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Ecological and Agrochemical Evaluation of Continuous Mineral Fertilizer Usage in Field Crop Rotation

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ABSTRACT

Fertilizers have a significant influence on the forming of the circulation of substances and energy in soils, agroecological state of lands, as well as the quality of agricultural products. Fertilizers and ameliorants, as some of the most effective means of restoring soil fertility, have a considerable influence on the agroecological condition and agrochemical indicators of arable soils in the process of their agricultural usage. The article researched such ecological aspects of using mineral fertilizers as changing the chlorine content in soil solution, potassium, calcium and magnesium content in soil intake complex as well as gross sodium content in soil after continuous usage of fertilizers in field crop rotation. The experimental part of the work was done in continuous stationary experiment in the field rotation of grain and beet crops with a set of crops traditional for the region defined in 1964. It was defined that the chlorine of fertilizers does not produce stable compounds in soil and migrates a lot in its profile. Using fertilizers in field crop rotation in a dose of 45–135 kg of K_2O/ha does not contribute to chlorine increase in physiologically active 1.5 m deep soil layer. At continuous fertilizer usage, there have been essential changes in the ashed fertile soil in the composition of its intake complex – the number of calcium and magnesium exchangeables has decreased, which entails worsening of the physical and chemical qualities and as a result leads to decreasing fertility level. The research results have evinced that the ratio between magnesium and potassium in a soil intake complex drops to 2.6–3.6 as a result of continuous potassium with fertilizer usage, according to the checking data without fertilizer application it makes up – 4.2, which corresponds to optimal ratio of Mg : K = 2–5.

Keywords: mineral fertilizers, exchangeable cations, chlorine, natrium, soil intake complex, environmental assessment.

INTRODUCTION

A continuous improvement of the environment is one of the most significant tasks of humanity. An important role in the process belongs to reasonable usage of chemicalization means of agriculture. Nowadays, the humanity is at the stage of growing ecological problems. Their range is very wide – from a local polluting of land plots to a global catastrophic threat. That is why humanity should learn to rationally intervene into natural cycles of biosphere trying to break them as little as possible [Waithaka and Shelmith, 2023; Hospodarenko, 2015].

Using fertilizers has always occupied a central position in the complex of measures for increasing agricultural crops yield. Fertilizers influence the formation of substance circulation and energy in soils, agroecological land condition as well as the quality of agricultural produce. Fertilizers and ameliorants, as some of the most effective means of restoring soil fertility, make a considerable impact on the agroecological state and arable soil agrochemical indicators in the process of their agricultural usage [Ulko, 2022].

Using mineral fertilizers in agroecosystem is an important condition of modern farming development. However, breaking the scientific fundamentals of using agrochemicals in agriculture can lead to unbalanced nutrition of crops, decreasing nutritional value of plant produce and deterioration of the environmental state. In agriculture, alongside with increasing crop yields and improving the produce quality, the issues of preserving and protecting the environment from technogenic pollution should be considered first. Instilling nature protecting and resource saving technologies is required for preserving soil, water and air [Hospodarenko and Prokopchuk, 2014; Hospodarenko, 2018].

The problem of the protecting and rational usage of lands is one of the most important tasks of humanity, because 98% of foods consumed by people are produced by tillage. Measures for increasing land productivity and its protecting are various and must be implemented comprehensively as a single system, complementing each other mutually and enhancing the action of others [Hospodarenko and Prokopchuk, 2014; Khomutova, 2021; Kirichenko, 2020].

Using artificial fertilizers enables to increase agricultural crop yields and improve the produce quality. Nitrogen, phosphorus and potassium mineral fertilizers are mostly used in agriculture. Owing to using mineral fertilizers, a 50% yield increase is provided [Krasilnikov et al., 2022]. That is why complete avoidance of using mineral fertilizers, which is sometimes suggested as one of the possible ways of agriculture development, is going to lead to catastrophic shortening of products [Hospodarenko, 2018].

However, failing to conform to scientifically substantiated measures when using fertilizers, imperfection of ways of their usage can cause a negative effect of mineral fertilizers on some biospheric components, the state of environment and people. There is a special concern that excessive dependance on mineral fertilizers can cause environmental consequences, such as surface water eutrophication, nitrate contamination of ground waters, contamination of soil with heavy metals, as well as pollution of the atmosphere as a result of nitrous oxide and ammonia emissions, acid rains etc. [Chandini et al., 2019; Savci, 2012].

