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EFFECT OF AMMONIUM SULFATE AND PHOSPHOGYPSUM APPLICATION ON NUTRIENTS DYNAMICS AND ACIDITY OF BLACK SOIL

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The problem of phosphogypsum accumulation in dumps of chemical plants has been an urgent problem for several decades. The ecological situation is aggravated by the fact that more and more areas are allocated for its conservation. A negative point in the application of phosphogypsum is the intake of radionuclides and fluorine into the soil and plants, small particles could be dispersed to the atmosphere by wind. But given the presence of macro-, mezo- and microelements in it and the high price of mineral fertilizers, it is now considered as a good fertilizer and ameliorants, especially for alkaline soils. The goal of the research was to study the effectiveness of phosphogypsum application (from Sumykhimprom) and ammonium sulfate in increasing doses of nitrogen 50–150 on the dynamics of nitrogen, phosphorus, potassium, calcium and hydrolytic acidity of typical middle loam black soil. An increase in nitrogen led to growing the content of hydrolyzed, nitrate and ammonium forms of nitrogen in the soil. The maximum availability of N-NO_3 in the soil is characteristic for the first period of sampling, in the tillering stage. At this period, the maximum difference is observed between the control and fertilized variants of the experiment. The application of phosphogypsum with N_{150} almost threefold increased the content of nitrates in the soil. Variants with lower doses of nitrogen also affect the accumulation of nitrates in layers 0–20 and 20–40 cm. After harvesting, an insignificant difference was found between the control and fertilized variants (except for N_{150}) with a general decrease in the level of nitrate availability to 0.1–0.2 mg/100 gm of soil. The impact of fertilizers was less on the content of labile phosphorus and exchangeable potassium. A year after fertilization, a significant increase in the value of hydrolytic acidity is observed in the fertilized variants.

It is especially noticeable at a dosage with nitrogen of 120–125. In these variants, the hydrolytic acidity in both the arable and subsoil layers exceeds 4 mmol$^+$/100 gm of soil. Changes in the content of water-soluble calcium are insignificant which can be explained by the fact that the solubility of calcium sulfate is not high enough and it takes more time for calcium to appear in an ionic form.

Key words: *ammonium nitrogen, nitrate nitrogen, hydrolyzed nitrogen, ammonium sulfate, phosphogypsum, mobile phosphorus, exchangeable potassium, hydrolytic acidity.*

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Introduction. The production of phosphate fertilizers is a complex technological process. The main raw materials in the world for its are apatites and phosphorites. In apatites there are some chemical components as fluorine and uranium which constrain the use of phosphogypsum as a fertilizer that is waste of thecnological processes. Phosphogypsum accumulates in chemical plants every year and this can affect the increase in greenhouse gas emissions (Kumar et al., 2020; Yuan et al., 2018). If it gets into lakes, rivers, bogs, seas and oceans, it causes large-scale environmental disasters (Zrelli et al, 2018).

Phosphate raw materials from different countries may differ in the content of chemical elements and radionuclides, its long-term use should be controlled by measuring radionuclides, phosphorus and sulfur in water basins and groundwater (Hilton, 2020; Tirado & Allsoop, 2012; Papastefanou et al., 2006; Olszewski et al., 2016; Tucher et al., 2018). Each country has its own standards for the content of toxic substances in fertilizers and there are also standards written for phosphogypsum.

The application of one ton of phosphogypsum as fertilizer, 265 kg of calcium, 215 kg of total sulfur, 20 – phosphorus oxide and 9.8 kg of silicon oxide are supplied to the soil (Korobka, et al., 2016). That is, phosphogypsum can be evaluated both as a fertilizer and an ameliorant.

Since in the near future a shortage of phosphorus raw materials is predicted, therefore, attention to phosphogypsum as a source of phosphorus does not subside (Gazzar-El, 2006; Mahmoud et al., 2020). The effectiveness of phosphogypsum of more than fifty crops has already been studied since the 80s of the last century and for the last three years it was enough to conduct research on the creation of sulfur-containing fertilizers on its basis.

