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RELATION OF MINERAL NITROGEN AND SULPHATE SULPHUR CONTENT IN SOIL TO CERTAIN SOIL PROPERTIES AND APPLIED CULTIVATION TREATMENTS*

Przemysław Tkaczyk[1], *Wiesław Bednarek*[1], *Sławomir Dresler*[2], *Jaromir Krzyszczak*[3], *Piotr Baranowski*[3]

[1]Department of Agricultural and Environmental Chemistry
University of Life Sciences, Akademicka 15, 20-033 Lublin, Poland
[2]Department of Plant Physiology, Institute of Biology and Biochemistry
Maria Curie-Skłodowska University, Akademicka 19, 20-033 Lublin, Poland
[3]Institute of Agrophysics, Polish Academy of Sciences, Doświadczalna 4, 20-290 Lublin, Poland
e-mail: jkrzyszczak@ipan.lublin.pl

A b s t r a c t. In the years 2008-2010 an environmental study was conducted, the objective of which was to estimate the current content of mineral nitrogen (nitrate V and ammonium) and sulphate sulphur in the soils of south-eastern Poland and to determine the relations of those elements with certain soil properties and cultivation treatments. 333 sampling points were designated, in which soil was sampled from 0-30, 30-60 and 60-90 cm depths. In the collected soil samples the Particle Size Distribution (PSD) was assayed with the use of Laser Diffraction Method (LDM), organic C using Tiurin method and pH in 1 mol KCl dm^{-3}. Phosphorus and potassium were assayed using Egner-Riehm method (DL), mineral nitrogen (with division into the nitrate (V) and the ammonium form) with the colorimetric method using a flow auto-analyser, total and sulphate sulphur with the nephelometric method and assimilable magnesium after the extraction from soil in 0.0125 mol $CaCl_2$ dm^{-3} with an ASA method. The highest content of nitrate (V) and ammonium nitrogen was noted in the 0-30 cm layer, irrespective of the spring or autumn date of soil sampling. The content of sulphate sulphur in the topsoil (0-30 cm) was the highest in organic and in heavy soils, but usually it did not differ significantly from medium, light and very light soils. The content of mineral nitrogen in the 0-30 and 0-90 cm layers was significantly and positively correlated with most of the assayed soil properties, whereas total and sulphate sulphur depended significantly and positively not only on soil properties, but also on the cultivation treatments.

K e y w o r d s: macronutrients, soil nitrogen, soil sulphate sulphur, soil reaction, agronomic category

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INTRODUCTION

Nitrogen is an element with fundamental importance in normal functioning of living organisms, and therefore also plants. It forms the structure of proteins, amino acids, enzymes, nucleotides and other compounds. In soil, nitrogen occurs mainly in the form of organic compounds and its availability for crop plants is one of the major factors affecting soil fertility and productivity. Intensive fertilisation with this element, at optimum supply of other nutrients, allows to achieve high yields with expected quality (Fotyma *et al*. 2004, 2005, Fotyma and Fotyma 2006, Mazur and Mazur 2015, Tkaczyk *et al*. 2016). However, an excessive content of mineral forms of nitrogen in soil may create certain problems related to various aspects of environmental protection, including the quality of ground and surface waters (Falkowska and Filipek 2009, Lipiński 2010). The dynamics of mineral nitrogen is a resultant of the interplay of soil, climatic and anthropogenic factors. This is because those factors have a decisive impact on the physical, chemical, biological and physicochemical processes that, as a result, affect the transformations of ammonium and nitrate (V) nitrogen (Fotyma and Fotyma 2006, Jadczyszyn *et al*. 2010, Dresler *et al*. 2011a,b).

Sulphur occurs in soil primarily in the form of organic compounds related to the presence of humus, and also is brought into soil with plant and animal residues and microorganisms. Inorganic sulphur compounds occur in arable soils primarily in the form of calcium, magnesium or potassium sulphates. Plants uptake sulphur mainly in the form of SO_4^{2-} ion through the roots, and in the case of air pollution – also in the form of SO_2 through the leaves (Kulczycki and Spiak 2003). One of the factors affecting sulphur transformations in soil are cultivation treatments (Lipiński 2000). Those treatments affect various soil properties, but such improvement of soil physical characteristics can be done not only by proper cultivation, but also by treatments such as melioration or fertilisation (Walczak *et al*. 1997, Lamorski *et al*. 2013). In other words, suitable agronomic practices can be used to exert an influence, to a certain degree, on changes in the content of mineral forms of nitrogen and sulphur in soil.