Environmental pollution when using mineral fertilizers occurs mainly through imperfect qualities and chemical composition of fertilizers as well as breaking their production technology, storing and applying mineral fertilizers. Accumulating nitrates in agricultural products mainly depends on the dose and terms of nitrogen fertilizer usage, the length of daylight and the time of sowing seeds as well as on lighting – in shaded plots, the nitrate content is higher [Walling et al., 2022]. Using phosphorous fertilizers has considerable ecological consequences. First of all, phosphorous fertilizers lead to increasing phosphorus accumulation in water bodies. Its considerable accumulation in water environment causes water body eutrophication [Ahmad et al., 2023]. Potassium fertilizers pollute the environment in a lesser degree. The negative influence is made by anions accompanying potassium: chloride, sulfate and others. Chlorine, can also be considered as a harmful admixture that is contained in potassium fertilizers. In large doses, it influences the yield of potatoes, grapes, tobacco, citrus and yardstick crops [Hospodarenko, 2018].

Therefore, the accurate choice of doses, terms and ways of fertilizer usage, the ratio of nutrients will not only provide high yields, but that will prevent contamination of soils and products with toxic elements and compounds as well as support the soil natural fertility on the required level [Lytvynovych, 2017; Maitra, 2020].

As a result of accumulating data about the influence of chemical elements on plants, humans and animals, the issue is of more thoughtful selection of nutrients and doses of their usage with the desired direction of their influence on biological and nutritional value of crop products is more acute. Plants are at the bottom of the food chain; that is why, the control of basic composition of crop products, the possibility of its regulating, studying the dependance of the state of plants, humans and animals on biochemical conditions of the territory is one of the main tasks of ecological agrochemistry [Hospodarenko, 2915].

MATERIALS AND METHODS

The article has researched such ecological aspects of mineral fertilizer application as the change of chlorine content in soil solution, the content of calcium and magnesium in soil intake complex and the content of gross natrium in soil after continuous usage of fertilizers in field crop rotation.

The experimental part of the work has been done in continuous stationary experiment in field crop rotation of grain and beet with a number of crops traditional for the region defined in 1964. Its basis is a 10-row crop rotation deployed in time and space and is carried out in 10 ways: without using fertilizers and with organic, mineral and with organic and mineral systems of fertilizing of three levels of applying fertilizers. The position of fields and variants is systematic. The scheme of the experiment was worked out to define the high doses of fertilizers in terms of ecology, the low ones - in terms of economic effectivity, and the combination of different doses and kinds of fertilizers enables to evaluate the potential possibilities of crop growing.

The research has used such two fertilizers: half-rotten bedding straw manure of cattle, ammonium nitrate, granulated superphosphate, and potassium chloride. During the first and second rotations of crops, potassium fertilizers were used as potassium salt mixed with the content of 40% of K_2O and 20% of Na_2O. Mineral fertilizer doses were defined according to the amount of N, P_2O, K_2O which were contained in corresponding manure doses and, depending on the crop they were differentially used in crop rotation fields. Soil samples were selected on the plot after harvesting clover in a layer of 0–160 cm after every 20 cm. The following determinations were made in the selected soil samples: exchangeable cations of calcium, magnesium, natrium and potassium by the method of Schollenberger in acetate and ammonium extract with pH 7 [Schollenberger and Simon, 1945], the content of chlorine in soil solution - the volumetric titration method.

RESULTS AND DISCUSSION

More than 90% of potassium fertilizers which are produced in the world constitute potassium chloride. It has to do with the chemical composition of the main potassium-containing deposits and a cheap technological process of obtaining fertilizers. Potassium chloride can be especially useful because of the deficit of chlorine in the soil [Kosolap and Krotinov, 2014].

It is known that the majority of crops can grow without taking up chlorine and its availability in nutritional environment is required only for normal development of some of them. The absorption of chlorine by corresponding crops takes place at the level of macroelements, whereas for others the need for that is so insignificant that it was referred to microelements group. However, some crops are sensitive to the chlorine availability in the soil [Hospodarenko, 2015].

