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THE EFFECT OF SOME SOIL PHYSICOCHEMICAL PROPERTIES AND NITROGEN FERTILISATION ON WINTER WHEAT YIELD

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A b s t r a c t. An environmental study, which was conducted at 45 agricultural farms located in south-eastern Poland (Lubelskie Voivodeship) over the period of 2015-2016, evaluated the effect of some soil physicochemical properties and nitrogen fertilisation on winter wheat yield. Soil physicochemical analysis was performed using conventional methods at the accredited laboratory of the Regional Chemical and Agricultural Station in Lublin. Factorial analysis was carried out after classifying the soil according to soil textural classes, pH classes, and phosphorus, potassium and magnesium abundance classes, as well as after determining three nitrogen rates applied for wheat and its previous crop: I – 0-30; II – 31-60; III – 61-90 kg N ha^{-1}. The study found a positive, but not always significant, effect of soil textural class (in particular, the content of silt and clay particles) and soil pH class (from acidic to alkaline) on winter wheat grain yield. Soil phosphorus, potassium and magnesium abundance was not found to have any significant effect on grain yield. However, these nutrients were observed to positively affect wheat grain yield. Nitrogen fertilisation applied for the evaluated crop and the previous crop was found to significantly affect winter wheat grain yield.

K e y w o r d s: fertilisation, fertility class, particle size distribution, soil reaction, winter wheat

INTRODUCTION

Winter wheat is a crop whose proportion in the cereal crop structure is the greatest. It belongs to crops of very high economic importance and in Poland the winter wheat acreage is about 2 million hectares. Due to its high requirements with regard to soil and agronomic practices, grain yield achieved may substantially vary depending on this crop's growing conditions (Cui *et al.* 2006, Brzozowska *et al.* 2008, Bednarek *et al.* 2009, Gürsoy *et al.* 2010, Amato *et al.* 2013, Gaj *et al.* 2013, Chwil 2014). Weather conditions during wheat growing season are also extremely important (De Vita *et al.*

2007, Kołodziej *et al.* 2007, Bulletin 2015, Bulletin 2016). Appropriate assessment of habitat interactions and proper agricultural practices are the major elements determining grain yield (Grant *et al.* 2001, Sieling *et al.* 2005, Suwara *et al.* 2007, Smutny *et al.* 2008, Woźniak and Stępniewska 2017). On the other hand, it is necessary to determine the importance of individual yield-forming factors in order to achieve intended economic effects (Noworolnik 2008, Montemurro 2009, Andruszczak *et al.* 2011, Gozdowski *et al.* 2011, Jaskulska *et al.* 2015). Research on crop yields is primarily focused on two or three-factor field or pot experiments. Few studies have attempted to determine the influence of a dozen or so factors on winter wheat yield and describe the enormous complexity of the relationships existing in agroecosystems (Rutkowska 2006, Podolska 2008, Panasiewicz and Koziara 2009, Bedousscac and Justes 2010, Kotwica *et al.* 2011). Environmental studies conducted under farm conditions can be considered to be particularly valuable because the effects of such studies are of practical significance and can be directly used in plant production.

The aim of the present study was to determine the effect of some soil physicochemical properties and nitrogen fertilisation on winter wheat yield.