On the other hand, representative data about macroelements such as nitrogen or sulphur and their relation with various cultivation treatments are also looked for by the modellers using and developing crop growth, production and yield prediction models. Those models dynamically simulate processes of C, N and water balance on daily or hourly time-steps to predict crop growth and are able to consider nutrient (N, P, K, S) balance in soil. Frequently, in crop growth simulation models the enforced system is used for evaluating individual and comprehensive management with numerous environments and totally different genotypes included (Pirttioja *et al*. 2015; Ruiz-Ramos *et al*. 2017). This way information about the impact of climate change on crop production and macronutrients transformation in the soil can be obtained.

The objective of the study was to determine, for a representative set of soils characteristic for the south-eastern part of Poland, the effect of certain soil properties and cultivation treatments on the occurrence of mineral forms of nitrogen and sulphur in soil and to deliver knowledge about the present status of the supply of soils in the above macronutrients in the study area.

MATERIAL AND METHODS

In the years 2008-2010 an environmental study was conducted, the objective of which was to estimate the current content of mineral nitrogen (nitrate V and ammonium) and sulphate sulphur in the soils of south-eastern Poland, and to determine the relations of those elements with certain soil properties and cultivation treatments. The study was conducted on the basis of points, selected in prior, uniformly covering the area of the study. The designated sampling points were situated in selected farms located on each of the agronomic categories of soils: very light, light, medium and heavy soils. If in the study area a soil category occurred on less than 10% of the area of lands under agricultural use, sampling points were not designated on such a soil. Among the sites selected as soil sampling points, 20% of them were situated on grasslands. Overall, within the area of the Lublin Region 333 soil sampling points were designated for the determination of mineral nitrogen, 261 of which were located on arable soils (36 on very light, 84 on light, 82 on medium and 59 on heavy soils), 72 on grasslands, including 6 on meadow-pasture lands (1 on very light, 3 on medium and 2 on heavy soils), 47 on meadows (6 on very light, 14 on light, 11 on medium, 8 on heavy soils and 8 on organic soil) and 19 on pastures (4 on very light, 6 on light, 6 on medium, 1 on heavy and 2 on organic soils). The share of plants in sowing structure for each year is presented in the Table 1. The plants sown in a given year are the forecrop for the subsequent year. On the other hand, information on organic fertiliser type and rate used by farmers on fields from which the soil samples were taken is presented in the Table 2.

Table 1. Share of plants in sowing structure (in %)

Crop group	Year				
	2007	2008	2009	2010	2007-2010 (average)
cereals	59.8	58.9	61.0	55.9	58.9
root crops	10.2	12.9	8.7	14.1	11.5
oilseeds	2.1	0.9	1.5	0.9	1.4
legumes	1.8	1.5	3.0	2.1	2.1
grasses	22.8	21.6	21.9	22.8	22.3
vegetables	2.4	3.3	3.0	3.3	3.0
others	0.9	0.9	0.9	0.9	0.9

The size of samples collected from the soil layers of 0-30, 30-60 and 60-90 cm was about 500 g; sampling was done with the use of soil sampling rods, drill rigs and GPS. In all three soil layers only the content of mineral nitrogen was determined, i.e. of ammonium nitrogen and nitrate (V) nitrogen, while the other soil properties were assayed only for the layer of 0-30 cm. The number of sampling points in the study area was determined on the basis of livestock population density. If it was less than 40 LSU (Livestock Unit) per 100 ha of AL (agricultural land) then 1 sampling point was designated, at 40-80 LSU/100 ha AL – 2 points, and if the stock density was higher than 80 LSU per 100 ha AL – 3 repetitions were made (according to IUNG-PIB recommendations). On grasslands the soil sampling points were designated on the basis of nature conditions, type of habitat (flood-meadow, deciduous forest, marsh, muck soils), type of use (meadows, pastures) and the intensity of use (according to IMUZ recommendations). The adopted measure of intensity of use of meadows and pastures was the number of grass foraging animals (cattle, sheep, goats, horses) per 1 ha of AL in a farm. On the basis of GUS (Central Statistical Office) data it was estimated that on 1.7% of the area of AL the density of cattle was higher than 1.5 LSU ha^{-1}, on 7.8% – from 0.75 up to 1.5 LSU ha^{-1}, and finally on 90.5% of the area it was lower than 0.75 LSU ha^{-1}. Chemical analyses were performed at the accredited laboratory of the Regional Agrochemical Station in Lublin. In the collected soil samples the particle size distribution was assayed with the laser diffraction method, organic C according to Tiurin method, pH in 1 mol KCl dm^{-3}, available phosphorus and potassium with the Egner-Riehm method (DL), mineral nitrogen with division into the nitrate (V) form (cadmium reduction method) and the ammonium form (modified Berthelot reaction with salicylates) with the colorimetric method using flow auto-analyser, total and sulphate sulphur with the nephelometric method, and magnesium after extraction from soil in 0.0125 mol $CaCl_2$ dm^{-3} with an ASA method (A catalogue of methods 2011).