The influence of potassium chloride on the yield quality of the majority of agricultural crops is conditioned by its effectivity. When fertilizers do not provide yield increase, one can even observe negative consequences. Their effectivity makes a positive impact on the produce quality [Souri, 2017]. The main advantage of applying chlorine fertilizers manifests itself in suppressing disease agents in wheat and barley [Kosolap and Krotinov 2014]. After washing out chlorine to the lower layers, the nitrification ability of arable layer of fertile soil increases compared to potassium sulfate [Wang, 2018]. Studies have defined that using potassium chloride increases the content of chlorine in plants. In this case, it is usually accumulated in unproductive parts of harvest. The physiological role of chlorine has not been completely studied. However, the fact that the sugar beet contains a large amount of chlorine in its leaves, whereas grain crops have it in straw, proves that it plays a certain role in plant vital activity. The crops that react negatively to chlorine are as follows: tobacco, potatoes, buckwheat, soy, peas, flax, cucumbers, onions, fruit and some others [Hospodarenko, 2015].

Chlorine salts are well soluble, therefore they actively migrate in soil profile. The tendency of chlorine distribution in soil is mainly defined by the processes of water migration [Wang, 2018]. Chloride-anion is not only poorly absorbed by the soil, but it is also characterized by negative adsorption [Sanchez et al., 2004].

Levelling the chlorine content according to soil profile is conditioned by two reasons. On the one hand, it is the absence of any specific accumulative barrier in the soil, but on the other hand, it is an active migration of chlorine in the profile with descending as well as ascending moisture flows. The composition of moisture which evaporates from the surface of non-saline soils contains about 1.5 mg/l of chlorine [Prokopchuk and Nikitina, 2017].

The chlorides that are contained in soils differ owing to their considerable solubility in water and are extracted as a result of their leaching by water and removing by yields. At using chlorine containing fertilizers and phosphates along the rows one can observe the decrease in absorption of phosphorus by plants and slower ripening yields [Vodiianitskii, 2017].

It has been defined that the content of chlorine in the plants grown on the plots fertilized with potassium chlorine was slightly going up despite its considerable amount in 1-meter deep soil layer. Under tilled crops, chlorine leaching from arable layer occurs much more intensively than under the crops of broadcast seeding [Shelke, 2019]. Chlorine is washed out of the soil by the precipitation rather fast, even though they have a heavy granulometric composition. The chlorine of potassium fertilizers is washed out into the lower soil layers to a depth of 40–100 cm. Chlorine amount in 1-meter deep soil layer depends on weather conditions: in dry years, chlorine is accumulated in 1-meter deep layer, but in wet years it is washed out of it [Shelke, 2019].

The results of the conducted studies prove it, as despite the large amount of chlorine which was used together with potassium chlorine in winter in a dose of 45–135 kg of K_2O for 1 ha of crop rotation square depending on the variant of experiment, the essential increase of its content of 0–160 cm profile soil has not been observed. This fact confirms again the data about chlorine intensive leaching by autumn-winter-spring precipitation, when productive moisture accumulation occurs. As a result chlorine is evenly distributed in the soil profile, and its major part is concentrated in the soil lower layers (Figure 1). Other researchers have revealed the fact that chlorine in soil in water extraction is observed in a considerable amount during 1–2 months after using fertilizers for sugar beets in autumn. However, it cannot always be observed at a depth of more than 60 cm next spring and under condition of using high doses of fertilizers only [Hospodarenko, 2015].

Therefore, chlorine content in a soil layer of 140–160 cm was 0.4–2.0 mg/kg higher than in a soil layer that was 0–20 cm deep. The moving of chlorine in the soil and subsoil profile can be explained by several factors. In the region, the moving of early spring water surplus to subsoil to a depth of 3–5 meters occurs periodically every 3–5 years. It is enabled by the fracturing and tonguing of humus profile of black soils as well as passes of shrews. Rain worms reach a depth of 8.5 m, moles can reach up to 5.3 m, ants - up to 3.2 m, different beetles and other insects – up to 1.6 m [Hospodarenko et al., 2013].