MATERIALS AND METHODS

This environmental study was conducted at 45 agricultural farms located in south-eastern Poland (Lubelskie Voivodeship). It evaluated winter wheat yield over the period of 2015 – 2016 depending on some soil physicochemical properties and nitrogen fertilisation. Grain yield and the nitrogen rate applied for wheat cultivar 'Sailor' and for the previous crop were determined based on interviews with the farmers. The previous crop was winter wheat (12), a cereal mixture (9), spring barley (6), potato (5), maize (4), winter oilseed rape (3), pulses (2), winter barley (2), spring wheat (1), winter triticale (1), and oats (1). The percentage proportion of soils on which winter wheat was grown was as follows: loamy sand – 4.4%, sandy loam – 26.7%, silt – 33.3%, and sandy silt – 35.6%. The plantations of this crop were located in the following municipalities: Piszczac, Komarówka Podlaska, Radzyń Podlaski, Hanna, Dębowa Kłoda, Sawin, Wierzbica, Konopnica, Trawniki, Piaski, Niedrzwica Duża, Borzechów, Dzierzkowice, Zakrzówek, Zakrzew, Żółkiewka, Łopiennik Górny, Krasnystaw, Kraśniczyn, Izbica, Uchanie, Stary Zamość, Zamość, Adamów, Goraj, Radecznica, Sułów, Sitno, Miączyn, Werbkowice, Mircze, Tyszowce, Rachanie, Ulhówek, Jarczów, Susiec, and Tarnogród (Fig. 1). The area of a single crop field was not more than four hectares. Soil physicochemical analysis was performed at the accredited laboratory of the Regional Chemical and Agricultural Station in Lublin. In soil samples taken from the 0-20 cm layer, the following were determined: pH in 1 M KCl dm^{-3}, particle size distribution by the laser method, available phosphorus and potassium content by the Egner-Riehm method, and available magnesium content by ASA after soil extraction with 0.0125 mol dm^{-3} of calcium chloride solution (A catalogue of methods 2011). The effects of soil textural class, pH, soil phosphorus, potassium and magnesium availability as well as nitrogen fertilisation of wheat and the previous crop were evaluated using non-orthogonal one-way classification analysis of variance. Factorial analysis was performed after first classifying the soils according to soil textural classes, pH classes, and phosphorus, potassium and magnesium availability classes as well as after determining three nitrogen rates applied for wheat and its previous crop: I – 0-30; II – 31-60; III 61-90 kg N ha^{-1}. The data on weather conditions during the study period were found in the weather bulletins published by the National Hydrological and Meteorological Service (Bulletin 2015, Bulletin 2016). The standard deviation shown in Tables 1-7 informs how widely the winter wheat grain yield values were dispersed around the mean. If the standard deviation was lower, this means that the observations were more concentrated around the mean grain yield.

Fig. 1. Distribution of the measurement points

RESULTS

The present study found soil textural class to have a significant effect on winter wheat yield (Tab. 1, Fig. 2). The yield of this crop systematically increased and was primarily dependent on the proportion of silt and clay particles, but not always significantly. The yield harvested from sandy loam was higher by 28.5% than that obtained from loamy sand. The yield harvested from sandy silt was higher by 33.6% than the yield obtained on loamy sand. The highest grain yield was found when plants were grown on silty soil. In this case, it was higher by almost 70% than that obtained on loamy sand. It was noted that the grain yields from crops grown on loamy sand, sandy loam and sandy silt did not differ statistically. On the other hand, the effect of silt was significant compared to the above-mentioned textural classes (Tab. 1).

Table 1. Effect of soil textural class on winter wheat yield, t ha^{-1}

Soil textural class	Number of samples	Yield	Standard deviation
Loamy sand	2	3.75a	0.35
Sandy loam	12	4.82a	0.86
Sandy silt	16	5.01a	0.83
Silt	15	6.26b	1.46
Total /Mean	45	5.32	1.27

a, b – means followed by the same letter are not significantly different at $\alpha = 0.05$

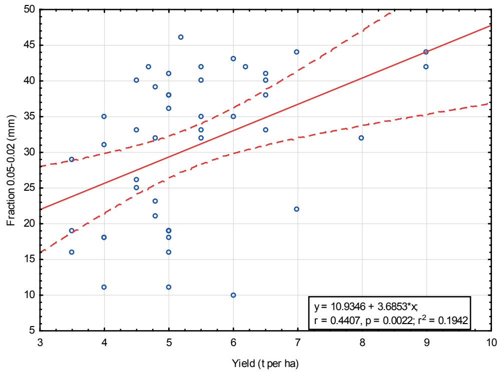

Fig. 2. Effect of soil silt content on winter wheat yield

In his research, Noworolnik (2008) also stressed that grain yield of winter wheat and winter barley was dependent, among other things, on soil particle size distribution and it was significantly higher on silts, light loams and heavy loamy sands derived from loams compared to heavy and light loamy sands. A study by Bednarek *et al.* (2009) also found that soil particle size distribution, in particular the content of particles < 0.02 mm, significantly affected winter wheat grain yield.

