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Selected monitoring properties of agricultural soil from the Imielin experimental site*
Wybrane parametry monitoringowe gleb rolnych obiektu doświadczalnego Imielin

Key words: fertilization, monitoring, nitrogen, soil properties
Słowa kluczowe: nawożenie, monitoring, azot, właściwości gleb

Introduction

Soil is a significant part of the natural environment that plays many environmental functions, such as providing a habitat for a wide range of organisms, influencing the distribution of plant species, or climate regulation. Soil always responds to changes in environmental factors and, because of that, it constantly changes and develops through time. Some changes in soil are of short duration and reversible, whereas others are a permanent soil feature (Cambardella et al., 1994; Bęś and Baciak, 2015).

Nowadays, in environmental monitoring, of crucial meaning is soil monitoring that may be defined as a repeated inspection of soil, including soil sampling and testing at permanent testing points together with the presentation of results in order to track the changes of various soil characteristics, particularly chemical, occurring at specific intervals under the influence of anthropogenic activities, including agriculture (Grabowska et al., 2014; Radziemska and Fronczyk 2015). Considering the significant increase of agricultural activities, and the resulting contamination, there is

a significant requirement for monitoring, characterization and identification of the soil environment. The content of harmful compounds caused by agricultural practices should be constantly monitored in relation to human health and living organisms. It must be noted that prevention of soil contamination is essential for the preservation of relevant physical and chemical properties, as well as soil quality and ensurance of protection of other elements of the natural environment (Matson et al., 1997; Schoenholtz et al., 2000; Nortcliff, 2002).

As commonly accepted, soil characteristics depend on the original rock or geological deposit, from which the soil is derived, along with other influences such as microbial activity and climate impact, which have the ability to modify the original material considerably, resulting in distinct horizons within the soil profile. This modification produces a wide variety of soils differing in physical and chemical properties.

The spatial variability of physical properties significantly influences the fate of water and pollutants (fertilizers) in the soil environment (Sun et al., 2003). Due to the fact that the soil type and its properties have an important meaning in regulating the mobility of chemical substances through the soil, there is a significant need for a large number of laboratory and in-situ tests in order to control and monitor unfavorable changes in the soil. In order to properly identify the soil characteristics, many physical, chemical and biological properties should be taken into consideration in soil monitoring programs due to their effect on the bioavailability of contaminants and the possibility of leaching into deeper layers of soil and to groundwater (Stewart, 1985; Morvan et al., 2008; Yong et al., 2015). Tests of physical properties commonly include determination of particle size distribution, loss on ignition, moisture content, hydraulic conductivity, porosity or bulk density. Considerable importance of determining the soil structure and texture is related to the necessity of explaining how these properties affect the fate and behaviour of pollutants in soil.

To conclude, protection of soil quality under agricultural use is a major challenge for sustainable development. The basic assessment of soil quality is necessary for proper management interventions. Properly chosen measurement techniques and the accuracy of laboratory tests of selected soil properties are the basis of effective monitoring.

The objective of this investigation was to determine the content of selected chemical properties of soil (pH, HAC, TEB, CEC, and BS) in different soil layers under two types of agricultural practice: variable rate application (VRA) and uniform (UNI) N dose.

Material and methods

The research was conducted in the 2012/2013 growing season in Poland on 22 ha of production fields located in central Poland (Imielin countryside) cropped with winter wheat (*Triticum aestivum* L.). Geologically, the area lies within the Vistula River Valley, within a geomorphological unit termed the Warsaw Basin. Poland is located in the temperate warm transitional zone, forming under the influence of different air masses mixing over its territory. The

average annual precipitation in Poland is around 628 mm, but in the mountainous areas it exceeds 1,100 to 1,400 mm. The most rainy season is in May, June, July and August.

The tested area was subdivided into strips running across the entire field length and fertilized with a variable (VRA) or uniform (UNI) nitrogen dose (Fig.). Soil was sampled from the depth intervals of 0.0–0.3, 0.3–0.6 and 0.6–0.9 m on May 13, 2013 from each plot after the application of the N fertilizer (UNI:

24% sulfan, 60 kg·ha^{-1}), and on September 17, 2013 from each plot after N fertilization (VRA: 55–105 kg·ha^{-1}; UNI: 80 kg·ha^{-1}), and after the winter wheat harvest. Table 1 presents the average yearly doses of the N fertilizers.

