

АГРОХИМИЯ, АГРОПОЧВОВЕДЕНИЕ, ЗАЩИТА И КАРАНТИН РАСТЕНИЙ/AGROCHEMISTRY,
AGROSOIL SCIENCE, PLANT PROTECTION AND QUARANTINEDOI: <https://doi.org/10.60797/JAE.2025.62.6>INFLUENCE OF MAGNESIUM FERTILIZERS ON THE DYNAMICS OF ACIDITY AND MINERAL
PHOSPHATES OF SOD-PODZOLIC SOILS UNDER OPTIMAL AND EXCESSIVE MOISTURE

Research article

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Abstract

The effect of magnesium sulfate on the change in the availability of phosphates introduced with fertilizer under various soil moisture conditions depending on the level of mineral nutrition was studied. It was found that *the use of $MgSO_4$ against the background of various doses of ammophos contributed to a decrease in soil acidity, both under optimal moisture conditions and under conditions of waterlogged soil.* It was revealed that the most optimal values of exchangeable and hydrolytic acidity for growing spring rape plants were obtained when introducing a magnesium-containing compound against the background of full and double doses of ammophos. *In the variants of introducing full and double doses of ammophos and magnesium sulfate, the following values of exchangeable soil acidity were obtained: pH 6.78 and pH 6.76, which corresponded to a neutral degree of acidity. Hydrolytic acidity of the soil is significantly reduced to 0.92–1.29 mg-eq./100 g of soil with the combined application of magnesium sulfate and various doses of ammophos.* It was found that when using the Kirsanov method, somewhat overestimated results of phosphate content were obtained, compared to the Olsen method. This is probably due to the increased availability of poorly soluble phosphates under the action of hydrochloric acid, which is used to obtain the extract. When using $NaHCO_3$ to obtain the extract, apparently poorly soluble phosphates are not subject to strong dissolution, due to which the values of the content of mobile forms of phosphorus are obtained lower.

Keywords: soil acidity, soil moisture, phosphate mobility, magnesium sulfate.ВЛИЯНИЕ МАГНИЕВЫХ УДОБРЕНИЙ НА ДИНАМИКУ КИСЛОТНОСТИ И МИНЕРАЛЬНЫХ ФОСФАТОВ
ДЕРНОВО-ПОДЗОЛИСТОЙ ПОЧВЫ ПРИ ОПТИМАЛЬНОМ И ИЗБЫТОЧНОМ УВЛАЖНЕНИИ

Научная статья

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Аннотация

Изучено влияние сернокислого магния на изменение доступности фосфатов, внесенных с удобрением при различных условиях режима увлажнения почвы в зависимости от уровня минерального питания. *Установлено, что применение $MgSO_4$ на фоне различных доз аммофоса способствовало снижению кислотности почвы, как при оптимальных условиях увлажнения, так и в условиях переувлажнения почвы.* Выявлено, что наиболее оптимальные для выращивания растений ярового рапса величины обменной и гидролитической кислотности были получены при внесении магнийсодержащего соединения на фоне полной и двойной доз аммофоса. *В вариантах внесения полной и двойной доз аммофоса и сульфата магния получены наилучшие показатели обменной кислотности почвы 6,78 ед. рН солев. и 6,76 ед. рН солев., что соответствовало нейтральной степени кислотности. Гидролитическая кислотность почвы значительно снижается до 0,92–1,29 мг-экв./100 г почвы при совместном внесении сульфата магния и различных доз аммофоса.* Выявлено, что при использовании метода Кирсанова получены несколько завышенные результаты содержания фосфатов, по сравнению с методом Олсена. Вероятно, это обусловлено повышением доступности труднорастворимых фосфатов под действием соляной кислоты, которую используют для получения вытяжки. При использовании $NaHCO_3$ для получения вытяжки, по-видимому, трудно растворимые фосфаты не подвергаются сильному растворению, в связи с чем и величины содержания подвижных форм фосфора получены ниже.