Phosphogypsum is most effective on sodium-enriched alkaline soils, and it has also been proven to be effective on irrigated land (Belal et al., 2019). On degraded lands, it appears as a valuable source of phosphorus and sulfur, which is important for oil and grain crops. On meadow black soil, its advantage in autumn application compared to ammonium phosphate has been proven and an aftereffect on subsequent crops of crop rotation is also observed (an increase in alfalfa yield was 47 %) (Hilton, 2020). When phosphogypsum was used on ordinary carbonate black soil of 4 t/ha, an increase in the phosphorus content by almost two times and sulfur of the sulfate form by ten times were observed.

The effectiveness of phosphorus fertilizers, the behavior of phosphorus in the soil depends precisely on the physicochemical characteristics, granulometric and mineralogical structure of the soil (Mühlbachová et al., 2018). German scientists have found that the regulation of pH by liming can reduce the rates of phosphorus fertilizers than the recommended ones. In soils where phosphorus has been reduced or not applied in recent decades, the availability of phosphorus becomes too low for optimal crop production (Tucher et al., 2018).

The patented methods of rolling phosphogypsum on urea in the production of granular fertilizers also show its effectiveness in preventing nitrogen loss from fertilizer and soil, reduces the fertilizer caking ability, and fertilizer granules become more durable (Deng et al., 2009; Mullahodzaev & Olifson, 2012). Phosphogypsum has also been studied in combination with ammonium nitrate and urea to create nitrogen-containing sulfur fertilizers in various ratios (Vashishtha et al. 2010; Mamataliyev, 2017).

The use of phosphogypsum for composting pig manure with corn stalk increases nitrous oxide (N_2O) emissions, but significantly reduces ammonia emissions, thus increasing the mineral content and total nitrogen in the compost (Li et al., 2018). The effect of phosphogypsum in the composting of sewage sludge was manifested in a decrease in ammonia and methane emissions and an increase in nitrous oxide. The positive effect of adding phosphogypsum on nitrogen retention in compost has been proven (Li et al., 2018).

The application of phosphogypsum together with lime gives a double effect, lime reduces the acidity of phosphogypsum (Carvalho & Nancente, 2014). Phosphogypsum, in comparison with the applied mineral fertilizer with phosphorus and sulfur content, is more effective in reducing the negative effect of exchangeable aluminum in the soil, but the effect depends on the type of research soil (Bouray et al., 2020). The effect of phosphogypsum and similar concentrations in soluble fertilizers may depend on the balance between calcium and sulfate ions. The high general solubility of phosphogypsum has been established, and as an additive to mineral fertilizers, it could increase microbiological activity in order to contribute to the rapid transformation of phosphorus into more accessible forms (Nayak et al., 2011).

The co-application of limestone and phosphogypsum significantly increases the calcium content throughout the soil profile. Liming maintains high magnesium levels with and without phosphogypsum, and the same trend has been observed for organic matter. In aftereffect, significant accumulation of sulfate is observed for the application of phosphogypsum (Nayak et al., 2011). The co-application of limestone and gypsum increased the yield of soybeans and sorghum, their nutrition with calcium.

Phosphogypsum had no significant effect on increasing the yield of soybeans in the case of no-till (Costa & Crusciol, 2016). The combined use of limestone and phosphogypsum improved the physicochemical properties of the soil and increased the yield of soybeans.

An important factor is taking into account the nutritional requirements of plants, the ratio of nutrients in fertilizer. In extreme weather conditions, rational fertilization increases the stress resistance of plants. As a result of the introduction of concentrated fertilizers in recent years and an increase in the yield of high-tech crops, a decrease in the content of sulfur in the soil has been established, and the content of this element in soil affects the formation of protein and stress resistance of plants, it is proved by the experimental data of scientists of the NSC "Institute of Soil Science and Agrochemistry Research named after O. N. Sokolovsky". Root application of ammonium sulfate increases the corn yield and resistance to abiotic stress (Gladkih et al., 2016).