The sampling depths were chosen to investigate which contaminants may be extracted in the runoff (Ahuja and Lehman, 1983); moreover, the depth 0.0–0.3 m is commonly used for agricultural soil testing in Poland. Samples collected from the depth of 0.6–0.9 m were
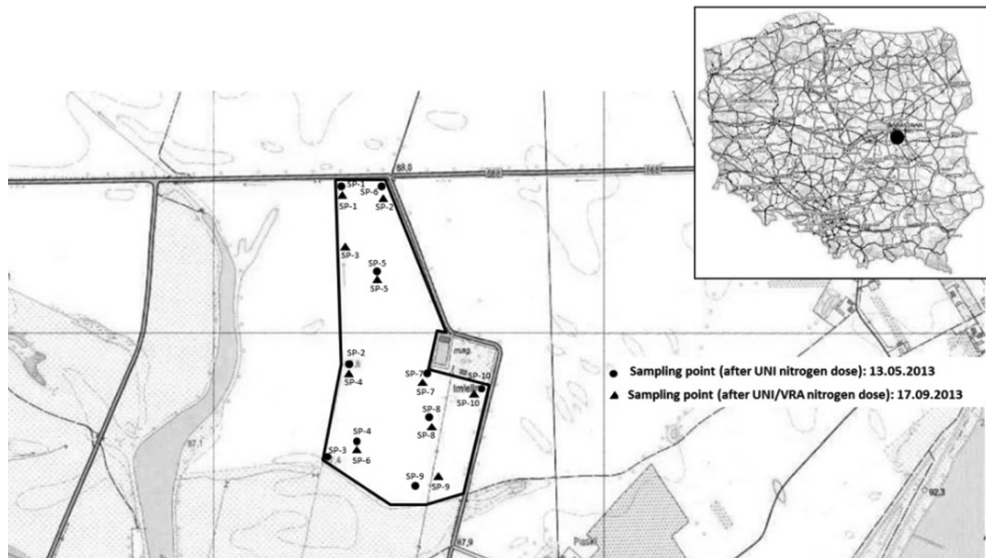

FIGURE. Study area and sampling locations
RYSUNEK. Lokalizacja obszaru badawczego i poboru próbek

TABLE 1. Rates and dates of nitrogen application in the tested area
TABELA 1. Dawki i daty aplikacji nawozów azotowych

Dates Daty	Type of fertilizer Typ nawozu	Nitrogen rates [kg·ha^{-1}] Dawka azotowa [kg·ha^{-1}]	
		UNI	VRA
I dose (18.04.2013) I dawka (18.04.2013)	24% sulfan 24-procentowy siarkowodór	60	–
II dose (14.05.2013) II dawka (14.05.2013)	34% ammonium nitrate 34-procentowy azotan amonu	80	55–105

collected to investigate the translocation of nutrients down the soil profile. The test area was additionally recognized by 20 drillings (1 sampling point per ha) in order to identify the geological and hydrogeological conditions.

Prior to the chemical analyses, the soil samples were air dried at room temperature and sifted through a nylon sieve of 1-mm mesh size to remove stones, coarse material, and other debris, and then stored in polyethylene bottles. Double deionized water (Milli-Q Millipore 0.055 μS·cm^{-1} resistivity) was used for all dilutions. The solution of each sample was cooled and filtered on a Whatman prewashed filter paper. All the samples were analyzed in duplicates.

Soil pH was determined using a multimeter 18.52.01 (Eijkelkamp, Netherlands) with a water-to-soil ratio of 2.5. To test the hydrolytic acidity (HAC) by Kappen's method, the soil samples were treated with 0.5 M·dm^{-3} Ca-acetate solution adjusted to pH 8.2 in the ratio of 1 : 2.5 (Klute, 1996). The total exchangeable bases (TEB-K$^+$, Na$^+$, Ca^{2+}, and Mg^{2+}) were tested by Kappen's method by determining individual cations after extraction from soil with CH_3COONH_4 (Klute, 1996). The cation exchange capacity (CEC) was calculated from the formula: CEC = HAC + TEB and the percentage base saturation from the formula: BS = 100 · TEB / CEC^{-1}.