Ключевые слова: кислотность почвы, увлажнение почвы, подвижность фосфатов, сернокислый магний.**Introduction**

In sod-podzolic soils characterized by increased acidity, as is known, phosphate absorption is caused mainly by sesquioxides [22].

Sod-podzolic soils occurring in low relief elements, as well as developing on heavy rocks (heavy cover loams) under conditions of poor drainage, are subject to periodic waterlogging in spring and autumn. As early as the 1930s, it was shown that oxidation and reduction processes occur in all soils with varying degrees of intensity [16]. Periodic waterlogging of sod-podzolic soils promotes the formation of mobile sesquioxides. This is considered as a cause that has a negative effect on the

phosphate regime of sod-podzolic soils. Researchers believed that biological absorption of phosphates occurs under aerobic conditions, while biological absorption is absent under anaerobic conditions. Later studies showed that phosphate mobility increases only under anaerobic conditions. However, as a result of the emergence of aerobic conditions, the mobility of phosphates in the soil and their availability to plants decreases [20].

It was suggested that the increase in phosphate mobility under anaerobic conditions is associated with the transition of some iron oxide compounds to ferrous compounds and the formation of more mobile forms of divalent iron phosphates [3]. After the transition of soils to aerobic conditions, a decrease in phosphate mobility is associated with the oxidation of ferrous iron and the conversion of more soluble ferrous phosphates into less soluble ferric phosphates [19].

In later studies, it was established that the solubility of phosphates in sod-podzolic soils is closely related to the transformation of iron compounds. During the period of waterlogging of soils with the development of recovery processes and the formation of significant amounts of ferrous iron, the solubility of phosphates increases. This is caused by the dissolution of iron films from the surface of clay minerals during the transition of free ferric iron into mobile ferrous forms, as well as the formation of active water-soluble organic acids capable of anion exchange with phosphate ions. When the soil dries out, films of iron hydroxide compounds are deposited on the surface of colloidal soil particles. This contributes to the formation of sparingly soluble forms of phosphoric acid residues, as well as a decrease in soil dispersion and the binding of soluble forms with freshly precipitated iron hydroxide, the oxidation of ferrous forms with the formation of sparingly soluble phosphorus compounds [10].

Thus, long-term studies show that the accumulation of mobile sesquioxides in soils of excessive seasonal waterlogging creates unfavorable conditions for the phosphate regime of sod-podzolic soil. It is noted that under conditions of excessive soil moisture, phosphates pass into a less soluble form.

When studying the mobility of aluminum in sod-podzolic soil, it was suggested that liming does not hinder the development of reduction processes in the soil and the formation of iron oxide [14].

Another opinion can be found in the literature on this issue. Considering the processes of absorption of phosphate ions in the soil by sesquioxides in various pH ranges, it was found that aluminum is the main factor in the binding of phosphoric acid residues in the soil. This process occurs at pH from 5.5 to 7.5. At pH 6.5, about 90% of soil phosphates are bound to aluminum. Consequently, with the simultaneous presence of calcium, magnesium and aluminum ions in the soil, phosphates still bind predominantly to aluminum, and not to calcium or magnesium. In the pH range from 3.0 to 5.0, some phosphates also bind to iron. But iron phosphates are much less resistant to dissolution than aluminum phosphates [12].

At soil acidity pH_{KCl} 6 and higher, almost complete precipitation of iron and aluminum, present in the form of hydroxides, occurs. This reduces the concentration of ions in the solution and prevents their interaction with phosphorus, making it unavailable to plants [18].

When using magnesium-containing fertilizers, a favorable nutritional regime is created, which promotes better absorption of phosphorus by plants and increases the effectiveness of phosphorus fertilizers. This is especially important on acidic soils, where the natural content of available forms of phosphorus and magnesium is often insufficient for normal growth and development of plants [21].

Despite the large number of studies conducted on this issue, there is no consensus on finding ways to assess the availability of phosphates in acidic soils.