Thus, the chlorine content, after using fertilizers for many years in a 1.5 m deep physiologically active soil layer with different levels and systems of fertilizing in field crop rotation slightly exceeds the level of unfertilized plots.

Cation balance for a certain soil can be more important than the amount of every present element. The ratio of exchangeable cations can be an important indicator of the soil structural endurance. The ionic exchange in soil is a dynamic process. The cations in the soil solution can be absorbed by plants or microorganisms or can potentially bind to anions, forming new compounds, or bind to soil colloids again [Markoski, 2018].

The importance of exchangeable cations in the soil changes depending on the type of soils and their horizons. The capacity of cation exchange is influenced by a number of chemical and physical parametres of soil which, together with climate and relief, influence its importance [Tomasic, 2013].

When analyzing exchangeable potassium content in soil intake complex (SIC) of ashed black soil, one can draw a conclusion that it was not changing significantly. Hence, in a layer of 0–20 cm, it constituted 0.59–0.85 ashes/kg depending on the variant of experiment (Figure 2).

The variant without fertilizing (0.59 ashes/kg) is characterized by the lowest content of potassium. In the variants of mineral system of fertilizing, it rose up to 0.69 ashes/kg with the first level of fertilizing, up to 0.77 ashes/kg with the second one and up to 0.85 ashes/kg at the third level. When using organic and organic and mineral systems of fertilizing, the content of exchangeable potassium was 0.78 ashes/kg and 0.75 ashes/kg, respectively.

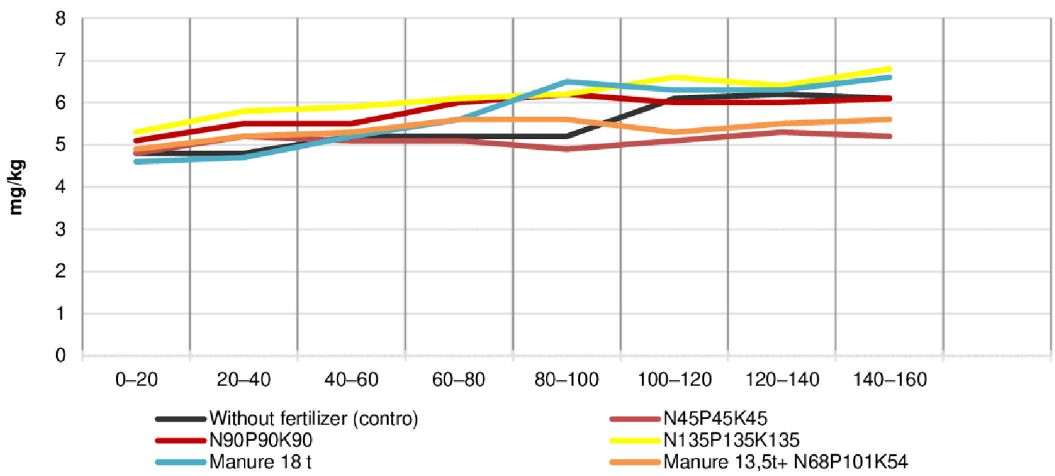

Figure 1. Chlorine content in soil after continuous fertilizer usage in crop rotation, (2023)