Thirty soil samples were collected from the depths 0.3, 0.6, and 0.9 m and then prepared in accordance with the PN-EN ISO 14688-1:2006, PN-B-02480:1986 and PN-88/B-04481 standards for the analyses of particle size distribution using the Casagrande's method in Prószyński's modification.

Based on the content of different fractions, the soils were named according to the specific standards used in geotechnics and soil mechanics.

Results and discussion

It must be emphasized that soil profile descriptions are valuable for deciding how soil may be used and predicting how soil may react to its intended use, and are not only useful for farmers, but also for soil engineers, ecologists, hydrologists and land use planners. Based on in-situ examination and laboratory tests it was found that in the tested area the top-soil (0–0.3 m) is composed of coarse clays, silty coarse clays and sandy silts. The layers below (0.3–0.6 m) consist of silty coarse clays, sandy coarse clays (sampling points: SP$_1$–SP$_3$; SP$_5$–SP$_9$), and fine and clayey sands (sampling points: SP$_4$, SP$_{10}$). The layers at the depth of 0.6–0.9 m are mainly composed of silty coarse clays and sandy silts, with the exception of boreholes SP$_4$ and SP$_{10}$ where fine sands occur. Laboratory tests have shown that the average content of the clay fraction is 12.2, 11.6, and 11.6% for soil samples taken from the depths 0.3, 0.6, 0.9 m, respectively. The average content of silt fractions in soil samples is in the range of 38.5–48.5% and decreases with depth.

The chemical composition of the soil from the field experiment depended on the depth and type of fertilization (variable or uniform nitrogen dose) (Table 2). The physical, chemical, and biological properties of soil directly depend on its pH value (Wyszkowski et al., 2009; Roelofsen et al., 2015; Yuan et al., 2015).

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TABLE 2. Range and average of selected chemical parameters of the investigated soils for different fertilization treatments

TABELA 2. Zakres i średnie wartości wybranych właściwości chemicznych gleb objętych badaniami w różnych systemach nawożenia

Nitrogen rates [kg·ha⁻¹]	Depth [m]	pH[a]	HAC[b] [mmol(+)· · kg⁻¹]	TEB[c] [mmol(+)· · kg⁻¹]	CEC[d] [mmol(+)· · kg⁻¹]	BS[e] [%]
I nitrogen dose/UNI						
60	0.0–0.3	5.43–6.46 5.96 (±0.33)	1.99–2.65 2.30 (±0.23)	0.93–3.16 2.31 (±1.33)	3.10–7.10 4.56 (±1.25)	30.03–61.33 47.29 (±14.69)
	0.3–0.6	5.52–6.52 6.07 (±0.34)	1.40–2.61 2.03 (±0.41)	0.93–4.93 2.00 (±1.41)	2.94–6.85 4.08 (±1.31)	26.25–72.07 44.56 (±17.23)
	0.6–0.9	5.52–6.68 6.16 (±0.43)	1.28–2.54 1.88 (±0.43)	0.31–4.76 1.80 (±1.42)	2.28–5.52 3.80 (±1.40)	13.50–72.31 41.83 (±19.39)
II nitrogen dose/UNI						
80	0.0–0.3	5.80–6.14 5.91 (±0.21)	1.84–2.57 2.31 (±0.30)	1.10–1.76 1.39 (±0.29)	3.74–4.32 3.70 (±0.37)	31.13–46.83 37.48 (±6.43)
	0.3–0.6	5.72–6.43 6.11 (±0.26)	1.93–2.39 2.09 (±0.18)	0.52–3.48 1.37 (±1.22)	2.74–5.41 3.46 (±1.15)	20.49–64.35 34.81 (±17.86)
	0.6–0.9	5.62–6.45 6.16 (±0.32)	1.19–2.78 1.90 (±0.57)	0.17–2.07 0.83 (±0.74)	1.60–4.85 2.73 (±1.25)	8.08–42.84 27.10 (±12.64)
II nitrogen dose/VRA						
55–105	0.0–0.3	5.64–6.46 6.00 (±0.34)	2.06–2.35 2.18 (±0.11)	1.33–4.61 3.08 (±1.23)	3.48–6.67 5.26 (±1.19)	38.28–69.02 57.42 (±12.53)
	0.3–0.6	5.61–6.78 6.10 (±0.46)	1.32–2.36 1.80 (±0.40)	0.77–5.21 2.80 (±1.74)	3.31–7.20 4.67 (±1.79)	28.28–72.62 60.36 (±19.31)
	0.6–0.9	5.60–6.79 6.27 (±0.51)	1.18–2.50 1.71 (±0.50)	0.32–5.16 2.55 (±2.10)	1.61–6.95 4.20 (±2.34)	29.08–75.23 61.92 (±20.01)