Table 2. Organic fertiliser type and rate used by farmers on fields from which the soil samples were taken

Fertiliser type	Year	Number of fields	Fertiliser rate (t ha^{-1})
manure	2008	60	22.5
	2009	65	21.9
	2010	84	23.2
urea	2008	3	18.6
	2009	4	19.25
	2010	3	9
slurry	2008	1	20
	2009	5	17.5
	2010	7	15
poultry manure	2008	1	7
	2009	2	6
	2010	4	6.5

The results obtained from the analyses were processed statistically using one-way non-orthogonal analysis of variance classification with Tukey semi-intervals of confidence (p = 0.05), and correlations were calculated between the content of the assayed forms of macroelements and certain properties of the soil and also the applied cultivation treatments. For the statistical calculations the following denotation of soil agronomic categories were used: very light soils – 1, light soils – 2, medium soils – 3 and heavy soils – 4.

RESULTS AND DISCUSSION

The content of nitrate (V) nitrogen in the soils under study presented in Table 3 displayed a certain regularity. In all three years of the experiment mean value of nitrate (V) nitrogen content was the highest in the top arable layer (0-30 cm), irrespective of the date of soil sampling, whether it was in spring or in autumn. The same can be stated for maximal observed value of nitrate (V) nitrogen content. In the deeper soil layers (30-60 and 60-90 cm) mean and maximal values decreased systematically. In the samples collected in spring from the topsoil layer (0-30 cm) the nitrate (V) nitrogen content was from 0.0 to 314, whereas mean value ranged from 9.13 to 12.7. In the layer of 30-60 cm – from 0.0 to 137 (for mean values it was from 5.09 to 7.93), and in the layer of 60-90 cm – from 0.0 to 94.8 (mean values from 4.42 to 6.56) mg N kg^{-1}. The content of nitrates in the first soil layer (0-30cm) was significantly higher than in the other two soil layers (30-60 and 60-90 cm). In the soil samples collected in autumn the content of nitrates (V) was also the highest in the topsoil layer (0-30 cm) and it was from 0.0 to 332, whereas mean value ranged from 10.7 to 15.6 mg N kg^{-1}, irrespective of the year of the experiment. In the deeper soil layers it varied in the range of 0.0-183 (6.61-11.3 mg N kg^{-1} for mean value) for 30-60 cm layer and 0.0-164 (4.37-6.68 mg N kg^{-1} for mean value) for 60-90 cm layer. A significantly higher content in the first layer, compared to the other two, was noted only in 2009 (Tab. 3).

Table 3. Mean, minimal and maximal (under the mean in brackets) values of nitrate (V) nitrogen content in soil, mg N kg^{-1}, averages from all sampling years

Year	I – spring sampling			II – autumn sampling		
	0-30 cm	30-60 cm	60-90 cm	0-30 cm	30-60 cm	60-90 cm
2008	12.3 efgh (0.0÷314)	7.93 abcde (0.0÷137)	6.56 ab (0.0÷49.1)	15.0 gh (0.1÷332)	11.3 defg (0.0÷171)	6.68 abcd (0.0÷121)
2009	9.13 bcdef (0.0÷95.8)	5.09 ab (0.0÷64)	4.71 ab (0.0÷64)	15.6 h (0.1÷293)	7.54 abc (0.0÷90.9)	4.97 a (0.0÷164)
2010	12.7 fgh (0.1÷245)	6.29 ab (0.0÷104)	4.42 a (0.0÷94.8)	10.7 cdef (0.0÷301)	6.61 abc (0.0÷183)	4.37 a (0.0÷71.9)

a, b, c, d, e, f, g, h – means labelled with the same letter are not significantly different at the significance level p = 0.05

The content of ammonium nitrogen in the soil was also the highest in the samples collected from the surface layer and decreased systematically in the deeper soil layers, irrespective of the sampling times (spring, autumn) and of the year of sample collection (Tab. 4). No significant differences were found in the content of that form of nitrogen in the deeper soil layers, irrespective of the year of sample collection.

