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Multicomponent mineral fertilizers vs. soil fertility after winter rape cultivation

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Abstract. The subject of the study was an analysis of the impact of multicomponent mineral fertilizers manufactured in Poland and abroad, on changes in the content of available phosphorus and potassium as well as exchangeable magnesium in the soil. The study also looked at the effect of varying doses of multicomponent fertilizers produced in Belarus, Russia and Poland. The experiments were carried out in 2015–2017 in Poland. The experimental plant was winter oilseed rape. The use of compound fertilizers of Belarusian, Russian, and Polish production did not have a significant impact on changes in soil pH during rapeseed cultivation. No differences in the effect of multicomponent fertilizers on changes in the content of available potassium and exchangeable magnesium were found. In the soils of both experiments, increasing the doses of tested multicomponent fertilizers had significant influence on the increase in the amount of available potassium and did not cause any changes in the abundance of exchangeable magnesium in the soil. Generally similar effects of multicomponent fertilizers Belarusian, Russian and Polish origin on investigated soil properties were noticed.

Key words: soil, available phosphorus, available potassium, exchangeable magnesium, multicomponent fertilizers

INTRODUCTION

The availability of nutrients present in the soil and in fertilizers for plants depends on many factors and is the subject of a number of scientific studies (Nogalska et al., 2012a,b; Macolino et al., 2013; Piekarczyk et al., 1014; Mazur, Mazur, 2015; Ma et al., 2015; Singh, Ryan, 2015; Jankowski et al., 2016).

Increasingly, the producers' offers include multicomponent fertilizers, NPK, NP and PK formulas. Compound fertilizers usually have better physical properties than one-component fertilizers, which facilitates their storage and sowing and guarantees plants an even and optimal nutrient uptake. The NPK fertilizers are usually produced in the form of one granule, which contains all components in the right proportions. When using multicomponent fertilizers, the fertilizer best suited to the nutritional needs of a particular plant and the current soil conditions should be selected from the entire range of available products.

Multicomponent fertilizers should be used in a rational manner, taking into account high yields, high crop quality and the effectiveness of fertilization, while at the same time using the benefits of agrochemical fertilizers (Nogalska et al., 2012b). When selecting a fertilizer, account should be taken of the supply of nitrogen, phosphorus and magnesium in the soil. In the case of rape cultivation, it is justified to use multicomponent fertilizers, also called mixed fertilizers. Due to about 3-fold higher uptake of potassium than phosphorus by rape plants, it is recommended to use a complex fertilizer with the widest possible ratio of phosphorus to potassium (P:K) (https://polifoska.pl).

There is a wide range of multicomponent fertilizers on the market, often with similar chemical composition, and differing in the quality and digestibility of nutrients, as well as price and trade name, and coming from different producers. In the successive years, an increase in the production of multicomponent fertilizers has been recorded. In 2017, Poland's production of multicomponent fertilizers amounted to 1882 thousand tons and it was 1.7% higher compared to the previous year (Statistical Yearbook of Agriculture 2016 and 2017). In the imports of fertilizers to Poland, the share of multicomponent fertilizers in 2016 amounted to less than 37% and they were imported mainly from the east (https://www.agrofakt.pl).

The subject of the study was an analysis if the impact of multicomponent mineral fertilizers manufactured in Poland and abroad, on soil pH and changes in the content of available phosphorus, potassium and exchangeable magnesium in the soil after the rape cultivation, is similar or different. The study also looked at the effect of varying

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doses of multicomponent fertilizers produced in Belarus, Russia and Poland.

MATERIALS AND METHODS

Field experiments

Two field experiments were carried out in 2015–2017 in Lipnik (53°41'N, 14°97'E) at the Agricultural Experimental Station belonging to the West Pomeranian University of Technology in Szczecin. The experimental plant was winter oilseed rape, hybrid DK EXPLICIT. The plot area was 15 m^2. The experiments was laid out as randomized blocks in 4 replications. The soil was loamy sand (USDA 2006), the IVa bonitation class (Dz.U. 2012 poz. 1246).