In the practice of agrochemical survey of soils of the Non-Chernozem territory of Russia and the CIS countries, mobile phosphates are determined using the standardized Kirsanov method [2].

Studies devoted to the comparative assessment of methods for determining phosphorus in soil have shown that the use of salt extract to extract phosphates in sod-podzolic soils in some cases has some overestimated results, which does not reflect the true values of phosphorus content in the soil. In this case, reduced yields of agricultural crops were often obtained. It is often noted that this pattern is due to the dissolution of poorly soluble phosphates of calcium, magnesium, iron and aluminum under the action of hydrochloric acid used as an extract [1], [5], [15], [23]. Numerous studies confirm the effectiveness of the Olsen method for all types of soils, including acidic ones, especially after liming [1], [13]. In this regard, the objectives of our research included studying the effect of magnesium fertilizers on changes in soil acidity and phosphate availability depending on the conditions of soil water supply using various soil analysis methods.

Research methods and principles

To study the effect of a magnesium-containing compound ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$) on acidity and optimization of the phosphate nutrition level on sod-podzolic loamy soil, a vegetation experiment was conducted. The object of the study was spring rapeseed (lat. *Brassica napus*) of the Rastnik variety (originator: Federal State Budgetary Scientific Institution "All-Russian Research Institute of Rape", Lipetsk). Rape is a crop that is demanding of the initial soil acidity. For growing this crop, soils with an acidity level close to neutral and neutral are selected. The experiment was carried out in 2024 in the phytoclass of the PhosAgro educational center of the Russian State Agrarian University — Moscow Agricultural Academy named after K.A. Timiryazev, in Wagner vessels with a capacity of 5 kg of soil. For the research we used sod-podzolic loamy soil taken from the control variant of a long-term field experiment with fertilizers, laid out under the supervision of D.N. Pryanishnikov in 1931 at the Dolgoprudny agrochemical experimental station. The soil was selected in 2011 for research devoted to studying the issues of finding ways to reduce soil acidity. Later, the soil was stored in the vegetation house of the Department of Agrochemistry of the Russian State Agrarian University — Moscow Agricultural Academy named after K.A. Timiryazev. Before laying the experiment in 2024, the following agrochemical parameters were determined in the studied soil: pH_{KCl} — 4.1 strongly acidic soil, according to CINA method [6]; Hg — 4.1 mg-eq / 100 g of soil, by Kappen method modified by CINA method [7]; S — 8.0 mg-eq / 100 g of soil, by Kappen method [8]; mobile forms of P_2O_5 — 30 mg/kg of soil, 2nd class of availability, by Kirsanov method [9]; mobile forms of K_2O — 80 mg/kg of soil, 2nd class of availability, by Kirsanov method [9].

In the studies, different levels of plant phosphorus supply were created by adding different doses of ammophos (with an active ingredient content of 12:52) and magnesium sulfate ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$). The experimental design included 7 options: 1.

Control (without fertilizers and magnesium sulfate); 2. Ammophos 1/3 dose (0.5 g/kg soil); 3. Ammophos 1/3 dose + MgSO_4 ; 4. Ammophos 1 dose (1.5 g/kg soil); 5. Ammophos 1 dose + MgSO_4 ; 6. Ammophos 2 doses (3.0 g/kg soil); 7. Ammophos 2 doses + MgSO_4 . The dose of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ was the same in all options and was 5 g/kg soil. In the experiment, the following water supply conditions were simulated: optimal — 60% of the full moisture capacity during the entire period of plant vegetation and waterlogged soil — 120% of the full moisture capacity. The conditions of waterlogged soil were created before the beginning of the budding phase of plants. The duration of waterlogged soil was 7 days, after which the soil moisture in the vessels was gradually reduced to the optimal level. After harvesting, the hydrolytic acidity of the soil was determined by Kappen method modified by CINA0 [7], the pH of the salt extract by CINA0 method [3], the content of mobile phosphates by Kirsanov method [9] and by Olsen method [24].

