

Augustin, C. and Cihacek, L.J. (2016) "Relationships between soil carbon and soil texture in the Northern Great Plains," *Soil Science*, 181(8), pp. 386–392. Available at: https://doi.org/10.1097/SS.0000000000000173.

Azlan, A. *et al.* (2012) "Correlation between soil organic matter, total organic matter and water content with climate and depths of soil at different land use in Kelantan, Malaysia," *Journal of Applied Sciences and Environmental Management*, 16(4), pp. 353–358. Available at: https://www.ajol.info/index.php/jasem/article/view/90982 (Accessed: March 20, 2022).

Bai, X. *et al.* (2021) "Applicability of laser diffraction method for soil particle size distribution analysis of five soil orders in the water erosion region of China," *Journal of Soil and Water Conservation*, 76(4), pp. 303–316. Available at: https://doi.org/10.2489/jswc.2021.00009.

Bechtold, J.S. and Naiman, R.J. (2006) "Soil texture and nitrogen mineralization potential across a riparian toposequence in a semi-arid savanna," *Soil Biology and Biochemistry*, 38(6), pp. 1325–1333. Available at: https://doi.org/10.1016/j.soilbio.2005.09.028.

Cambouris, A.N. *et al.* (2016) "Corn yield components response to nitrogen fertilizer as a function of soil texture," *Canadian Journal of Soil Science*, 96(4), pp. 386–399. Available at: https://doi.org/10.1139/cjss-2015-0134.

Campbell, J.R. (2003) "Limitations in the laser particle sizing of soils," in I.C. Roach (ed.) *Advances in regolith*. Canberra: CRC LEME, pp. 38–42. Available at: http://crcleme.org.au/Pubs/Advancesin-regolith/Campbell.pdf (Accessed: February 21, 2022).

Cui, J., Askari, M.S. and Holden, N.M. (2015) "Grassland soil carbon and nitrogen stocks under temperate livestock grazing," *Soil Research*, 53(50) pp. 485–493. Available at: https://doi.org/10.1071/SR14252.

Fajer, M. (2014) *Przewodnik do ćwiczeń z gleboznawstwa dla studentów I roku geografii [A guide to soil science exercises for first-year geography students]*. Katowice: Wydawnictwo Uniwersytetu Śląskiego.

Fan, X. *et al.* (2021) "The influence of soil particle size distribution and clay minerals on ammonium nitrogen in weathered crust elution-deposited rare earth tailing," *Ecotoxicology and Environmental Safety*, 208, 111663. Available at: https://doi.org/10.1016/j.ecoenv.2020.111663.

Fotyma, M., Kęsik, K. and Pietruch, C. (2010) „Azot mineralny w glebach jako wskaźnik potrzeb nawozowych roślin i stanu czystości wód glebowo-gruntowych [Mineral nitrogen in soils as an indicator of the fertilization needs of plants and the cleanliness of soil and groundwater]," *Nawozy i Nawożenie (Fertilizers and Fertilizaton)*, 38 pp. 5–80.

Gabryszuk, M., Barszczewski, J. and Wróbel, B. (2021) "Characteristics of grasslands and their use in Poland," *Journal of Water and Land Development*, Vol. 51, pp. 243–249. Available at: https://doi.org/10.24425/jwld.2021.139035.

Goodwin, L.D. and Leech, N.L. (2006) "Understanding correlation: Factors that affect the size of r," *The Journal of Experimental Education*, 74(3), pp. 249–266. Available at: https://doi.org/10.3200/JEXE.74.3.249-266.

Gorączko, A. and Topoliński, S. (2018) „Wpływ kształtu cząstek ilastych na wyniki analiz granulometrycznych gruntów spoistych [Influence of shape anisotropy on the results of grain size analysis of the clayey soils]," *Przegląd Naukowy – Inżynieria i Kształtowanie Środowiska*, 27(2), pp. 142–151. Available at: https://doi.org/10.22630/PNIKS.2018.27.2.14.

GUS (2021) *Rolnictwo w 2020 roku (+ archiwum) [Agriculture in 2020 (+ archive)]*. Warszawa: Główny Urząd Statystyczny. Available at: https://stat.gov.pl/obszary-tematyczne/rolnictwo-lesnictwo/rolnictwo/rolnictwo-w-2020-roku,3,17.html (Accessed: February 21, 2022).

Hassink, J. (1997) "The capacity of soils to preserve organic C and N by their association with clay and silt particles", *Plant and Soil*, 191 (1), pp. 77–87. Available at: https://doi.org/10.1023/A:1004213929699.