Table 2. Effect of soil pH class on winter wheat yield, t ha^{-1}

pH class	Number of samples	Yield	Standard deviation
I, alkaline (>7.2)	4	6.18a	1.01
II, neutral (6.6-7.2)	13	5.60a	1.38
III, slightly acidic (5.6-6.5)	16	5.04a	1.02
IV, acidic (4.6-5.5)	12	5.31a	1.40
Total/ Mean	45	5.37	1.25

a – means followed by the same letter are not significantly different at $\alpha = 0.05$

Soil pH class was not found to have any significant effect on winter wheat yield (Tab. 2). It was, however, noted that the grain yield harvested from neutral soils was about 5.5% higher, while that obtained from alkaline soils exceeded that harvested from acidic soils by 16.4%.

Winter wheat is a crop that best grows and produces the highest yield on structural soils that are warm and permeable, with high sorption capacity and slightly acidic or neutral reaction, but it does not tolerate acidified soils ($pH_{KCl} < 5.5$). The above observations regarding soil pH were confirmed in the present study. Noworolnik (2008) also noted that grain yield of winter wheat and winter barley was the highest from soils with a pH > 6.5 and high nutrient availability.

Table 3. Effect of available phosphorus content in soil on winter wheat yield, t ha^{-1}

Fertility class	Number of samples	Yield	Standard deviation
I, very high *	13	6.25a	1.38
II, high	7	4.83a	0.69
III, medium	10	5.01a	0.77
IV, low	11	5.06a	1.51
V, very low	4	4.88a	0.25
Total/ Mean	45	5.33	1.26

a – means followed by the same letter are not significantly different at $\alpha = 0.05$; * – based on Anonymus (1990)

The content of available phosphorus in soil was not found to have any significant effect on winter wheat yield (Tab. 3). It was, however, noted that increasing available phosphorus content resulted in an increase in grain yield, but it was irregular. In the very high fertility class, the yield was 28% higher than in the very low fertility class.

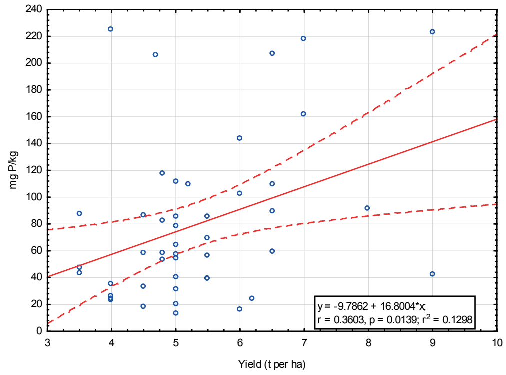

Fig. 3. Effect of available phosphorus content in soil on winter wheat yield

Gaj *et al.* (2013) found that winter wheat grain yield was significantly affected by different levels of phosphorus and potassium fertilisation, whereas Gozdowski *et al.* (2011) observed that the strongest spatial relationships were found between available phosphorus/magnesium content in soil and grain yield. Noworolnik (2008) and Bednarek *et al.* (2009) also emphasise the positive role of soil phosphorus availability for increased winter wheat yield.

Table 4. Effect of available potassium content in soil on winter wheat yield, t ha^{-1}

Fertility class	Number of samples	Yield	Standard deviation
I, very high	9	5.86a	1.62
II, high	5	4.72a	0.74
III, medium	9	5.94a	1.65
IV, low	17	5.03a	0.92
V, very low	5	5.00a	0.79
Total/ Mean	45	5.33	1.26

a – means followed by the same letter are not significantly different at $\alpha = 0.05$

Available potassium content was not found to have any significant effect on winter wheat yield (Tab. 4). It was, however, noted that this yield systematically increased from the very low fertility class towards the medium fertility class, whereas in the very high fertility class it also remained at a high level. In the medium potassium fertility class, the yield was higher by about 19%, while in the very high fertility class by 17%, compared to very low potassium fertility.