The obtained experimental results were processed by the method of dispersion analysis according to the generally accepted technique [11].

Main results

Determination of pH of salt extract from soil and hydrolytic acidity by the Kappen method are shown in Table 1.

Table 1 - The effect of magnesium sulfate application on the acidity indices of sod-podzolic soil depending on soil moisture conditions

DOI: <https://doi.org/10.60797/JAE.2025.62.6.1>

Experimental variant	pH of salt extract	Hydrolytic acidity, mg-eq./100 g of soil
Optimal conditions for water supply to plants (60% of total moisture capacity)		
Control (without fertilizers)	4.12	4.60
Ammophos (1/3 dose)	4.20	5.30
Ammophos (1/3 dose)+ MgSO_4	6.61	1.15
Ammophos (1 dose)	4.13	5.29
Ammophos (1 dose)+ MgSO_4	6.82	1.13
Ammophos (2 dose)	4.23	5.22
Ammophos (2 dose)+ MgSO_4	6.80	1.05
Least Significant difference ₀₅	0.25	0.18
Soil flooding (120 % of total moisture capacity)		
Control (without fertilizers)	4.21	4.64
Ammophos (1/3 dose)	4.18	4.72
Ammophos (1/3 dose)+ MgSO_4	6.57	0.92
Ammophos (1 dose)	4.23	4.79
Ammophos (1 dose)+ MgSO_4	6.78	1.29
Ammophos (2 dose)	4.49	4.85
Ammophos (2 dose)+ MgSO_4	6.76	1.15
Least Significant difference ₀₅	0.27	0.18

Table 1 shows, that an increase in the ammophos dose slightly changes the exchange and hydrolytic acidity, both with optimal water supply and with waterlogged soil. Changes in these indicators are within the limits of the Least Significant difference₀₅.

The introduction of MgSO_4 at all doses of ammophos contributed to a significant decrease in soil acidity, both under optimal moisture conditions and under conditions of soil waterlogging. Similar changes are observed in relation to the hydrolytic acidity of the soil, which decreased against the background of the use of magnesium sulfate. With optimal water supply to plants in the variant with the introduction of ammophos (1/3 of the dose), a change in the pH of the salt was found from 4.12 to 6.61 pH, Hydrolytic acidity from 5.30 to 1.15 mg-eq./100 g of soil. In the variant where ammophos was introduced in a full dose (Ammophos (1 dose)) together with MgSO_4 , the pH of the salt was 6.82. versus 4.13 pH without adding magnesium sulfate, Hydrolytic acidity was 1.13 mg-eq./100 g of soil, versus 5.29 mg-eq./100 g of soil without adding magnesium. With a double dose of ammophos (Ammophos (2 dose)) and adding magnesium sulfate, the pH was 6.80 versus 4.23 pH without adding magnesium, Hydrolytic acidity was 1.05 mg-eq./100 g of soil, versus 5.22 mg-eq./100 g of soil in the control without magnesium.

When flooding the soil, the patterns of change in the exchangeable and potential acidity values are close to the results obtained with optimal soil water supply. A decrease in soil acidity was revealed with the simultaneous application of ammophos and magnesium sulfate. In the variants of applying Ammophos (1 dose) and Ammophos (2 dose) and magnesium sulfate, the best indices of exchangeable soil acidity were obtained: 6.78 pH and 6.76 pH, which corresponded to a neutral degree of acidity. For comparison, in the control variants without applying magnesium, the exchangeable acidity was obtained at a level from 4.23 to 4.49 pH, which indicates a strongly acidic degree of soil acidity. The hydrolytic acidity of the soil significantly decreases to 0.92-1.29 mg-eq./100 g of soil with the combined application of magnesium sulfate and various

doses of ammophos against 4.72-4.85 mg-eq./100 g of soil. Thus, it can be concluded that the combined application of an optimal dose of mineral fertilizers and a magnesium-containing compound improves the quality of the soil for growing spring rape, which is a crop that is demanding of soil acidity.