Ammonium sulfate as a fertilizer also has disadvantages because it belongs to the third hazard class for peroral and inhalation toxicity, it can also cause irritation to the eyes and skin (Lepeshkin et al., 2010). It has been established that in the conditions of humid Polissia and a high level of groundwater, it is not recommended to apply ammonium sulfate of more than 90–100 kg in nitrogen, therefore fertilizer causes the migration of zinc and copper as a result of the reaction of the soil environment. The introduction of ammonium sulfate leads to an increase in the content of nitrate nitrogen in the soil (Ferrari et al., 2015).

Using of ammonium sulfate, such essential elements for plants, such as nitrogen, sulfur, cobalt, copper, zinc, iron, manganese, lead, potassium, nickel, chromium are supplied (Skwierawska et al., 2008). The application of ammonium sulfate 200 kg/ha nitrogen increased the content of copper and sulfur in toxic doses, but enlarged the content of organic matter (Tkachuk, 2017). At the same time, the application of ammonium nitrate increased the content of lead in the soil, ammonium chloride –content of chlorine.

The use of phosphogypsum as a suspension is effective relative to powdery which improve winter wheat harvest (Tarhoniy & Anyshynets, 1998). The use of phosphogypsum without irrigation was more effective compared to the variants with irrigation because of decreasing of exchangeable sodium in the CEC, the effective dose of ameliorant in this regard was 6 t/ha. The pH decreased with the application of the ameliorant by 0.11–0.23, depending on the dose, 1.4–6 t/ha (Makarova, 2013).

Chemical amelioration with phosphogypsum leads to changes in granulometric composition, increasing in the percentage of physical sand and, accordingly, decreasing physical clay, that is a positive effect for heavy soils structuring (Makarova et al., 2020; Mykhaylyuk & Kozachenko, 2009).

Increasing the potential of grain yield can be regulated by the application of fertilizers, ameliorants, growth regulators, and pesticides (Shvartau & Mykhalska, 2016). Studying the behavior of ions in soil under various conditions will provide information and dosage recommendations and predict the next cycle.

Materials and research methods. The experiment has been carried out in the field of the educational, scientific and industrial complex of Sumy National Agrarian University in 2014–2017. The soil is typical deep black soil, low-humus middle loam on loess. Humus content is 4.1 % according to Tiuryn, pH_{KCl} – 6.7, hydrolytic acidity according to Kappen – 2.62 mg-equ., content of exchangeable ammonium with Nesler's reagent – 1.30, content of labile phosphorus according to Chirikov – 10.59, exchangeable potassium according to Chyrykov – 22.5, $N\text{-}NO_3$ by colorimetric method – 1.4 mg/100 g of soil. Before the beginning of the experiment, a compensatory sowing of buckwheat was carried out. The repetition was 3, the square of each plot was 36 m^2.

Sowing of spring barley was carried out on April 13–20. Sampling was carried out with a Kachynskyi's drill to a depth of 0–20 and 20–40 cm in the main stages of plant development: in the germination stage, bloom stage and at the time of harvest. The content of alkaline-hydrolyzed nitrogen was determined by

Kornfield, the content of nitrate nitrogen was determined colorimetrically with phenoldisulfonic acid, ammonium nitrogen – colorimetrically with Nesler's reagent, water-soluble calcium by a flame photometer method, the content of labile phosphorus and exchangeable potassium according to Chyrykov. All obtained experimental data were processed statistically by Dospiekhov.

Phosphogypsum from chemical plant "Sumykhimprom" was taken near the village of Tokari, Sumy district, Sumy oblast, Ukraine. Phosphogypsum was applied in autumn of 2014, 2015, and 2016. Ammonium sulfate with phosphogypsum were mixed in a ratio of 1 : 2 and there was made a granulate that contains total nitrogen 14.3 %, phosphorus oxide 1.0 %, calcium sulfate 24 %, which was used for the variant 2, for further variants, the ammonium content was added more under the research program.