Table 4. Mean, minimal and maximal (under the mean in brackets) values of ammonium nitrogen content in soil, mg N kg^{-1}, averages from all sampling years

Year	I – spring sampling			II – autumn sampling		
	0-30 cm	30-60 cm	60-90 cm	0-30 cm	30-60 cm	60-90 cm
2008	8.02 b (0.0÷122)	4.72 abc (0.0÷193)	3.56 ab (0.0÷182)	6.33 abc (0.0÷308)	3.83 a (0.0÷121)	2.69 a (0.0÷82.6)
2009	5.36 abc (0.0÷90.6)	3.60 a (0.0÷103)	2.96 a (0.0÷83.2)	8.45 c (0.0÷439)	3.84 ac (0.0÷81.9)	3.14 ac (0.0÷101)
2010	9.68 d (0.0÷212)	4.16 abd (0.0÷92.5)	3.46 ad (0.0÷127)	5.07 ab (0.0÷84.7)	4.30 ab (0.0÷134)	3.33 a (0.0÷116)

a, b, c, d – means labelled with the same letter are not significantly different at the significance level p = 0.05

Fotyma *et al*. (2004, 2005), Fotyma and Fotyma (2006) and Jadczyszyn *et al*. (2010) noted that the average content of mineral nitrogen in the soils of Poland (0-90 cm) was 76-90 kg N ha^{-1} in spring and 83-97 kg N ha^{-1} in autumn, whereas the respective values for nitrate nitrogen were 50-60 kg N ha^{-1} in spring and 60-70 kg N ha^{-1} in autumn. The variation of that content was very high and depended primarily on the particle size distribution of the soil, on the crop plant and its forecrop, on the time passed since the application of natural fertilisers and on nitrogen balance. Also other factors related to the cultivation technology and environmental factors were important (Falkowska and Filipek 2009, Lipiński 2010, Dresler *et al*. 2011a,b). However, fertilisation is still the factor with the fundamental effect on the content of this (mineral) form of nitrogen in soil (Chmielewska and Dechnik 1987, Ciećko *et al*. 1996, Bednarek and Tkaczyk 2002, Bednarek and Reszka 2008, Skwierawska *et al*. 2011, Mazur and Mazur 2015).

The content of sulphate sulphur in the soils under study is presented in Table 5. At the spring sampling time of 2009, the content of sulphate sulphur in the mineral soils varied from 1.09 to 23.43 mg S kg^{-1}, whereas in the organic soils was varying in the range of 1.98-16.50 mg S kg^{-1}. As for the mean value of the content of sulphate sulphur, it varied from 4.55 mg in the very light soils to 6.63 mg S kg^{-1} in the heavy soils and it was equal 11.4 mg S kg^{-1} in the organic soils; in 2010 maximal observed value was the lowest in light soils (10.07 mg S kg^{-1}) and highest in heavy (22.44 mg S kg^{-1}) and organic (23.43 mg S kg^{-1}), whereas mean value was the lowest in the medium soils (5.18 mg S kg^{-1}) and the highest in the heavy soils (6.50 mg S kg^{-1}), while in the organic soils it was 12.9 mg S kg^{-1}. In the subsequent years (2009, 2010) it did not differ significantly. In the autumn of 2008 the content of sulphate sulphur varied from 0.07 up to 25.08 mg S kg^{-1}, whereas mean values of this content in the mineral soils varied from 2.92 (very light soils) to 4.55 mg S kg^{-1} (heavy soils) and 12.8 mg S kg^{-1} (organic soils). In 2009 and 2010 the content of sulphate sulphur did not depend significantly on the agronomic soil category, but it varied in the range of 0.17-30.56 mg S kg^{-1} (2009) and 0.66-33.46 mg S kg^{-1} (2010). In 2008 it was significantly higher in the organic soils than in the medium soils.

Table 5. Mean, minimal and maximal (under the mean in brackets) values of sulphate sulphur content in soil, mg S kg^{-1}

Soil agronomic category	I – spring sampling date			II – autumn sampling date		
	2008	2009	2010	2008	2009	2010
Very light	n.a.	4.55 abcd (1.65÷7.59)	5.45 abcd (2.81÷10.07)	2.92 abc (0.33÷8.75)	7.06 abcd (0.59÷21.45)	7.82 abcd (2.57÷33.46)
Light	n.a.	6.01 abcd (1.49÷23.43)	5.94 abcd (2.24÷17.16)	4.32 abc (0.07÷9.83)	6.77 abcd (1.32÷15.28)	4.09 a (1.65÷9.57)
Medium	n.a.	5.02 ab (1.16÷8.42)	5.18 abd (1.16÷11.22)	3.09 a (0.17÷8.09)	6.34 abcd (0.33÷21.05)	4.29 ab (0.66÷10.89)
Heavy	n.a.	6.63 abcd (1.09÷19.64)	6.50 abcd (1.49÷22.44)	4.55 abc (0.17÷11.55)	7.03 abcd (0.17÷30.56)	4.92 ab (0.89÷13.99)
Organic	n.a.	11.4 bcd (1.98÷16.50)	12.9 d (4.29÷23.43)	12.8 c (1.98÷25.08)	10.2 abcd (0.46÷17.66)	9.41 abcd (2.24÷17.0)

a, b, c, d – means labelled with the same letter are not significantly different at the significance level p = 0.05; n.a. – not available