A positive effect of available soil potassium content on winter wheat yield was found by Noworolnik (2008) and Bednarek *et al.* (2009) in earlier studies. At the same time, in the case of fields investigated in their study, Gozdowski *et al.* (2011) noted that available potassium availability exhibited the highest spatial variation and they found the nature of this variation to be accidental in relation to winter wheat grain yield (compared to phosphorus and magnesium).

Table 5. Effect of available magnesium content in soil on winter wheat yield, t ha^{-1}

Fertility class	Number of samples	Yield	Standard deviation
I, very high	2	5.25a	1.77
II, high	6	5.13a	1.04
III, medium	12	5.75a	1.28
IV, low	13	5.38a	1.50
V, very low	12	5.01a	1.09
Total/ Mean	45	5.33	1.26

a – means followed by the same letter are not significantly different at $\alpha = 0.05$

Content of available magnesium in soil was not found to have any significant effect on winter wheat yield (Tab. 5). It was, however, noted that this yield systematically increased from the very low fertility class towards the medium fertility class, and a relatively high yield was found in the high and very high fertility classes. The yield harvested from soils with medium magnesium abundance was higher by 15%, while that from soils with very high magnesium levels was greater by 4.8% than the yield obtained from soils with very low content of this element.

Bednarek *et al.* (2009) found soil magnesium abundance to positively affect winter wheat grain yield. In their research, Gozdowski *et al.* (2011) observed a strong spatial relationships between soil magnesium abundance and grain yield of this crop plant. Noworolnik (2008), on the other hand, stressed that a lower variation in winter wheat and winter barley grain yield was found depending on soil magnesium content than in relation to potassium or phosphorus levels, among other things.

Table 6. Effect of nitrogen fertilisation on winter wheat yield, t ha^{-1}

N rate	Number of samples	Yield	Standard deviation
I	18	4.75a	0.78
II	24	5.34a	0.94
III	3	8.67b	0.58
Total/ Mean	45	5.33	1.26

a, b – means followed by the same letter are not significantly different at $\alpha = 0.05$

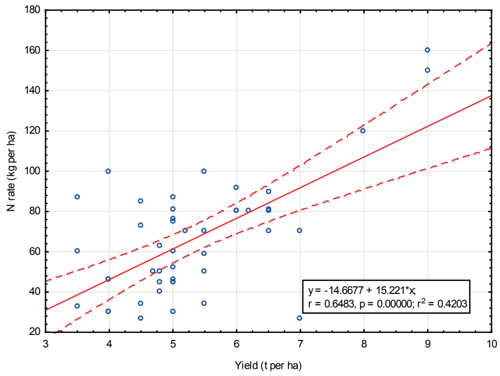

Fig. 4. Effect of nitrogen fertilisation on winter wheat yield

Nitrogen fertilisation of winter wheat had a significant effect on the increase in grain yield (Tab. 6, Fig. 4). Under the influence of the highest rate (III), this increase was significantly higher than under the influence of rates I and II. Application of the double rate resulted in a 12.4% increase, whereas in the case of the triple rate this increase was 82.5% compared to the single rate.

A positive effect of nitrogen fertilisation on increasing winter wheat grain yield has been found, among others, by Cui *et al.* (2006), Rutkowska (2006), Suwara *et al.* (2007), Podolska (2008), Kotwica *et al.* (2011), Haliniarz *et al.* (2013), and Jaskulska *et al.* (2015). A beneficial influence of nitrogen fertilisation on grain yield of this crop has also been noted by Grant *et al.* (2001), Montemurro (2009), Brzozowska *et al.* (2008), and Amato *et al.* (2013). Yield was predominantly determined by ear density and thousand grain weight, while to the least extent by the number of grains per ear. De Vita *et al.* (2007) and Podolska (2008) stressed that winter wheat grain yield and processing quality were mainly dependent on the applied nitrogen rate and nitrogen application method. Rutkowska (2006), as well as Woźniak and Stępniewska (2017), in turn, additionally found that weather conditions, in particular rainfall, had a major effect on wheat yield quantity and quality and on utilisation of fertiliser nitrogen (Bulletin 2015, Bulletin 2016).