The experiment scheme is as follows: 1. Control. 2. Phosphogypsum (PG)+ N_{50}. 3. PG+N_{75}. 4. PG+N_{100}. 4. PG+N_{125}. 5. PG+N_{150}. Method of spring barley cultivation is generally accepted for the area.

Results. It is known that the content of mineral nitrogen in the soil depends on many indicators, among which the main role is played by microbiological activity in the soil, that ensures the transformation of nitrogen-containing compounds into available mineral forms of nitrogen. The content of nitrate nitrogen is very dynamic, the content of alkaline-hydrolyzed and ammonium nitrogen is more stable. The table 1 shows the results of determining the content of hydrolyzed nitrogen in layers of 0–20 and 20–40 cm in all variants of the experiment.

Table 1

Content of hydrolized nitrogen in the soil (mg/100 g), in average 2015–2017

Variant	Depth of soil sampling, sm	Hidrolized nitrogen during barley plants development		
		tillering	blooming	harvesting
Control	0–20 20–40	15.46 14.96	14.03 14.00	8.46 8.00
PG + N_{50}	0–20 20–40	16.05 17.01	15.01 14.00	9.02 8.01
PG + N_{75}	0–20 20–40	17.01 17.00	14.09 14.05	10.02 10.00
PG + N_{100}	0–20 20–40	17.09 16.99	16.04 15.03	10.08 10.00
PG + N_{125}	0–20 20–40	18.02 19.00	15.05 14.06	10.09 10.01
PG + N_{150}	0–20 20–40	19.00 18.99	13.04 14.04	8.50 8.05
HIP_{05} 0–20 cm 20–40 cm		0.5 0.3	0.5 0.35	0.6 0.4

The maximum content of hydrolyzed nitrogen in the soil is observed in the tillering stage and was in the range of 14.96–19.00 mg/100 g of soil. At this time, the difference between the variants of the experience is clear and signifacant. Moreover, the nitrogen content in the soil increases according to nitrogen dose.

During the vegetation of barley, the content of hydrolyzed nitrogen decreases by 8–10 mg/100 g of soil. At the same time, the difference between some variants is smoothed out, which is due to both the microbiological activity of the soil and the activity of the plants root system. Such tendency is typical for both arable and subsoil soil layers.

The content of alkaline-hydrolyzed nitrogen is significantly related to the amount of the ammonium form of this element. As you know, the processes of transformation of this form of nitrogen cause the accumulation of ammonium ion in the soil. The table 2 shows the results of determination of NH_4^+-N in the soil in average for three years in layers of 0–20 and 20–40 cm.

Table 2

Content of ammonium nitrate in the soil (mg/100 g), in average 2015–2017

Variant	Depth of soil sampling, sm	NH_4-N during barley plants development		
		tillering	blooming	harvesting
Control	0–20 20–40	4.33 4.36	2.36 2.43	1.26 1.33
PG + N_{50}	0–20 20–40	5.53 5.20	2.90 2.39	1.39 1.20
PG + N_{75}	0–20 20–40	6.22 6.20	2.69 2.70	1.39 1.29
PG + N_{100}	0–20 20–40	6.79 6.73	2.59 2.79	1.10 1.39
PG + N_{125}	0–20 20–40	7.28 7.20	3.19 3.00	1.89 1.80
PG + N_{150}	0–20 20–40	7.55 7.50	3.09 3.00	1.49 1.70
HIP_{05} 0–20 cm 20–40 cm		0.9 0.5	0.10 0.15	0.11 0.96

From the data in the table, it can be seen that the dynamics of the content of ammonium nitrogen in the soil is characterized by the same tendency that were observed for hydrolyzed nitrogen.

It is revealed that the maximum content of NH4-N is typical for the first period of sampling in spring (tillering phase). At this time, the amount of ammonium nitrogen in the soil in the control variant was 4.33 mg/100 g of soil and in phosphogypsum+N_{150} – 7.55 mg/100 g of soil. During the growing season, the supply of plants with ammonium nitrogen significantly decreases, and the difference between some variants also decreases.