Hassink, J. *et al.* (1993) "Relationships between soil texture, physical protection of organic matter, soil biota, and C and N mineralization in grassland soils," *Geoderma*, 57(1/2), pp. 105–128. Available at: https://doi.org/10.1016/0016-7061(93)90150-J.

Igaz, D. *et al.* (2020) "Laser diffraction as an innovative alternative to standard pipette method for determination of soil texture classes in Central Europe," *Water*, 12(5), 1232. Available at: https://doi.org/10.3390/w12051232.

IMGW-PIB (2021) *Klimat Polski 2020 [Climate of Poland]*. Warszawa: IMGW-PIB. Available at: https://www.imgw.pl/badania-nauka/klimat (Accessed: February 10, 2022).

IUNG-PIB (2017) *Monitoring chemizmu gleb ornych Polski [Monitoring of the chemistry of Poland's arable soils]*. Puławy: Instytut Uprawy, Nawożenia i Gleboznawstwa. Available at: https://www.gios.gov.pl/chemizm_gleb/index.php?mod=wyniki&cz=C (Accessed: February 21, 2022).

Jaja, N. (2016) *Understanding the texture of your soil for agricultural productivity*. Virginia Cooperative Extension, Virginia Tech, Virginia State University. Available at: https://www.pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/CSES/CSES-162/CSES-162-PDF.pdf (Accessed: February 21, 2022).

Kun, Á. *et al.* (2013) „Comparison of pipette and laser diffraction methods in determining the granulometric content of fluvial sediment samples," *Journal of Environmental Geography*, 6(3–4), pp. 49–54. Available at: https://doi.org/10.2478/jengeo-2013-0006.

Kunlani, B., Khwanchum, L. and Vityakon, P. (2020) "Land use changes affecting soil organic matter accumulation in topsoil and subsoil in Northeast Thailand," *Applied and Environmental Soil Science*, 2020, 8241739, pp. 1–15. Available at: https://doi.org/10.1155/2020/8241739.

Kuś, J. (2015) „Glebowa materia organiczna – znaczenie, zawartość i bilansowanie [Soil organic matter – importance, content and balancing]," *Studia i raporty IUNG-PIB*, 45(19) pp. 27–53. Available at: https://doi.org/10.26114/sir.iung.2015.45.02.

Lopez, A., Gustavsson, H. and Korkiala-Tanttu, L. (2021) "Comparison between hydrometer and laser diffraction methods in the determination of clay content in fine-grained soils," *IOP Conference Series: Earth and Environmental Science*, 710(1), 012012. Available at: https://doi.org/10.1088/1755-1315/710/1/012012.

Matus, F.J. (2021) "Fine silt and clay content is the main factor defining maximal C and N accumulations in soils: a meta-analysis," *Scientific Reports*, 11, 6438. Available at: https://doi.org/10.1038/s41598-021-84821-6.

Najmadeen, H.H. (2011) "Effects of soil organic matter, total nitrogen and texture on nitrogen mineralization process," *Al-Nahrain Journal of Science*, 14(2), pp. 144–151. Available at: https://doi.org/10.22401/JNUS.14.2.19.

Pan, C. *et al.* (2013) "Biophysical properties as determinants for soil organic carbon and total nitrogen in grassland salinization," *PLoS ONE*, 8(1), e54827. Available at: https://doi.org/10.1371/journal.pone.0054827

Pietrzak, S. and Hołaj-Krzak, J. (2022) "The content and stock of organic carbon in the soils of grasslands in Poland and the possibility of increasing its sequestration," *Journal of Water and Land Development*, 54, pp. 68–76. Available at: https://doi.org/10.24425/jwld.2022.141556.

Płoskonka, D. (2010) "Różnice w wynikach analiz uziarnienia przeprowadzonych różnymi metodami [Differences in results of grain-size analysis made by various methods]," *Landform Analysis*, 12, pp. 79–85. Available at: http://geoinfo.amu.edu.pl/sgp/LA/LA12/LA12_10.pdf (Accessed February 15, 2022).

PN-R-04028:1997 *Analiza chemiczno-rolnicza gleby. Metoda pobierania próbek i oznaczanie zawartości jonów azotanowych i amonowych w glebach mineralnych [Agrochemical soil analysis. Method of sampling and determination of nitrate and ammonium ions in mineral soils]*. Warszawa: Polski Komitet Normalizacyjny.

Podlasek, A., Koda, E. and Vaverková, M.D. (2021) "The variability of nitrogen forms in soils due to traditional and precision agriculture: case studies in Poland," *International Journal of Environmental Research and Public Health*, 18(2), 465. Available at: https://doi.org/10.3390/ijerph18020465.