It is known that in order to obtain a high yield of good quality agricultural crops, including spring rape, it is necessary to optimally provide plants with the main nutrients. For this, it is also necessary to correctly determine the initial provision of the soil with available forms of nutrients. Currently, zonal methods are used to assess the provision of the soil with mobile forms of phosphorus, which are standardized and used in the Russian Federal Service for Agro-Chemical Studies. At the same time, it should be noted that there are other methods for determining the phosphorus content in the soil, which can also be used to more accurately characterize soil fertility and assess the effectiveness of fertilizers.

The results of determination of mobile phosphates by method Kirsanov and available phosphates by method Olsen in sod-podzolic soil after harvesting rapeseed plants are shown in Table 2.

Table 2 - Content of mobile phosphates depending on soil moisture when applying ammophos and magnesium sulfate

DOI: <https://doi.org/10.60797/JAE.2025.62.6.2>

Experimental variant	by method Kirsanov	by method Olsen
	P ₂ O ₅ mg/kg soil	
Optimal conditions for water supply to plants (60% of total moisture capacity)		
Control (without fertilizers)	25	12
Ammophos (1/3 dose)	79	70
Ammophos (1/3 dose)+ MgSO ₄	90	71
Ammophos (1 dosedose)	411	258
Ammophos (1 dose)+ MgSO ₄	389	235
Ammophos (2 dose)	695	503
Ammophos (2 dose)+ MgSO ₄	719	521
<i>*Least Significant difference₀₅</i>	20	15
Soil flooding (120 % of total moisture capacity)		
Control (without fertilizers)	32	11
Ammophos (1/3 dose)	103	55
Ammophos (1/3 dose)+ MgSO ₄	104	59
Ammophos (1 dosedose)	361	198
Ammophos (1 dose)+ MgSO ₄	365	200
Ammophos (2 dose)	556	344
Ammophos (2 dose)+ MgSO ₄	652	381
<i>*Least Significant difference₀₅</i>	19	10

Note: **least Significant difference₀₅* is calculated taking into account all options except the control one

Table 2 shows that when ammophos is added to the soil at both moisture levels, there is a sharp increase in the content of mobile phosphates determined by methods Kirsanov and Olsen. When using method Olsen, the content of mobile phosphorus forms was lower by an average of 11–27% under optimal water supply and by 41–46% under overmoistening compared to the values obtained using method Kirsanov. When determining the content of mobile phosphorus forms by method Kirsanov, 79–695 mg/kg of soil was obtained, by the Olsen method 70–503 mg/kg of soil under conditions of optimal soil moisture. Under excessive moisture, the content of mobile phosphorus forms by method Kirsanov was 103–556 mg/kg of soil, by method Olsen 55–344 mg/kg of soil. It can be assumed that when using method Kirsanov, slightly overestimated results are obtained for the phosphate content, compared to the Olsen method. This is probably due to the increased availability of poorly soluble phosphates under the action of hydrochloric acid, which is used to obtain the extract. When using NaHCO₃ to obtain extract, the poorly soluble phosphates apparently do not undergo strong dissolution, and therefore the values of the content of mobile forms of phosphorus are obtained lower.

When introducing MgSO₄ against the background of different doses of ammophos, ambiguous results were obtained. With optimal water supply and overmoistening, the introduction of magnesium sulfate against the background of 1/3 dose and full dose of ammophos revealed changes in the content of mobile forms are not reliable when determined by both method Kirsanov and method Olsen. It should be noted that in most cases a decrease in the content of mobile forms of phosphorus was obtained, although these changes are not reliable. A decrease in the mobility of phosphorus can be explained by the formation of insoluble phosphates under the influence of soil factors. It was found that when introducing magnesium sulfate against the background of a double dose of ammophos, an increase in mobile phosphates was noted with optimal water supply by 4% for both methods of determining phosphorus. Under conditions of over-moistening, when using method Kirsanov, the phosphorus content in the variant ammophos (2 doses) + MgSO₄ increased by 17%, when using method Olsen by 10% compared to the

variant without magnesium application (ammophos (2 doses)). It was concluded that the use of magnesium against the background of a double dose of ammophos contributes to an increase in the mobility of phosphorus, when determined by method Kirsanov and method Olsen.