Nitrogen fertilisation of the previous crop significantly affected winter wheat grain yield (Tab. 7). Application of the double rate resulted in a significant increase in grain yield (by about 20%), whereas application of the triple rate did not produce such effects compared to the single rate. Bednarek *et al.* (2009), Bedousscac and Justes (2010), Gürsoy *et al.* (2010), Kotwica *et al.* (2011) and Jaskulska *et al.* (2013) found nitrogen fertilisation of the previous crop to have a positive effect on winter wheat yield. Bednarek *et al.* (2009), Bedousscac and Justes (2010) as well as Gürsoy *et al.* (2010) stressed that the highest winter wheat grain yield was harvested after field pea, while the lowest one after cereal crops. The effect of nitrogen fertilisation and soil amendment on grain yield of this crop was dependent on the previous crop and it was much higher in short-term monoculture than from a stand after winter oilseed rape (Kotwica *et al.* 2011). In turn, Jaskulska *et al.* (2013) found the highest winter wheat grain yield in a stand after winter oilseed rape, while the lowest one – after maize.

Table 7. Effect of nitrogen fertilisation of the previous crop on winter wheat yield, t ha^{-1}

N rate	Number of samples	Yield	Standard deviation
I	28	5.09a	1.14
II	12	6.10b	1.44
III	5	4.90ab	0.82
Total/ Mean	45	5.33	1.26

a, b – means followed by the same letter are not significantly different at $\alpha = 0.05$

CONCLUSIONS

1. Winter wheat grain yield was positively dependent, but not always significantly, on soil textural class (in particular, the content of silt and clay particles) and soil pH class (from acidic to alkaline).
2. Content of available phosphorus, potassium and magnesium in soil was not found to have a significant effect on winter wheat grain yield. However, these nutrients were observed to positively affect grain yield of the crop plant in question.
3. Nitrogen fertilisation applied for the evaluated crop and the previous crop were found to significantly effect winter wheat grain yield.

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WPŁYW NIEKTÓRYCH WŁAŚCIWOŚCI FIZYKOCHEMICZNYCH GLEBY ORAZ NAWOŻENIA AZOTEM NA PLONOWANIE PSZENICY OZIMEJ

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Streszczenie. W badaniach środowiskowych przeprowadzonych w 45 gospodarstwach rolnych położonych w południowo-wschodniej Polsce (województwo lubelskie), w latach 2015-2016, oceniono wpływ niektórych właściwości fizykochemicznych gleby oraz nawożenia azotem na plon ziarna pszenicy ozimej. Analizę fizykochemiczną gleby wykonano metodami konwencjonalnymi w akredytowanym laboratorium Okręgowej Stacji Chemiczno-Rolniczej w Lublinie. Analizę czynnikową przeprowadzono po wcześniejszym podziale gleby na grupy granulometryczne, klasy odczynu oraz klasy zasobności w fosfor, potas i magnez przyswajalny, a także określeniu trzech dawek azotu zastosowanych pod pszenicę oraz jej przedplon: I – 0-30; II – 31-60; III – 6-90 kg $N \cdot ha^{-1}$. Odnotowano pozytywny, ale nie zawsze istotny, wpływ grupy granulometrycznej (szczególnie cząstek pylastych i ilastych) oraz klasy odczynu gleby (od kwaśnego do zasadowego) na plon ziarna pszenicy ozimej. Stwierdzono pozytywny jednak nieistotny wpływ zasobności gleby w przyswajalne formy fosforu, potasu i magnezu na plon pszenicy. Nawożenie azotem zarówno pszenicy jak i przedplonu wpłynęło istotnie na plon ziarna tej rośliny.

Słowa kluczowe: nawożenie, klasy zasobności, skład granulometryczny, odczyn gleby, pszenica ozima