[a]soil pH – 1 : 2.5 soil sample : water ratio; [b]hydrolytic acidity; [c]total exchangeable cation bases; [d]cation exchange capacity; [e]base saturation ratio; SD± standard deviation; full dataset $n = 60$.

Soil pH also affects organic carbon solubility and causes increase in the availability of biologically toxic aluminum with decreasing value of pH (Flis et al., 1993; Andersson et al., 2000). Some researchers have studied agricultural soils, in which the pH changed as a result of anthropogenic activities, e.g. ash or biochar application, liming, fertilization (Chagnon et al., 2001; Thirukkumaran

and Parkinson, 2000; Liu and Zhang, 2012). In addition, the application of N fertilizers has short- or long-term effects on soil pH and may also be more pronounced in agricultural systems (Cleland and Harpole, 2010). High application rates of nitrogen fertilizers lead to temporarily very high osmotic potentials and potentially toxic concentrations of the N forms added (Omar and Ismail, 1999). Urea, anhydrous ammonia and aqua ammonia may increase soil pH considerably when ammonia is converted to ammonium (Geisseler and Scow, 2014).

In the datasets of the Monitoring studies (2012) of the chemistry of arable soils in Poland, the humus horizons of soils in research stands located in the Masovian district showed pH values within the range of 6.0–6.4. These results indicate that the soil samples collected after the first rate of nitrogen fertilizer (I/VRA) from the topsoil (0.0–0.3 m) were characterized by a pH ranging from 5.43 to 6.46, with an average value of 5.96. Furthermore, N application may decrease soil pH, leading to the mobilization of Al and the leaching of nutrient cations (Vitousek et al., 1997). The highest value of pH was observed in samples collected from the soil depth of 0.6–0.9 m. Soil pH measured after a variable rate application (II/VRA) of the nitrogen dose into the soil increased from 5.96 to 6.00. Our reported values of pH were higher than those observed by Muema et al. (2015) who studied the use of mineral N in the combination with organic inputs. In a literature review, Geisseler and Scow (2014) have noted that indirect effects of long-term application of NH_4^+ fertilizers result in soil pH reduction by 0.26 units.

The sorption capacity of soil, which is determined by the value of hydrolytic acidity and sum of exchangeable basic cations and is an important factor influencing the growth and development of plants, and the accumulation of micro- and macronutrients in their tissues, depends largely on the content of organic matter and clay fraction (Hartmann et al., 1998). In arable soils, the sorption properties depend on their particle size distribution and the applied fertilization (Ersahin et al., 2006). Hydrolytic acidity (HAC), which determines strongly or loosely bound H^+ and Al^{3+} ions absorbed by the sorption complex of the soil, is an indicator of soil acidity. Typical values of hydrolytic acidity found in natural Polish soils fall in the range of 1–3 mmol(+)·kg^{-1} for light arable soils, 1–5 mmol(+)·kg^{-1} for forest soils, and a few to few dozen mmol·kg^{-1} for heavy soils. Monitoring studies (2012) of the chemistry of arable oils in Poland in the humus horizons of soils in research stands located in the Masovian district showed the HAC content within the range of 2.03 to 3.38 mmol(+)·kg^{-1}. Values of hydrolytic acidity determined in soil samples depended on the rate of fertilization (VRA or UNI), and the depth from which they were collected (Table 2). Average values of hydrolytic acidity determined in the study after the first rate of nitrogen fertilizer (I/VRA) application at soil depth of 0.0––0.3 m were in the range of 1.99––2.65 mmol(+)·kg^{-1}, with an average value of 2.3 mmol(+)·kg^{-1}. In the presented study, a clear decreasing tendency of this parameter was observed with increasing depth of sample collection. The highest values of hydrolytic acidity (HAC) were