Thus, it can be concluded that the relative changes in the content of mobile forms of phosphate are similar when determined by methods of Kirsanov and Olsen. The studies obtained similar patterns of the dynamics of the phosphate regime of soils, both with optimal water supply and with overmoistening. It was found that when using a 0.5 N NaHCO_3 solution to obtain a soil extract, lower values of available phosphorus forms were obtained. It was suggested that method Olsen, compared with method Kirsanov, more accurately reflects the content of available phosphates in the soil. This is due to the smaller size of the effect of sodium bicarbonate on the processes of dissolution of poorly soluble phosphorus reserves in the soil.

Conclusion

1. It was found that the introduction of MgSO_4 against the background of full and double dose of ammophos provided an increase in the pH of the salt extract to 6.82–6.80 pH under optimal moisture conditions, under conditions of excess moisture supply, the soil acidity was 6.78–6.76 pH, which corresponds to a neutral degree of soil acidity.

2. It was revealed that the combined use of ammophos and magnesium sulfate contributed to a decrease in the hydrolytic acidity of the soil under optimal water supply to 1.05–1.15 mg-eq./100 g of soil, and under conditions of excess moisture to 0.92–1.25 mg-eq./100 g of soil.

3. It was shown that the use of combined application of magnesium and ammophos provides an improvement in the quality of the soil for growing spring rape, which is a crop that is demanding in terms of soil acidity.

4. It was noted that when introducing increasing doses of ammophos into the soil with optimal moisture, the content of mobile phosphates increases sharply, up 695 mg / kg of soil determined by method Kirsanov and up 503 mg / kg of soil determined by method Olsen. Similar changes are observed with excessive moisture, 556 mg / kg of soil and 344 mg / kg of soil, respectively, compared to control options.

5. The introduction of MgSO_4 had a noticeable effect on increasing reserve of mobile phosphates when applied jointly with a double dose of ammophos. Under conditions of optimal soil moisture, changes in content of mobile phosphorus reserves amounted to 4% when determined by both method Kirsanov and method Olsen. Under conditions of overmoistening of the soil, the increase in available phosphorus when determined by method Kirsanov was 17%, when determined by method Olsen — 10%.

6. It was determined that use of 0.5 N NaHCO_3 solution to obtain a soil extract showed that method Olsen, compared to method Kirsanov, more accurately reflects content of available phosphates in soil. This is due to smaller size of effect of sodium bicarbonate on processes of dissolution of poorly soluble phosphorus reserves in soil.

Благодарности

Авторы выражают благодарность профессору кафедры химии, д.с.-х.н. Белопухова С.Л., заведующему кафедрой химии, профессору д.с.-х.н. Дмитриевскую И.И., руководителю Образовательного центра ФосАгро Долгушкина П.Н. за помощь и поддержку данных исследований.

Конфликт интересов

Не указан.

Рецензия

Сообщество рецензентов Международного научно-исследовательского журнала

DOI: <https://doi.org/10.60797/JAE.2025.62.6.3>

Acknowledgement

The authors express their gratitude to the Professor of the Chemistry Department, Doctor of Agricultural Sciences Belopukhov S.L., Head of the Chemistry Department, Professor, Doctor of Agricultural Sciences Dmitrievskaya I.I., Head of the PhosAgro Educational Center Dolgushkin P.N. for their assistance and support of this research.

Conflict of Interest

None declared.

Review

International Research Journal Reviewers Community
DOI: <https://doi.org/10.60797/JAE.2025.62.6.3>

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