Experiment I

Two factors were studied in the experiment: I factor – 4 multicomponent mineral fertilizers (NPK 6, 20, 30). i.e. two Belarusian (1 i 2), Russian (1) and Polish (Polifoska 6) fertilizers, II factor – 3 doses of fertilization: minimum, optimal, maximum. The dose of multicomponent fertilizer was determined for phosphorus, which is the most expensive ingredient. Therefore, the differences in fertilization levels – minimum, optimal and maximum – were calculated based on the demand of rape in relation to phosphorus. The minimum dose was 50% lower than the optimal dose of 1.0 dt P_2O_5 per hectare, and the maximum dose was 50% higher than that. Doses of multicomponent fertilizers were 2.5, 5.0 and 7.5 dt per hectare, respectively. Polifoska is a complex granular NPK(S) 6-20-30-(7) fertilizer in the form of light gray to dark gray or pink, even granules. The producer of the fertilizer is Zakłady Chemiczne "POLICE" S.A.-Police. This fertilizer is recommended for use in all crops: winter and spring cereals, industrial, fodder and root crops, grasslands and vegetables as well as in fruits and in horticulture.

Experiment II

The study compared two factors: I factor – three multicomponent mineral fertilizers of Belarusian (3), Russian (2) and Polish production – Polifoska 8, respectively. Applied fertilizers were characterized by the following composition of NPK(S): Belarusian (3) 8-24-24, Russian (2) 9-25-25-(4) and Polish 8-24-24-(9). II factor – 3 doses of fertilization (minimum, optimal, maximum), amounting respectively 2.0, 4.0 and 6.0 dt per hectare. Fertilization levels were calculated based on the soil phosphorus supply. The minimum dose was 50% less than the optimal dose of 1.0 dt P_2O_5 per hectare, and the maximum dose was 50% higher. Polifoska 8 is an NPK(S) 8-24-24-(9) granular fertilizer. The fertilizer has uniform light gray to dark gray or light pink granules, sized 2–5 mm, at least 92%. Polifoska 8 contains 8% nitrogen (N) in ammonium form, 24% phosphorus (P_2O_5) soluble in neutral ammonium citrate and water, i.e. available in the form of mono- and diammonium phosphate, including 21% soluble in water. The fertilizer contains 24% potassium (K_2O) soluble in water, in the form of potassium chloride and 9% sulfur dioxide (SO_3) soluble in water, in the form of sulfate. Chemical composition of Polifoska 8 is to promote good root formation and proper development. The producer of the fertilizer is Zakłady Chemiczne "POLICE" S.A.-Police (https://nawozy.eu).

In the successive years (2015, 2016 and 2017) of the experiment the same cultural practices were applied to oilseed rape. After harvesting the preceding oat crop, the stubble was turned down using a stubble cultivator. Then, after about two weeks, plowing was carried out using medium rotary plow. Just before sowing, after manual application of multicomponent fertilizers, the soil was tilled to a depth of about 8 cm with a string roller. The sowing was carried out using the ØYORD seed drill on August 26. After 14 days from the sowing of rape, when the seedlings developed at least one pair of true leaves, herbicidal spraying was performed (Metazanex 500 SC 2 dm^3 ha^{-1}). Then, about a week after herbicide, the insecticide protection was applied (Alstar Pro 100 EW 0.1 dm^3 ha^{-1}), and after the next 7 days, a supplement herbicidal treatment was carried out to volunteer cereal plants and other monocot weeds (Supero 05 EC). The last treatment performed after subsequent 7 days was a fungicide treatment with double action: fungicidal and regulating the crop stand the plants conformation (Toprex 375 EC at dose of 0.3 dm^3 ha^{-1}). In early spring with the start of vegetation (about 3–4 March), the first nitrogen fertilization was carried out in the amount of 80 kg N ha^{-1} as ammonium nitrate. The second dose of nitrogen fertilization was applied in the phase of the third internode elongation (5–7 April) at 80 kg N ha^{-1} as ammonium nitrate. Then, the fungicide treatment was performed within a few days' interval (Alstar Pro 100 EW 0.1 dm^3 ha^{-1}). In the final stage of flowering, an insecticide treatment was performed (Trion 250 EW 0.6 dm^3 ha^{-1} plus Proteus 110 OD 0.6 dm^3 ha^{-1}). The harvest was carried out using a combine harvester after reaching the full maturity of rape seeds.

Chemical analysis of soil

Soil samples were taken after winter rape harvest, using Egner-Riehm's cane from a 0–20 cm layer in accordance with the standard (PN-R-04031: 1997) from each plot. Number of field replication was four. Further preliminary soil preparation for the physico-chemical analyzes was carried out according to PN-ISO 11464 (1999).