determined in soil collected after the second rate of nitrogen fertilization (II/UNI). Soil collected from the depth of 0.6––0.9 m had the lowest values of this parameter [1.71–1.90 mmol(+)·kg^{-1}], with samples taken from the field after all types of fertilization (I/UNI, II/UNI, II//VRA). It can therefore be assumed that a change in the hydrolytic acidity (HAC) of the analyzed soils occurred under the influence of the type of fertilization system. Nazarkiewicz and Kaniuczak (2012) reported that an unfavorable effect of mineral fertilizers on the hydrolytic acidity (HAC) of soil depending on the N : P : K and on the soil pH were confirmed during a four-year experiment. On the other hand, Bednarek et al. (2012) stated that a multi-year fertilization with slurry and NPK did not significantly affect the hydrolytic acidity regardless the doses, whereas mineral fertilizers increased its values. In contrast, Gondek and Filipek-Mazur (2005) reported an elevated hydrolytic acidity in their study on mineral, organic and organic-mineral fertilizers.

The content of basic cations and sorption properties in soil are parameters that determine and regulate the processes, in which nutrient components leach out of the soil (Hartmann et al., 1998), thus shaping the effectiveness of fertilization, which is of high importance in the processes of plant nutrition, especially in soils used in agriculture (Bartkowiak and Długosz, 2010). According to Enujeke et al. (2013), manure fertilization leads to higher increase in the sum of cations than mineral fertilizers. The average values of the total sums of exchangeable cations (TEB) determined in the soil after first rate of nitrogen fertilizer (II/VRA) was applied at the soil depth of 0.0–0.3 m were found to be in the range of 0.93––3.16 mmol(+)·kg^{-1}, with an average value of 1.80 mmol(+)·kg^{-1}. The lowest average value of this parameter (0.8––1.4 mmol(+)·kg^{-1}) was noted in soil collected after the second uniform (UNI) rate of nitrogen fertilization at all three depths. On the other hand, the highest values of the total sums of exchangeable cations (TEB) were observed in soil after application of variable nitrogen rates (VRA). Irrespective of the depth from which the soil samples were collected, the sums of exchangeable basic cations (TEB) were negatively correlated with increasing depth of sample collection. With regard to cation exchange capacity (CEC), soils collected after uniform nitrogen rates (I/UNI) were characterized by values in the range of 2.28––7.10 mmol(+)·kg^{-1}, with values decreasing with the increasing depth of the soil profile.

Saturation of the sorptive complex with base cations is an important parameter for the quality assessment of soils, because it decides about the soil fertility and resistance to chemical degradation (Jasiewicz et al., 2007). The base saturation ratio (BS) is used to characterize how the soil particle surface is filled with basic cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+). Moreover, intensive agricultural use of soil may induce both enrichment and impoverishment of the sorptive complex in base cations (Peinemann et al., 2000). Typical values of the base cation saturation ratio (BS) found in natural Polish soils (0.0–0.2 m) fall in the range of 35.12 to 65.12% (Monitoring of arable soils... 2012). The base cation saturation ratio (BS) was also found to decrease

with depth, especially in the soil samples collected after the uniform rate of nitrogen (I/UNI; II/UNI). The soil samples collected after the variable rate of nitrogen fertilizer (II/VRA) were characterized by a BS ranging from 28.28% (0.3––0.6 m) to 75–23% (0.6–0.9 m), with an average value of 59.90%. The results correspond well with those presented by other authors, who measured the degree of saturation of the sorptive complex with base cations (BS) in the Ap horizons where BS increased with depth (Paluszek, 2014).