Kulczycki and Spiak (2003) determined that in the arable horizon of soils of south-west Poland the content of total sulphur varied from 72 to 490 mg kg^{-1}, and that of sulphate sulphur from 4.9 to 53.7 mg kg^{-1}. The content of those forms of S depended to the greatest extent on the content of organic carbon and total nitrogen, and to a lesser degree on the value of pH and on the content of particles < 0.02 mm. Kozłowska-Strawska and Kaczor (2004) noted that the content of sulphate sulphur in soil depended also on the species of plant grown (spring wheat, spring barley, spring rapeseed) and on the form in which sulphur fertilisation was applied. The highest concentration of S-SO_4 in soil was found under the effect of fertilisation with $(NH_4)_2SO_4$, K_2SO_4 and Na_2SO_4. Szulc *et al*. (2004) reported at the same time that the method of soil cultivation modified the content of total sulphur, organic sulphur and sulphate sulphur, mainly through its effect on changes in the content of organic matter. In relation to the method of soil cultivation and reaction, the content of sulphate sulphur varied from 9.2 to 15.4% of the total content of that element in soil. Irrespective of the method of soil cultivation, liming caused an increase in the content of total sulphur, at the same time decreasing the content of sulphate sulphur in soil. Terelak (2005) noted that mineral soils of Poland contained from 0.1 to 500.0 mg S-SO_4 kg^{-1} (average of 19 mg S-SO_4 kg^{-1}), and more than 55% of them were soils with a low content of that form of sulphur. The area of soils with medium and high levels of $S\text{-}SO_4$ constituted 25.1 and 13.1%, respectively, and soils with anthropogenic contamination with sulphur accounted only for 3.7% (regions with high level of industrialisation).

The content of nitrates (V) in the layer of 0-30 cm of soil sampled in the spring of 2008 was positively and significantly dependent on pH_{KCl}, $C_{org.}$, and on the content of assimilable forms of the assayed macroelements (Tab. 6).

Table 6. Content of mineral nitrogen, total and sulphate sulphur in relation to certain soil properties and cultivation treatments, p = 0.05

Variable	I $N\text{-}NO_3$, (0-30 cm)	I $N\text{-}NH_4$, (0-30 cm)	I (2008) $N_{min.}$ (0-30 cm)	I (2008) $N_{min.}$ (0-90 cm)	I $S_{tot.}$	I $S\text{-}SO_4$
pH_{KCl}	0.097	–0.058	*	0.102	*	*
$C_{org.}$	0.055	0.096	0.097	0.141	0.515	0.178
P	0.209	0.184	0.058	0.057	0.551	0.258
K	0.159	*	0.096	0.176	*	*
Mg	0.132	0.141	0.122	0.113	0.058	0.226
Forecrop	*	–0.086	*	*	–0.243	*
Org. fert. (t ha^{-1})	*	–0.052	*	*	*	*
Min. fert. (kg N ha^{-1}), 2008	*	–0.057	0.045	0.052	–0.184	*
I, $N\text{-}NO_3$ (0-30 cm)	–	0.190	0.791	0.789	0.334	0.126
I, $N\text{-}NH_4$ (0-30cm)	0.190	–	0.739	0.563	0.459	0.282
I (2008), $N_{min.}$ (kg N ha^{-1}) (0-30 cm)	0.791	0.739	–	0.889	0.154	0.139
I (2008), $N_{min.}$ (kg N ha^{-1}) (0-90 cm)	0.789	0.563	0.889	–	0.154	0.138
Fraction 0.05-0.02 mm (0-30 cm)	0.097	*	*	*	*	*
Fraction 0.02-0.002 mm (0-30 cm)	0.110	–0.062	*	*	*	*
Fraction < 0.002 mm (0-30 cm)	0.104	–0.067	*	*	0.227	*