The soil pH was determined potentiometrically in accordance with the standard (ISO 10390/1997P). Available forms of phosphorus and potassium in the soil were determined by means of the Egner-Riehm's method (Egner et al., 1960). In order to determine the exchangeable forms of magnesium content in the soil, a buffered barium chloride solution was used (pH 8.1) (ISO 13536:2002P). In the extract, the magnesium content was determined using Atomic Absorption Spectrometer Apparatus (Thermo Fisher Scientific iCE 3000 Series).

Statistical analysis

The results were statistically processed using the analysis of variance in a 2-factor random blocks design. Confidence sub-intervals (HSD) were calculated using Tukey's multiple test, assuming a significance level at $p = 0.05$. In addition, the analysis of variance with regression for the main effect of the quantitative factor – the dose of fertilizer – was performed for selected soil features. The significance of regression equations was determined using the F-Fisher-Snedecor test. Regression lines are shown on figures. Statistical analysis of results was carried out using the Statistica 10.0 software.

Soil and weather conditions

Soil from the experiment I was characterized by the following parameters: pH_{KCl} 5.2, available phosphorus (P_{avail} = 56.5), available potassium (K_{avail} = 110.9), exchangeable magnesium (Mg_{exchan} = 64.4 mg·kg^{-1}). It was the soil with an average content of analyzed macronutrients (PN-R-04023:1996, PN-R-04022:1996/Az1:2002, ISO 13536:2002P).

Soil from the experiment II was characterized by the following parameters: pH_{KCl} 5.3, P_{avail} = 47.5, K_{avail} = 97.9, $Mg_{exchang}$ = 54.4 mg·kg^{-1}. It was the soil with moderate content of available phosphorus and exchangeable magnesium and low of available potassium (PN-R-04023:1996, PN-R-04022:1996/Az1:2002, ISO 13536:2002P).

The average annual temperature value in 2015, calculated in relation to the years 1961–1990, was higer and anomaly was +2^{o}C. In addition, the humidity conditions in most of the growing season were not favorable. The hottest month turned out to be August, when temperatures in the case of winter rape cultivation are of key importance, because the optimal date of sowing this plant in Poland falls on the second half of August, and the end of summer and the beginning of autumn was dry. Soil should be very carefully prepared for sowing, and the caking resulting from drying is an extremely unfavorable phenomenon. It was not until September that temperatures have decreased, and October was even a cool month. Compared to the long-term period, the December of which year (2015, 2016) turned out to be the warmest ever recorded.

Also in the vegetative period of 2016, the temperature was higher compared to long-term average, and the humidity conditions were not very favorable. The weather pattern in January and February 2016 did not favour wintering of winter rapeseed crops. The temperature in March was rather typical; it did not differ from the average for many years, favoring the start of vegetation on winter rape plantations. However, the cold spell with precipitation deficiency occurring in April, slowed down the rate of its development and did not support abundant flowering. The biggest temperature deviations *in plus* occurred in May. However, they deepened the water shortages, as a result of which plantations were in poor condition. And although rainfall appeared in the beginning of June, it did not improve the status of the rape plantation. Also July rainfall, which was about 30% in excess of the long-term average, should be assessed rather negatively, because it increased the scattering of seeds from cracking siliques. The autumn weather pattern of the discussed year was also not favourable. Rainfall in August and September fluctuated below the standard (respectively by 60% and 30% vs. long-term average), which significantly hindered the soil tillage and sowing of winter oilseed rape.

The growing season in 2017 was only slightly warmer compared to the average of many years. In April, cold and rainy days were not conducive to the intensive growth of rape. Excessive soil moisture hindered the performance of chemical treatments on many plantations. In the second half of June, abundant rainfall deepened the poor health condition of rapeseed. Also, the harvest was made difficult due to wet ground (http://old.imgw.pl/).

RESULTS AND DISCUSSION

Comparison of multicomponent fertilizers

Multicomponent fertilizers applied in experiment A and B did not changed significantly the seed yield of winter rape. Soil from the control treatment was characterized by pH_{KCl} 5.18 and pH_{KCl} 5.19, respectively in experiment I and II. According to current standards (ISO 10390/1997P), it was acidic soil. As a result of the multicomponent fertilizers use, some acidification of the soil was noted, but the differences were not significant and the soil should still be classified as acidic (Table 1 and 2).