Conclusions

The application of nitrogen fertilizers in two types of agricultural practice – variable rate application (VRA) or uniform (UNI) N dose modified the basic physical and chemical properties of soils. The values of such parameters as pH, hydrolytic acidity (HAC), total sums of exchangeable cations (TEB), cation exchange capacity (CEC) and base cation saturation ratio (BS) also depend on the depth from which the soil samples were collected. The soil samples collected after the first rate of nitrogen fertilizer from the topsoil were characterized by a pH with an average value of 5.96, and the highest value of pH was observed at the soil depth of 0.6–0.9 m. The highest values of hydrolytic acidity were determined in soil collected after the second rate of nitrogen fertilization. The lowest average values of the total sums of exchangeable cations were determined in soil after the first rate of nitrogen fertilizer and at soil depth of 0.0–0.3 m. The

cation exchange capacity of soils collected after uniform nitrogen rates was characterized by values decreasing with the increase of soil depth. The base cation saturation ratio also decreased with depth, especially in the soil samples collected after the uniform rate of nitrogen.

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Summary

Selected monitoring properties of agricultural soil from the Imielin experimental site. The effects of two types of agricultural practice: variable rate application (VRA) and uniform (UNI) N dose on selected chemical properties of soil were compared in a field fertilization experiment. Nitrogen, in doses 60 or 80 kg·ha^{-1} (UNI) and 55–105 kg·ha^{-1} (VRA), was applied to soil farmed with winter wheat (*Triticum aestivum* L.). The research was conducted in the 2012/2013 growing season in Poland on 22 ha of production fields located in the Imielin countryside (central Poland). The soil samples were taken from three depths: 0.0––0.3, 0.3–0.6, and 0.6–0.9 m, and the pH, HAC, TEB, CEC, and BS were determined. The application of the nitrogen fertilizer in the two types of agricultural practice – variable rate application (VRA) and uniform (UNI) N dose modified the basic physical and chemical properties of soil. The highest values of pH and hydrolytic acidity were observed at the soil depth of 0.6–0.9 m after the first rate of nitrogen fertilizer was applied. Cation exchange capacity of soils collected after uniform nitrogen rates were characterized by values decreasing with the increasing depth of the soil profile.

Streszczenie

Wybrane parametry monitoringowe gleb rolnych obiektu doświadczalnego Imielin. Wpływ dwóch rodzajów nawożenia: zmienną (VRA) i stałą dawką azotu (UNI) na wybrane właściwości chemiczne gleb została określona na podstawie doświadczeń polowych. Dawki azotu w ilościach 60 i 80 kg·ha^{-1} (UNI) oraz 55–105 kg·ha^{-1} (VRA) były dodawane do gleby, na której uprawiano pszenicę ozimą (*Triticum aestivum* L.). Badania przeprowadzono w sezonie wegetacyjnym 2012/2013 na 22 ha polu upraw-

nym zlokalizowanym w miejscowości Imie-
lin (centralna Polska). Próbki gleb pobrano
z trzech głębokości: 0,0–0,3, 0,3–0,6 i 0,6–
–0,9 m, i oznaczono w nich: pH, EC, Hh, S,
T, V. Aplikacja nawozów azotowych w zmien-
nej (VRA) i stałej dawce (UNI) azotu modyfi-
kowała podstawowe fizyko-chemiczne właś-
ciwości gleby. Największymi wartościami pH
i kwasowości hydrolitycznej charakteryzowa-
ła się gleba pochodząca z głębokości pomia-
rowej 0,6–0,9 m, pobrana po pierwszej dawce
wysiewu nawozów. Kationowa pojemność
gleb pochodzących z poboru po drugiej daw-
ce nawożenia stałą dawką azotu charaktery-
zowała się wzrostem swej wartości w miarę
zwiększania się głębokości pomiarowej.

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