* non-significant coefficient, I – spring time of sampling

The correlation between $N\text{-}NO_3$ and the content of mineral nitrogen was the highest (r_{xy} = 0.791; n = 1998). Also the content of ammonium nitrogen in the 0-30 cm layer of soil sampled in the spring of 2008 was positively and significantly correlated with the content of organic carbon and with assimilable forms of the assayed macroelements, whereas it was negatively and significantly correlated with pH_{KCl}, clay and colloidal fraction, nitrogen fertilisation applied under the forecrop in 2008, and organic fertilisation (Tab. 6). The highest correlation was noted between NH_4 (0-30 cm) form of nitrogen and mineral nitrogen (r_{xy} = 0.739; n = 1998). The content of mineral nitrogen in soil samples collected in the spring of 2008 from the layer of 0-30 cm (kg N ha^{-1}) was significantly and positively correlated with the content of organic carbon and assimilable forms of macroelements. The highest correlation, r_{xy} = 0.889, was obtained for the content of mineral nitrogen in the layers of 0-30 and 0-90 cm; in the 0-90 cm layer of soil, in the spring of 2008 it was additionally correlated (apart from the enumerated properties) with pH_{KCl}, mineral forms of nitrogen (0-30 cm) and sulphur, and the fraction of soil particles < 0.05 mm (Tab. 6). Obtained insignificant correlations between organic fertilisation and assayed forms of nitrogen and sulphur, despite significant and positive correlation of C_{org} content with sulphur and nitrogen content, may be the result of various effects. Either large number of analysed samples smoothed out the results, or this result can be related to the ammonium nitrogen nitrification process which is more efficient in compacted soils and intensifies in the vegetation period. Most likely, however, the rates of organic fertilisers were too low to had a significant effect on the sulphur and nitrogen content.

The particle size distribution affected significantly nitrate (V) nitrogen content in topsoil (positive significant correlation), whereas only the smallest fractions affected ammonium nitrogen content in topsoil (significant negative correlation). It may be related to the fact that the content of nitrogen (both nitrate and ammonium) depends primarily on the date of soil sampling, the particle size distribution and the depth of the soil samples collection. In the arable layer (0-30 cm) the content of nitrate (V) nitrogen increased significantly from very light to heavy soils and, irrespective of the agronomic category of soil, was significantly higher for the autumn sampling date than for the spring sampling date. Ammonium nitrogen content decreased from very light soils to heavy soils and was lower in autumn sampling date compared to spring sampling date. The share of ammonium nitrogen in the total pool of mineral nitrogen diminished considerably from very light up to heavy soils, and was significantly lower for the autumn than for the spring sampling date. This is due to the process of nitrification of ammonium nitrogen. The difference in the content of nitrate nitrogen in autumn and spring is also partly due to the leaching process of this form of mineral nitrogen occurring in late autumn and winter, and partly to the nitrification and denitrification processes.

The content of total sulphur in the soil depended significantly and positively on most of the analysed factors, and significantly and negatively on nitrogen fertilisation under the forecrop (in 2008) and under the main crop. The strongest dependence of $S_{tot.}$ was noted in relation to the content of organic carbon, available phosphorus and of ammonium and nitrate (V) nitrogen in the soil. The content of sulphate sulphur in the soil was significantly and positively correlated with the levels of organic carbon, content of P, Mg, N-NO_3, N-NH_4, $N_{min.}$ (from 0-30 cm layer, sampled spring 2008) and total sulphur (Tab. 6).

CONCLUSIONS

1. The highest content of nitrate (V) and ammonium nitrogen in the soils under study was noted in the 0-30 cm layer, irrespective of the spring or autumn time of soil sampling.

2. The content of sulphate sulphur in the topsoil (0-30 cm) was the highest in organic soils and in heavy soils. However, usually the content of sulphate sulphur in heavy soils did not differ significantly from its levels in medium, light and very light soils.

3. The content of nitrate (V) nitrogen in soil samples collected in spring depended significantly and positively on the assayed soil properties, and did not depend on the applied cultivation treatments. In a majority of cases the content of ammonium nitrogen depended significantly and positively on the assayed soil properties, and significantly and negatively on the cultivation treatments.

4. The content of mineral nitrogen in the soil layers of 0-30 and 0-90 cm was significantly and positively correlated with most of the assayed soil properties. The content of this nitrogen form did not depend significantly on the forecrop used in the cultivation of plants and also on organic fertilisation.

5. The content of total sulphur and sulphate sulphur depended significantly and positively on most of the assayed soil properties, and to a lesser degree on the applied cultivation treatments.

REFERENCES

A catalogue of methods for conducting agrichemical tests in agricultural and chemical stations (in Polish). 2011 OSCH-R Lublin, 1-19.

Bednarek W., Reszka R., 2008. Influence of liming and mineral fertilization on the content of mineral nitrogen in soil. J. Elementol., 13(3), 301-308.