The winter rape is one of the most demanding crops in terms of soil fertility and fertilization (Hołubowicz-Kliza, 2014). The high nutritional requirements of plants must be covered with natural soil resources or supplemented by fertilization. After the harvest of rape, in both experiments, the content of available phosphorus in soil remained at the medium level (PN-R-04023:1996). In experiment I, one of the Belarusian fertilizers (2) should be distinguished, after application of which significantly more available phosphorus in the soil remained (50.5 mg kg^{-1}) than did after the other three fertilizers (Table 1). In the discussed fertilizer there could be a different proportion between the content of $H_2PO_4^{-1}$ and HPO_4^{-2} anions that are differently absorbed by plants. There was no difference in the effect depending on the use of any of the other three fertilizers. Fertilizers contain in their composition the same amount of P_2O_5 (20%).

Table 1. Comparison of the effect of fertilizers on changes in the pH value and the content of available phosphorus and potassium as well as exchangeable magnesium in soil, experiment I, average from 2016–2017.

Parameters	Fertilizers				$LSD_{0,05}$
	Belarusian (1)	Belarusian (2)	Russian (1)	Polifoska 6	
pH in H_2O	5.61	5.49	5.46	5.36	n.s.
pH in KCl	5.11	4.94	4.79	4.74	n.s.
		[mg kg^{-1}]			
Available phosphorus / P_{avail}	45.6	50.5	45.8	47.9	4.84
Available potassium / K_{avail}	119.8	116.2	118.0	112.6	n.s.
Exchangeable magnesium / Mg_{exchan}	52.2	53.5	49.2	49.8	n.s.
Sum	217.6	220.2	213.0	210.3	-

n.s. – not significant difference

Table 2. Comparison of the effect of fertilizers on changes in the pH value and the content of available phosphorus and potassium as well as exchangeable magnesium in soil, experiment II, average from 2016–2017.

Parameters	Fertilizers			$LSD_{0.05}$
	Belarusian (3)	Russian (2)	Polifoska 8	
pH in H_2O	5.63	5.42	5.49	n.s.
pH in KCl	4.92	4.79	4.68	n.s.
		[mg kg^{-1}]		
Available phosphorus / P_{avail}	48.8	46.5	51.2	n.s.
Available potassium /K_{avail}	98.3	99.6	104.7	n.s.
Exchangeable magnesium / Mg_{exchan}	48.9	48.2	51.5	n.s.
Sum	196.0	194.3	207.4	-

n.s. – not significant difference

The use of three fertilizers in the second experiment, i.e. Belarusian (3), Russian (2), and Polifoska 8, containing the same amount of phosphorus (25% P_2O_5), resulted in no difference in the effect of available phosphorus content in the soil after winter rape harvest (Table 2).

The soils under the experiments varied in terms of available potassium content. In experiment I, the soil contained 110.9 mg K kg^{-1} and it was a medium-abundant soil, in experiment II, the amount was 97.9 mg K kg^{-1} which classifies it in the low-abundance range. The introduction of seven fertilizers into the soil resulted in an increase in the content of available potassium, but it did not change its rating in terms of K supply. Spychalski et al. (2016) reported that the highest content of analyzed potassium forms was found in soils from plots where complex NPK fertilization was applied. The four fertilizers in this study contained in their composition the same amount of potassium (30% K_2O), while the other three contained potassium in the amount of 24% K_2O, but it had no effect on changes in the amount of available soil potassium in either experiment (Table 1 and 2) .

The content of exchangeable magnesium in the soil from both experiments was on similar levels in the range of 48.2–53.5 mg Mg kg^{-1} (Table 1 and 2). The applied compound fertilizers did not contain magnesium and, as a result of their introduction into the soil, there has been no variation in the amount of exchangeable form of this element in the soil.

Uniform action of the applied multicomponent fertilizers is more visible if we compare the sum of the contents of the analyzed macronutrients in the soil. In experiment I, these values range from 210.3 to 220.2 mg kg^{-1}, the difference is only 4.7%, and in experiment II, the difference is 6.7%.

Comparison of the effect of multicomponent fertilizers doses

The effect of different doses was similar for all fertilizers investigated in the experiments – interactions were not significant. In this situation only main effects were presented in the tables and figures.