The content of ammonium nitrogen after harvesting of spring barley was only 1.10–1.89 mg/100 g of soil. However, the differences between the variants are very insignificant. The described patterns are typical for both the arable and subsoil layers. This indicates that the influence of annual conventional tillage to a depth of 25 cm led to the formation of the arable layer, where the processes of transformation of nitrogen-containing compounds occured with the same intensity. Data on the content and dynamics of nitrate nitrogen in soil are shown in the table 3.

Table 3

Content of nitrogen nitrate in the soil (mg/100 g), in average 2015–2017

Variant	Depth of soil sampling, sm	N-NO_3 during barley plants development		
		tillering	blooming	harvesting
Control	0–20 20–40	0.49 0.47	0.20 0.20	0.10 0.10
PG + N_{50}	0–20 20–40	0.63 0.63	0.23 0.21	0.12 0.12
PG + N_{75}	0–20 20–40	0.87 0.87	0.28 0.27	0.12 0.12
PG + N_{100}	0–20 20–40	0.98 0.90	0.27 0.26	0.15 0.15
PG + N_{125}	0–20 20–40	1.19 1.10	0.30 0.30	0.17 0.17
PG + N_{150}	0–20 20–40	1.39 1.30	0.33 0.35	0.27 0.28
HIP_{05} 0–20 cm 20–40 cm		0.15 0.11	0.09 0.05	0.05 0.05

For NO_3-N, the same tendency as for hydrolyzed and ammonium nitrogen was noted, but at a different quantitative level. The maximum supply of nitrate nitrogen to the soil is typically for the first period of sampling, in the tillering stage. At this time, the maximum difference is observed between the control and fertilized variants of the experiment. Application of phosphogypsum with N_{150} increased the content of nitrates in the soil almost threefold. Variants with lower nitrogen doses also affect the accumulation of nitrates in the soil for both soil layers, but to a lesser extent.

A determination of nitrates in soil at the harvest time concluded that there are insignificant differences between the control and fertilized variants (except for with last variant +N_{150}) with a general decrease in the level of nitrate to 0.1–0.2 mg/100 g of soil.

Result of analyzing the content of labile forms of phosphorus in the soil in the arable and subsoil layers are shown in chart 4. As known, the influence of the root system of plants on soil phosphates, which increases with sufficient nitrogen nutrition. Maximum content of labile forms of phosphorus in the soil is observed during the tillering stage. It was set insignificant differences in the availability of phosphorus in the soil when phosphogypsum is applied along with nitrogen fertilization. Some noticeable differences are observed in the soil layer 20–40 cm.

Table 4

Content of labile form of phosphorus in the soil (mg/100 g), in average 2015–2017

Variant	Depth of soil sampling, sm	P-P_2O_5 during barley plants development		
		tillering	blooming	harvesting
Control	0–20 20–40	10.3 11.1	7.5 8.6	5.3 5.4
PG + N_{50}	0–20 20–40	10.3 12.5	8.2 8.5	4.9 5.7
PG + N_{75}	0–20 20–40	10.3 12.6	8.3 8.5	6.5 5.2
PG + N_{100}	0–20 20–40	11.2 13.6	8.5 8.8	6.4 5.7
PG + N_{125}	0–20 20–40	10.9 13.4	8.3 8.8	6.4 5.9
PG + N_{150}	0–20 20–40	11.0 13.2	8.5 8.7	6.5 5.9
HIP_{05} 0–20 cm 20–40 cm		0.62 0.51	0.59 0.43	0.50 0.46

Over time, the amount of labile phosphates in the soil decreases. During the bloom stage, the phosphorus content in the soil layers 0–20 and 20–40 cm ranges from 7.5 to 8.8 mg/100 g of soil, depending on the variants. No difference was found between the variants according to the content of this element.

It should be noted that during the growing season in 2015, the arable and subsoil layers of the soil were fairly evenly provided with labile forms of phosphorus. This is probably due to regular tillage, which was carried out annually and ensured the formation of a uniform layer with the same supply of available phosphorus. By the harvesting, the phosphorus content is slightly reduced, but no differences between the variants are observed. The table 5 shows the results of determining exchangeable potassium in the soil.