Bednarek W., Tkaczyk P., 2002. The influence of mineral fertilization on the content of some nitrogen forms in soil (in Polish). Z.P.P.N.R., 484, 55-60.

Chmielewska B., Dechnik I., 1987. Influence of mineral fertilization on the content of some nitrogen forms in brown soil developed from loess (in Polish). Roczniki Nauk Rolniczych, A 106(4), 197-205.

Ciećko Z., Wyszkowski M., Szagała J., 1996. Effects of nitrogen fertilization on the content of N-NO_3 and N-NH4 in different soils (in Polish). Z.P.P.N.R., 440, 27-33.

Dresler S., Bednarek W., Tkaczyk P., 2011a. Effect of soil properties and nitrogen fertilization on distribution of NO3-N in soils of eastern Poland. Commun. Soil Sci. Plant Anal., 42, 2100-2111.

Dresler S., Bednarek W., Tkaczyk P., 2011b. Nitrate nitrogen in the soils of eastern Poland as influenced by type of crop, nitrogen fertilization and various organic fertilizers. J.C.E.A., 12(2), 367-379.

Falkowska K., Filipek T., 2009. Dynamics of changes of content of mineral nitrogen in top layer of soils in the zone affected by nitrogen fertilizer plant "Puławy" S.A. (in Polish). Ochrona Środowiska i Zasobów Naturalnych, 40, 95-102.

Fotyma E., Fotyma M., Pietruch Cz., 2004. The content of mineral nitrogen Nmin in arable soils of Poland (in Polish). Nawozy i Nawożenie, 3(20), 11-54.

Fotyma E., Fotyma M., Pietruch Cz., 2005. The content of mineral nitrogen in the soils of Poland (in Polish). Nawozy i Nawożenie, 2(23), 41-48.

Fotyma E., Fotyma M., 2006. The normatives of Nmin content in the soil and N-NO3 concentration in the soil solution of arable land in Poland (in Polish). Nawozy i Nawożenie, 1(26), 44-56.

Jadczyszyn T., Pietruch C., Lipiński W., 2010. Soil monitoring in Poland for the content of mineral nitrogen in the years 2007-2009 (in Polish). Nawozy i Nawożenie, 38, 84-110.

Kozłowska-Strawska J., Kaczor A., 2004. The influence of plants fertilization with different sulphur compounds on sulphate sulphur content in soil (in Polish). Annales UMCS, 59(2), 515-520.

Kulczycki G., Spiak Z., 2003. Total sulphur and sulphate sulphur content in the soils of South-West Poland (in Polish). Nawozy i Nawożenie, 4(17), 75-81.

Lamorski K., Pastuszka T., Krzyszczak J., Sławiński C., Witkowska-Walczak B., 2013. Soil water dynamics modeling using the physical and support vector machine methods. Vadose Zone Journal, 12 (4).

Lipiński W., 2000. The chosen factors shaping the occurrence of sulphur in agricultural soils in the Lublin region (in Polish). Folia Universitatis Agriculturae Stetinensis, Agricultura, 204 (81), 77-82.

Lipiński W., 2010. The content of mineral nitrogen in arable soils of nitrate vulnerable zones (NVZ) (in Polish). Nawozy i Nawożenie, 38, 111-120.

Mazur Z., Mazur T., 2015. Effects of long-term organic and mineral fertilizer applications on soil nitrogen content. Pol. J. Environ. Stud., 24(5), 2073-2078.

Pirttioja N., Carter T., Fronzek S., Bindi M., Hoffmann H., Palosuo T., Ruiz-Ramos M., Tao F., Trnka M., Acutis M., Asseng S., Baranowski P., Basso B., Bodin P., Buis S., Cammarano D., Deligios P., Destain M., Dumont B., Ewert F., Ferrise R., François L., Gaiser T., Hlavinka P., Jacquemin I., Kersebaum K., Kollas C., Krzyszczak J., Lorite I., Minet J., Minguez M., Montesino M., Moriondo M., Müller C., Nendel C., Öztürk I., Perego A., Rodríguez A., Ruane A., Ruget F., Sanna M., Semenov M., Sławiński C., Stratonovitch P., Supit I., Waha K., Wang E., Wu L., Zhao Z., Rötter R., 2015. Temperature and precipitation effects on wheat yield across a European transect: a crop model ensemble analysis using impact response surfaces. Clim. Res., 65, 87-105.