In experiment I, as a result of variation in the dose of multicomponent fertilizers, there was no change in the amount of available phosphorus in the soil. It remained at the level of 46.8 to 48.3 mg kg^{-1}, indicating that an increased amount of phosphorous introduced with the fertilizer was taken up by plants (Gaj, 2013). The effect may be

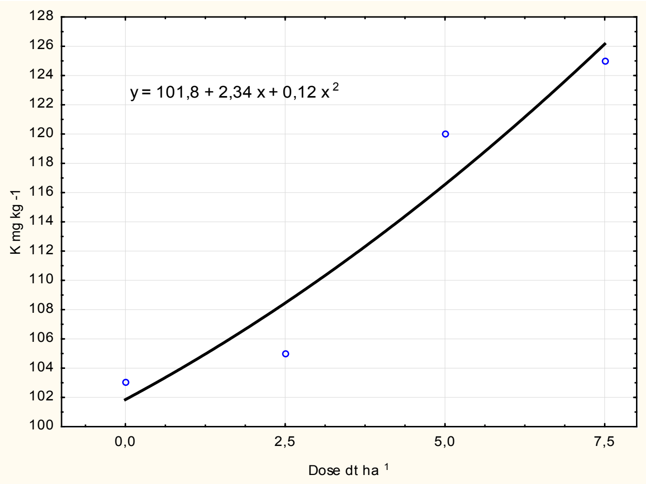

Figure 1. Regression equation between dose of fertilizer and available potassium content in the soil, experiment I.

Table 3. Comparison of the effects of fertilizers doses on changes in the pH value and the content of available phosphorus and potassium and exchangeable magnesium in soil, experiment I, average from 2016–2017.

Parameters	Dose [dt ha^{-1}]				$LSD_{0.05}$
	0	2.5	5.0	7.5	
pH in H_2O	5.60	5.43	5.48	5.53	n.s.
pH in KCl	5.18	4.88	4.90	4.89	n.s.
	[mg kg^{-1}]				
Available phosphorus – P_{avail}	46.8	46.8	47.4	48.3	n.s.
Available potassium – K_{avail}	103.4	105.1	119.7	125.3	15.39
Exchangeable magnesium – Mg_{exchan}	54.0	50.7	50.0	52.8	n.s.
Sum	204.2	202.6	217.1	226.4	-

n.s. – not significant difference

Table 4. Comparison of the effects of fertilizers doses on changes in the pH value and the content of available phosphorus and potassium and exchangeable magnesium in soil, experiment II, average from 2016–2017.

Parameters	Dose [dt ha^{-1}]				$LSD_{0.05}$
	0	2.0	4.0	6.0	
pH in H_2O	5.99	5.69	5.47	5.38	n.s.
pH in KCl	5.19	4.98	4.67	4.75	n.s.
	[mg kg^{-1}]				
Available phosphorus – P_{avail}	41.7	45.5	48.9	52.1	6.21
Available potassium – K_{avail}	85.9	90.2	94.9	117.5	22.27
Exchangeable magnesium – Mg_{exchan}	46.5	50.6	47.5	50.5	n.s.
Sum	174.1	186.3	191.3	220.1	

n.s. – not significant difference

caused by phosphorus compounds being strongly bound by the soil and changed into non-available forms.

In experiment II, variation in the dose of multicomponent fertilizers was reflected in a significant increase in the amount of phosphorus available for plants to 52.1 mg P kg^{-1} of soil. The optimal dose resulted in an increase in the amount of available phosphorus in the soil by 17.3%, and at the maximum dose – by 24.9% as compared to the content in non-fertilized soil. Results presented in Figure 2 indicate that increasing the fertilizer dose by 50% resulted in