Table 5

Content of exchangeable potassium in the soil (mg/100 g), in average 2015–2017

Variant	Depth of soil sampling, sm	$K\text{-}K_2O$ during barley plants development		
		tillering	blooming	harvesting
Control	0–20 20–40	15.6 13.4	8.1 6.7	11.8 11.8
PG + N_{50}	0–20 20–40	15.4 12.5	8.1 6.5	12.3 12.3
PG + N_{75}	0–20 20–40	15.5 15.2	7.3 8.0	12.0 11.7
PG + N_{100}	0–20 20–40	15.7 15.4	11.3 8.1	12.7 12.2
PG + N_{125}	0–20 20–40	15.7 15.8	10.0 8.0	13.0 12.7
PG + N_{150}	0–20 20–40	15.6 15.4	9.4 7.0	13.4 13.3
HIP_{05} 0–20 cm 20–40 cm		0.21 0.15	0.62 0.41	0.38 0.29

Despite the fact that typical black soil is a soil well supplied with labile forms of potassium, there is a very intensive absorption of it by plants during the growing season. As can be seen from the data in the table 5, the content of exchangeable potassium in the soil in the first period of sampling, was expressed in significant values – up to 16 mg/100 g of soil. However, there are no differences between the variants.

Over time, the content of labile potassium in the soil decreases severely and at the bloom stage in the 0–20 cm layer is 8.1–11.3 mg/100 g of soil. In the soil layer of 20–40 cm, the content of labile forms of potassium is lower than in the layer of 0–20 cm, fluctuations in the content are almost absent.

After harvesting, the amount of labile potassium increases. This can be explained by the intense absorption of this element in the middle of the growing season of spring barley. It is also interesting to note that there is a tendency to an increase in the potassium content in both the arable and subsoil layers in the variants using phosphogypsum with $N_{100\text{-}150}$. In our opinion, the insignificant stimulating effect of fertilizers in relation to potassium is justified by the defixing effect of calcium on soil potassium, which causes a slight increase in its content in the soil.

Table 6 shows the results of determining the hydrolytic acidity and water-soluble calcium after harvesting spring barley on average for three years of research.

Table 6

Hydrolytic acidity and content of water-soluble calcium at harvesting time of spring barley in the soil, in average 2015–2017

Variant	Depth of soil sampling, sm	H_H, mg-equ/100 g	Ca water-soluble, mg/100 g
Control	0–20 20–40	2.89 3.04	5.5 5.0
PG + N_{50}	0–20 20–40	2.85 3.37	5.5 5.0
PG + N_{75}	0–20 20–40	2.99 3.37	5.0 4.5
PG + N_{100}	0–20 20–40	2.98 3.94	4.5 4.0
PG + N_{125}	0–20 20–40	3.85 4.20	4.5 4.0
PG + N_{150}	0–20 20–40	3.94 4.11	4.0 4.0
HIP_{05} 0–20 cm 20–40 cm		0.19 0.17	0.4 0.4

After fertilization, a significant increase in the value of hydrolytic acidity is observed in the fertilized variants. It is especially noticeable at a dosage with nitrogen of 120–150. In these variants, the hydrolytic acidity in both the arable and subsoil layers slightly exceeds 4-4.5 mg-equ/100 g of soil.

Of undoubted interest are the results of the determination of water-soluble calcium in soil samples taken at the time of harvest. It was found that significant changes did not occur in the soil, but this can be explained by the fact that the solubility of calcium sulfate is not high enough and it takes time for the appearance of calcium in ionic form. Physicochemical absorption takes place and calcium as a bivalent cation is absorbed by the soil-absorbing complex of black soil. Over time, the calcium cation will be available for the following exchange reactions in the soil environment.