Ruiz-Ramos M., Ferrise R., Rodríguez A., Lorite I.J., Bindi M., Carter T.R., Fronzek S., Palosuo T., Pirttioja N., Baranowski P., Buis S., Cammarano D., Chen Y., Dumont B., Ewert F., Gaiser T., Hlavinka P., Hoffmann H., Höhn J.G., Jurecka F., Kersebaum K.C., Krzyszczak J., Lana M., Mechiche-Alami A., Minet J., Montesino M., Nendel C., Porter J.R., Ruget F., Semenov M.A., Steinmetz Z., Stratonovitch P., Supit I., Tao F., Trnka M., de Wit A., Rötter R.P., 2017. Adaptation response surfaces for managing wheat under perturbed climate and CO2 in a Mediterranean environment. Agricultural Systems (in press), doi: http://dx.doi.org/10.1016/j.agsy.2017.01.00.

Skwierawska M., Zawartka L., Nogalska A., 2011. Effect of different sulfur doses and forms on changes in the mineral nitrogen content of soil. J. Elementol., 16(1), 93-102.

Szulc W., Rutkowska B., Łabętowicz J., 2004. The content of total sulphur and sulphate sulphur in soil profile in conditions of different soil cultivation systems (in Polish). Annales UMCS, 59, 55-62.

Terelak H., 2005. Heavy metals and sulphur in arable soils of Poland (in Polish). Problemy Ekologii, 9(5), 259-264.

Tkaczyk P., Bednarek W., Dresler S., Krzyszczak J., 2016. Evaluation of soil reaction and content of assimilable nutrients in soils of South-Eastern Poland. Acta Agroph., 23 (2), 249-260.

Walczak R.T., Witkowska-Walczak B., Baranowski P., 1997. Soil structure parameters in models of crop growth and yield prediction. Physical submodels. Int. Agrophys., 11, 111-127.

ZALEŻNOŚĆ ZAWARTOŚCI AZOTU MINERALNEGO I SIARKI SIARCZANOWEJ W GLEBIE OD NIEKTÓRYCH JEJ WŁAŚCIWOŚCI I ZABIEGÓW AGROTECHNICZNYCH

Przemysław Tkaczyk[1], *Wiesław Bednarek*[1], *Sławomir Dresler*[2], *Jaromir Krzyszczak*[3], *Piotr Baranowski*[3]

[1]Katedra Chemii Rolnej i Środowiskowej UP w Lublinie, ul. Akademicka 15, 20-033 Lublin
[2]Zakład Fizjologii Roślin, Instytut Biologii i Biochemii
Uniwersytet Marii Curie-Skłodowskiej, ul. Akademicka 19, 20-033 Lublin
[3]Instytut Agrofizyki im. Bohdana Dobrzańskiego PAN, ul. Doświadczalna 4, 20-290 Lublin
e-mail: jkrzyszczak@ipan.lublin.pl

Streszczenie. W latach 2008-2010 przeprowadzone zostały badania środowiskowe których celem była ocena aktualnej zasobności gleb południowo-wschodniej Polski w azot mineralny (azotanowy V i amonowy) i siarkę siarczanową, a także określenie związków tych składników z niektórymi właściwościami gleby i przeprowadzanymi zabiegami agrotechnicznymi. Wyznaczono 333 punkty pobierania próbek glebowych, w których gleba została pobrana z warstw 0-30, 30-60 i 60-90 cm. W pobranych próbkach oznaczono: skład granulometryczny metodą dyfrakcji laserowej, C organiczny wg metody Tiuryna, pH w 1 mol KCl dm^{-3}. Fosfor i potas przyswajalny oznaczony został metodą Egnera-Riehma (DL), azot mineralny z podziałem na formę azotanową (V) i amonową metodą kolorymetrii z użyciem autoanalizatora przepływowego, siarkę ogólną i siarczanową metodą nefelometryczną, a magnez przyswajalny po ekstrakcji z gleby w 0.0125 mol $CaCl_2$ dm^{-3} metodą ASA. Największą zawartość azotu azotanowego (V) i azotu amonowego w badanych glebach stwierdzono w warstwie 0-30 cm, niezależnie od wiosennego czy jesiennego terminu poboru próbek. Zawartość siarki siarczanowej w warstwie wierzchniej (0-30 cm) była największa w glebach organicznych oraz ciężkich, nie różniła się na ogół istotnie od zawartości w glebach średnich, lekkich i bardzo lekkich. Zawartość azotu mineralnego w warstwach 0-30 i 0-90 cm zależała istotnie i dodatnio od większości oznaczanych właściwości gleby, natomiast zawartość siarki ogółem i siarczanowej zależała istotnie i dodatnio nie tylko od właściwości gleby, ale także od zabiegów agrotechnicznych.

Słowa kluczowe: makroskładniki, azot mineralny, siarka siarczanowa, odczyn gleby, kategoria agronomiczna