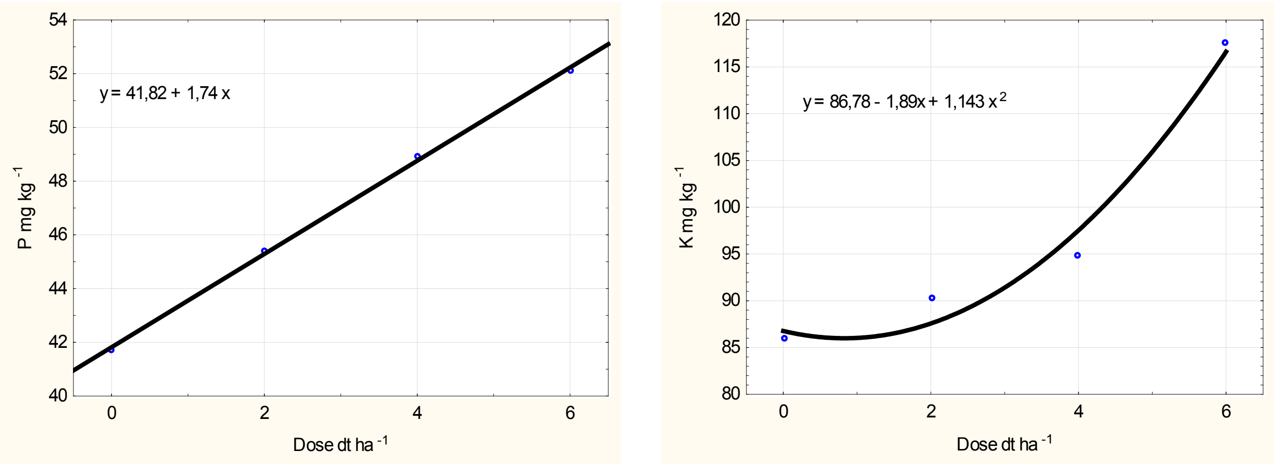

Figure 2. Regression equation between dose of fertilizer and available phosphorus and potassium content in the soil, experiment II.

a proportional increase in the phosphorus content available in the soil, described by linear regression line. The excess of introduced phosphorus was not completely absorbed by plants (Table 4 and Figure 2).

Unlike phosphorus, potassium is almost completely bound to the mineral part of the soil, which is a factor that makes its assimilation to plants subject to different rules (Grzebisz et al., 2004). The dose of compound fertilizers had significant influence on the amount of available potassium in the soil. In both experiments, using fertilization at the maximum level, the soil was brought up to an available potassium content of 125.3 and 117.5 mg K kg^{-1}, i.e. to an average K supply (Table 3 and 4). In experiment I, the effects of fertilizers were not proportional to the size of the dose and could by described by second degree line (Figure 1). Analyzing the results from experiment II, the stronger effect of higher fertilizers dose was observed (Figure 2). Using successively the minimum, optimum and maximum doses, an increase in the amount of potassium available in the soil by 5.0%, 10.5% and at the maximum dose by 36.8% in comparison to the K supply of non-fertilized soil, was obtained (Table 4). The result in both experiments indicates that the excess of introduced potassium was not completely absorbed by plants.

Based on the results of experiments with rape and triticale, Ciubak (2009) reports that doubling the doses of multicomponent mineral fertilizers also increased the content of available phosphorus and potassium in soil as compared to single doses.

Diversification of doses of the tested multicomponent fertilizers did not alter the abundance of exchangeable magnesium in soils from both experiments (Table 3 and 4).

CONCLUSIONS

1. The use of compound fertilizers of Belarusian, Russian, and Polish production did not have a significant impact on changes in soil pH in both experiments during rapeseed cultivation.

2. In the experiments carried out, no differences in the performance of the seven multicomponent fertilizers regarding changes in the content of available phosphorus in the soil, were found. However, one of the Belarusian fertilizers used in experiment I should be distinguished, after application of which significantly more available phosphorus remained in the soil.

3. No differences in the effect of multicomponent fertilizers on changes in the content of available potassium and exchangeable magnesium were found.

4. Results obtained in the experiment with four multicomponent fertilizers (Belarusian, Russian and Polish) indicate that the increased amount of phosphorus introduced with fertilizers was taken up by plants without causing its content to increase in the soil. In the experiment with three multicomponent fertilizers, the differentiation of their dose was reflected in a significant increase in the amount of phosphorus available for plants.

5. In the soils of both experiments, increasing the doses of tested multicomponent fertilizers had significant influence on the increase in the amount of available potassium and did not cause any changes in the abundance of exchangeable magnesium in the soil.

6. Generally similar effects of multicomponent fertilizers Belarusian, Russian and Polish origin on investigated soil properties were noticed.

REFERENCES

Ciubak J., 2009. Wpływ wieloskładnikowych nawozów mineralnych na wielkość i jakość plonów roślin przeznaczonych na cele energetyczne oraz niektóre wskaźniki żyzności gleby. Publisher West Pomeranian University of Technology in Szczecin, Poland: Dissertation and Monographs, 95 pp.

Dz.U. 2012 poz. 1246. Rozporządzenie Rady Ministrów z dnia 12 września 2012 r. w sprawie gleboznawczej klasyfikacji gruntów.

Egner H., Riehm H., Domingo W., 1960. Untersuchungen über die chemische Bodenanalyse als Grundlage für die Beurteilung des Nährstoffzustandes der Böden. II. Chemische Extraktionsmethoden zur Phosphor- und Kaliumbestimmung. Kungliga Lantbrukshögskolans Annaler, 26: 199-215.