Qiu, W.W. *et al.* (2021) „Soil particle size range correction for improved calibration relationship between the laser-diffraction method and sieve-pipette method," *Pedosphere*, 31(1), pp. 134–144. Available at: https://doi.org/10.1016/S1002-0160(20)60055-8.

Risch, A.C. *et al.* (2019) "Soil net nitrogen mineralisation across global grasslands," *Nature Communications*, 10, 4981. Available at: https://doi.org/10.1038/s41467-019-12948-2.

Ryżak, M. and Bieganowski, A. (2010) „Determination of particle size distrubution of soil using laser diffraction – comparison with areometric method," *International Agrophysics*, 24(2), pp. 177–181. Available at: http://www.international-agrophysics.org/Determination-of-particle-size-distrubution-of-soil-using-laser-diffraction-comparison,106369,0,2.html (Accessed: February 15, 2022).

Sarkar, I., Khan, Md.Z. and Hanif, Md. (2019) "Soil organic fractions in cultivated and uncultivated soils of costal area in Bangladesh," *Journal of Agricultural Chemistry and Environment*, 08(03), pp. 129–144. Available at: https://doi.org/10.4236/jacen.2019.83011.

Shahandeh, H., Wright, A.L. and Hons, F.M. (2011) "Use of soil nitrogen parameters and texture for spatially-variable nitrogen fertilization," *Precision Agriculture*, 12(1), pp. 146–163. Available at: https://doi.org/10.1007/s11119-010-9163-8.

Šinkoviová, M. *et al.* (2017) "Soil particle size analysis by laser diffractometry: result comparison with pipette method," *IOP Conference Series Materials Science and Engineering*, 245(7), 072025. Available at: https://doi.org/10.1088/1757-899X/245/7/072025.

Skłodowski, P. (2009) "Klasyfikacja uziarnienia gleb i utworów mineralnych – PTG 2008 [Particle size distribution and textural classes of soils and mineral materials – classification of Polish Society of Soil Sciences 2008]," *Roczniki Gleboznawcze*, 60(2), pp. 5–16.

Soinne, H. *et al.* (2021) "Soil organic carbon and clay content as deciding factors for net nitrogen mineralization and cereal yields in boreal mineral soils," *European Journal of Soil Science*, 72(4), pp. 1497–1512. Available at: https://doi.org/10.1111/ejss.13003.

Strączyński, S. and Wróbel, S. (2000) "Zawartość mikroelementów w glebach o zróżnicowanych kategoriach agronomicznych [Micronutrient concentration in soils of diverse agronomic categories]", *Zeszyty Problemowe Postępów Nauk Rolniczych*, 471(1), pp. 549–554.

Stupnicki, R. (2015) *Podstawy biostatystyki [Fundamentals of biostatistics]*. Warszawa: Wydawnictwo AWF. Available at: https://www.wskfit.pl/PDF/artykuly/Biostat.pdf (Accessed: February 21, 2022).

Taubner, H., Roth, B. and Tippkötter, R. (2009) "Determination of soil texture: Comparison of the sedimentation method and the laser-diffraction analysis," *Journal of Plant Nutrition and Soil Science*, 172, pp. 161–171. Available at: https://doi.org/10.1002/JPLN.200800085.

Udom, B.E., Benwari, A.O. and Osaro, E.T. (2015) "Organic carbon and nitrogen distribution in particle-size fractions of soils under cassava, plantain and rubber based land use," *International Journal of Soil Science*, 10, pp. 166–176. Available at: https://doi.org/10.3923/ijss.2015.166.176.

Watros, A. *et al.* (2019) „Mineral nitrogen content in soils depending on land use and agronomic category", *Applied Ecology and Environmental Research*, 17(3) pp. 5663–5675. Available at: https://doi.org/10.15666/aeer/1703_56635675.

Wiesmeier, M. *et al.* (2016) "Projected loss of soil organic carbon in temperate agricultural soils in the 21st century: Effects of climate change and carbon input trends," *Scientific Reports*, 6(1), 32525. Available at: https://doi.org/10.1038/srep32525.

Yang Y. *et al.* (2019) "Is the laser diffraction method reliable for soil particle size distribution analysis?," *Soil Science Society of America Journal*, 83(2), pp. 276–287. Available at: https://doi.org/10.2136/sssaj2018.07.0252.

Zhou W. *et al.* (2019) "Effects of soil pH and texture on soil carbon and nitrogen in soil profiles under different land uses in Mun River Basin, Northeast Thailand", *PeerJ*, 7, e7880. Available at: https://doi.org/10.7717/peerj.7880.