Discussion. According to the scheme of our experiment, the same researches were not conducted. But for example, on black soils with a pH of 8.3 in the Rostov region, during the germination of oil flax for an application of 5 t/ha of phosphogypsum in autumn, an increase in the content of nitrate nitrogen in the soil by 1.2 mg/kg, potassium 8.8 mg/kg of labile phosphorus, 18 mg/kg potassium, 5.9 $S\text{-}SO_4$ (Akanova et al., 2019). But during the harvest time, the situation changes, the difference in the content of $N\text{-}NO_3$ decreases and in general the content of potassium in the area fertilized with phosphogypsum decreases by 19 mg/kg (we got the same tendency). Using phosphogypsum, an improvement in the physical properties of the soil is noted, such as a decrease in soil density by 0.11–0.13 gm/cm^3 (Akanova et al., 2019).

Fertilizer ammonium sulfate provides the plant with a macroelement nitrogen and a mesoelement sulfur. Scientists emphasize the advantages of this fertilizer over others like urea and ammonium nitrate, saying that it is the best fertilizer for saline, calcareous soils (Chien et al., 2011; Hafes & Kobata, 2012). Ammonium sulfate does not have potentially toxic aqueous ammonia and nitrites for plants growing in alkaline soils, there is no loss of ammonia due to evaporation when applied to acidic and neutral soils, the availability of phosphorus and some microelements increases as a result of acidification, does not affect the emission of carbon dioxide, nitrate is less leached out compared to other fertilizers. It is more effective in comparison with the application of elemental sulfur, since it takes more time for its conversion to sulfate for plants to be available. The acidifying effect can have a negative effect on acidic soils, and liming is recommended, which will be more financially profit. At the same time, these costs are compensated by the price of sulfur applied as a mesoelement (Khodanitska et al., 2018; Barczak et al., 2019; Skwierawska et al., 2008).

The co-application of nitrogen and sulfur has a positive effect on the yield and quality of grain crop as sulfur increases the efficiency of nitrogen use. Deficiency of sulfur in the soil leads to a decrease in the absorption of nitrates in comparison with the ammonium form due to the fact that there is a decrease in the activity of nitrate reductase (Bona, et al. 2011, Syrova 2020).

Our previous studies have shown that the content of phosphogypsum with ammonium sulfate increased the content of nitrogen, phosphorus and even potassium in spring barley plants during the growing season (Zakharchenko, 2020). But the difference in the effect when $N_{50\text{-}100}$ was applied between the variants has not been established during the tillering stage, during the bloom stage the difference between all the experimental variants is significant. The effectiveness of phosphorus from phosphogypsum was insignificant on barley plants, the difference in fertilized variants was greater during the bloom stage. The potassium content was not changed by applied fertilizer, although a slight increase was also observed on fertilized variants with nitrogen above 75.

Phosphogypsum, when applied with urea, reduced the loss of ammonia. If you mix phosphogypsum and urea 2.3:1, then the loss of ammonia from urea would be 85 % less than its separately application (Baurakli, 1990; Rzeczycka et al., 2001). The same conclusion was obtained by other scientists who compared the composting losses of phosphogypsum, superphosphate with chicken and cattle manure – phosphogypsum is better for reducing ammonia (Prochnov et al., 1995).

The activity of calcium increases from the application of phosphogypsum and lime cake or their co-application (Skrylnyk, 2017). An increase in the content of labile forms of phosphorus is noted only at high doses of phosphorus. So, for the application of 24 t/ha of phosphogypsum, compared with the control, an increase in phosphorus of 3 mg /kg of soil was obtained, for the application of 4.8 t/ha of the effect, a decrease in phosphorus in the soil was noted. At the same time, the content of exchangeable potassium increased significantly both with the application of lime and with the application of potassium by 20–26 mg/kg of soil at 4.8 and 24 t/ha. Phosphogypsum increases the absorption capacity and lowers the lime cake.

The application of phosphogypsum on dark chestnut secondary-alkanized soil at a rate of 6 t/ha increased the calcium content by 2.67 times compared to the control without ameliorants, the sodium content in the aqueous extract increased almost by 1.3 times, the anion content doubled and the content of bicarbonate ions did not change. The amount of exchangeable cations during its application increased by 1.3 times (Davydchuk, 2013).