Gaj R., 2013. Efektywne wykorzystanie składników mineralnych z nawozów we współczesnym rolnictwie. CDR w Brwinowie oddział w Poznaniu, ISBN 978-83- 60232-52-1.

Grzebisz W., Diatta J.B., Popp T., Szczepaniak W., 2004. Potas w produkcji roślinnej. International Potash Institute Basel/ Switzerland, 90 pp., ISBN 3-9801577-3-3.

Hołubowicz-Kliza G., 2014. Uprawa rzepaku. IUNG Poland, 151 pp., ISBN 978-83-7562-177-8.

ISO 10390/1997P Soil quality - Determination of pH.

ISO 13536:2002P Soil quality - Determination of the potential cation exchange capacity and exchangeable cations using barium chloride solution buffered at pH = 8,1.

Jankowski K.J., Hulanicki P.S., Krzebietke S., Żarczyński P., Hulanicki P., Sokólski M., 2016. Yield and quality of winter oilseed rape in response to different systems of foliar fertilization. Journal of Elementology, 21(4): 1017-1027, doi: 10.5601/jelem.2016.21.1.1108.

Ma B-L., Biswas D.K., Herath A.W., Whalen J.K., Ruan S.Q., Caldwell C., Earl H., Vanasse A., Scott P., Smith D.L., 2015. Growth, yield, and yield components of canola as affected by nitrogen, sulfur, and boron application. Journal of Plant Nutrition and Soil Science, 178: 658-670, doi: 10.1002/ jpln.201400280.

Macolino S., Lauriault L.M., Rimi F., Ziliotto U., 2013. Phosphorus and potassium fertilizer effects on alfalfa and soil in a non-limited soil. Agronomy Journal, 105(6): 1613-1618.

Mazur Z., Mazur T., 2015. Influence of long-term fertilization on phosphorus, potassium, magnesium, and sulfur content in soil. Polish Journal of Environmental Studies, 24(1): 185-190, doi: 10.15244/pjoes/29203.

Nogalska A., Czapla J., Skwierawska M., 2012a. The effect of multi-component fertilizers on spring triticale yield, the content and uptake of macronutrients. Journal of Elementology, 17(1): 95-104, doi: 10.5601/jelem.2012.17.1.09.

Nogalska A., Czapla J., Sienkiewicz S., Skwierawska M., 2012b. The effect of multi-component fertilizers on the yield and mineral composition of winter wheat and macronutrient uptake. Journal of Elementology, 17(4): 629-638, doi: 10.5601/jelem.2012.17.4.06.

Piekarczyk M., Jaskulska I., Gałęzewski L., Kotwica K., Jaskulski D., 2014. Productivity of winter oilseed rape and changes in soil under the influence of fertilization with the use of ash from straw. Acta Scientiarum Polonorum – Agricultura, 13(3): 45-56.

PN-R-04022:1996/Az1:2002. Agricultural chemical analysis of the soil – Determination of available potassium in mineral soils.

PN-R-04023:1996. Agricultural chemical analysis of the soil – Determination of available phosphorus in mineral soils.

PN-R-04031:1997. Soil chemical and agricultural analysis – Sampling.

PN-ISO 11464:1999. Soil quality – Pre-treatment of samples for physico-chemical tests.

Singh B., Ryan J., 2015. Managing Fertilizers to enhance soil health. First edition, IFA, Paris, France, Copyright IFA, 24 pp.

Spychalski W., Głowacki A., Woszczyk M., 2016. Potassium contents in post-mining soils after 35-year-long field experiment: the effect of physical-chemical composition of soils. Journal of Research and Applications in Agricultural Engineering, 61(4): 160-163.

Statistical Yearbook of Agriculture 2016. Central Statistical Office Warszawa Poland, 460 pp.

Statistical Yearbook of Agriculture 2017. Central Statistical Office Warszawa Poland, 495 pp.

USDA 2006. United States Department of Agriculture-Handbooks: 690 pp.

https://nawozy.eu/ [accessed 04.10.2018].

http://old.imgw.pl/ [accessed 04.10.2018].

https://polifoska.pl/nawozy/polifoska-5 [accessed 07.10.2018].

https://www.agrofakt.pl/ceny-nawozow-mineralnych-czy-beda-stabilne/ [accessed 07.10.2018].

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