Increased doses of nitrogen application (more than 150 kg) in the form of ammonium sulfate reduced the reaction of the soil environment, the concentration of calcium and magnesium in the arable layer (Fageria et al., 2010 Chien et al, 2011). The results of our experiment also show the tendency to decreasing of water-soluble calcium and increasing of acidity with rising of nitrogen rate in sulfate ion.

Mixed phosphogypsum with nitrogen fertilizer result in an increasing of yield of crop and improving of nutrients regimes in soil. For example, the co-application of biochar and phosphogypsum is more effective than their separate application (Mahmoud et al., 2017). Their mixture increased the nitrogen content of the soil, decreased soil density and increased corn yields.

Conclusions. The use of phosphogypsum in combination with nitrogen fertilization fulfills an important task in maintaining a high level of soil fertility while ensuring the required level of nitrogen nutrition. Due to the effect of interaction and mutual compensation, physicochemical and chemical absorption, phosphogypsum has a positive effect on the supply of calcium to the soil. With an increase in the nitrogen dose, soil acidification occurs in the arable soil layer. In prospect, the study will be continued for obtaining of data about aftereffect of phosphogypsum on plants, taking into account the solubility of the components, accumulation of fluorine and radionuclides.

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ВПЛИВ СУЛЬФАТУ АМОНІЮ ТА ФОСФОГІПСУ НА ДИНАМІКУ ПОЖИВНИХ ЕЛЕМЕНТІВ ТА КИСЛОТНІСТЬ ЧОРНОЗЕМУ

Проблема накопичення фосфогіпсу у відвалах хімічних заводів в світі і, зокрема, в Україні, стоїть гостро вже декілька десятиліть. Екологічна ситуація кандидат сільськогосподарських наук, доцент, погіршується тим, що під його збереження відводяться все нові і нові площі. Негативним моментом при внесенні фосфогіпсу є надходження радіонуклідів та фтору у грунт та рослини, дрібні часточки розвіюються при високій швидкості вітру. Але, враховуючи наявність в ньому макро-, мезо- та мікроелементів, високу ціну на мінеральні добрив, зараз він вважається гарним добривом та меліорантом, особливо на солонцевих ґрунтах. Метою дослідження було дослідити ефективність сумісного внесення фосфогіпсу (Сумихімпром) та сульфату амонію у зростаючих дозах азоту 50–150 на динаміку азоту, фосфору, калію, кальцію та показник гідролітичної кислотності чорнозему типового середньосуглинкового. Збільшення азоту приводило до збільшення вмісту гідролізованої, нітратної та амонійної форм азоту в ґрунті. Максимальна забезпеченість ґрунту нітратним азотом характерна для першого строку відбору зразків, у фазу кущення. В цей час спостерігається і максимальна різниця між контролем та удобреними варіантами досліду. Внесення фосфогіпсу з N_{150} майже у три рази збільшив вміст нітратів у ґрунті. Варіанти з меншими дозами азоту також впливають на накопичення нітратів у шарах 0–20 і 20–40 см. Після збирання врожаю встановлено незначна різниця між контролем та удобреними варіантами (крім N_{150}) при загальному зниженні рівня забезпеченості нітратами до 0,1–0,2 мг/100 г ґрунту. Вплив добрив був меншим на вміст рухомого фосфору та обмінного калію. На удобрених варіантах спостерігається суттєве підвищення величини гідролітичної кислотності. Особливо воно помітно при дозуванні з азотом 120–125. На цих варіантах гідролітична кислотність як в орному, так і в підорному шарах перевищує 4 мг-екв/100 г ґрунту. Зміни у вмісті водорозчинного кальцію незначні, що можна пояснити тим, що розчинність сірчанокислого кальцію недостатньо висока і потрібен час для появи кальцію в іонному вигляді.

Ключові слова: *амонійний азот, нітратний азот, легкогідролізований азот, сульфат амонію, фосфогіпс, рухомий фосфор, обмінний калій, гідролітична кислотність.*

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