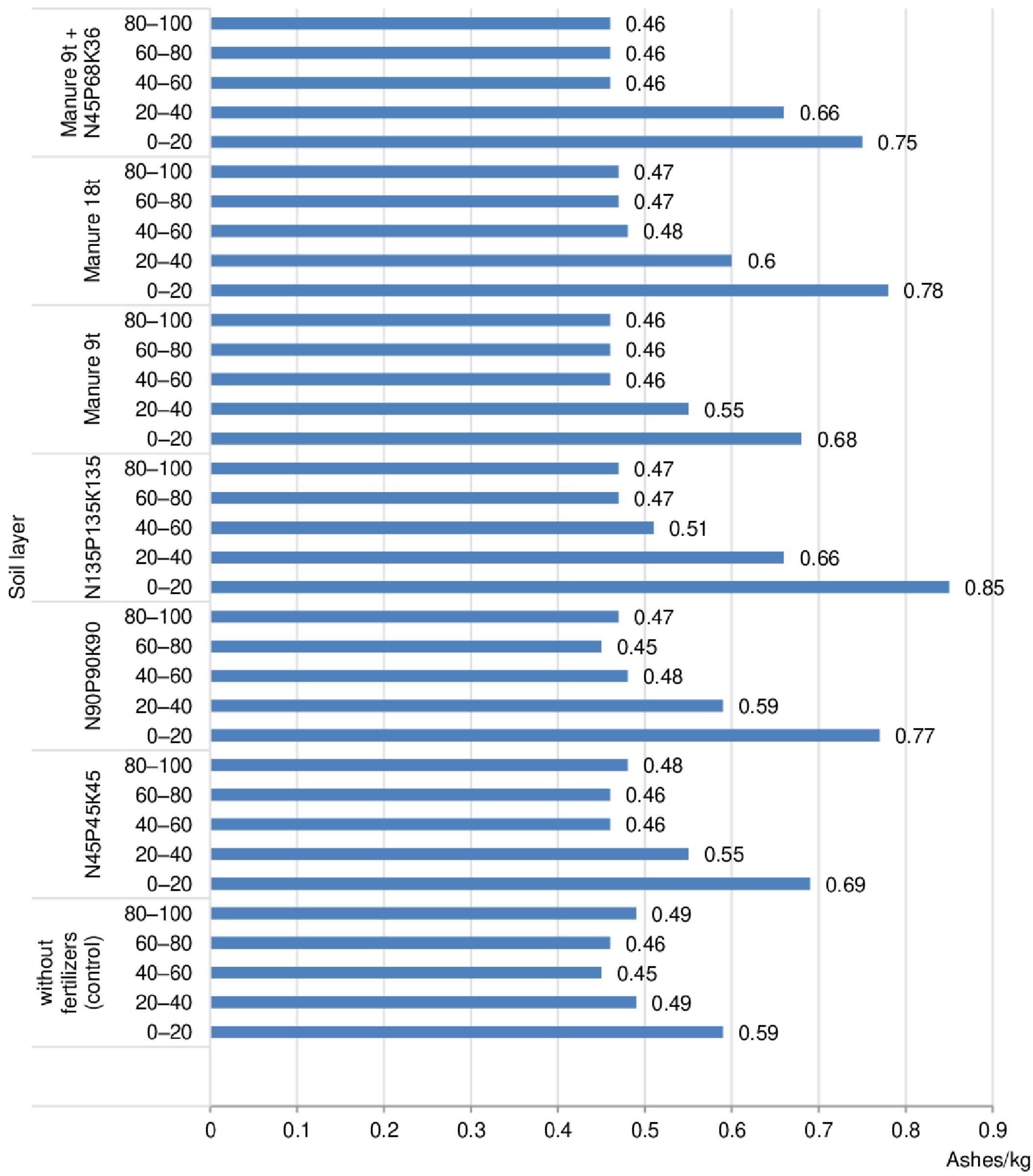

Figure 2. The change of the content of exchangeable K^+ in ashed black soil after continuous (1965–2023) usage of fertilizers in field crop rotation

One of the most important indicators that influence the stabilizing and accumulating of humus in soil is its content of exchangeable bases of calcium and magnesium.

Along with the main nutrients, magnesium has an important meaning in plant nutrition. It is considered that lack of magnesium in plant nutrition is observed to be less than 2 ash/kg of soil when its exchangeable forms are included [Hospodarenko, 2018]. The results of the conducted studies indicate that magnesium deficit for plant nutrition is not observed on the experimental plot. Its content in 1-meter deep soil layer makes up within 2.19–2.68 ashes/kg (Figure 3). Here, one can observe a slight increase in exchangeable magnesium content down the soil profile and its slight decrease when mineral fertilizer usage dose is increased. Evidently, it has to do with the fact that plants consume it more in the top soil layer. The greater amount of fertilizer, the higher crop yield is, which in its turn causes greater nutrient removal.

The same situation is observed with exchangeable calcium content, the content of which made up 23.7–28.3 ash/kg in a 1-meter deep layer with fertilizer variants mentioned before (Figure 4).

Calcium enables to enlarge the space between layers of colloidal clay. It also flocculates clay where tiny particles are broken and held together

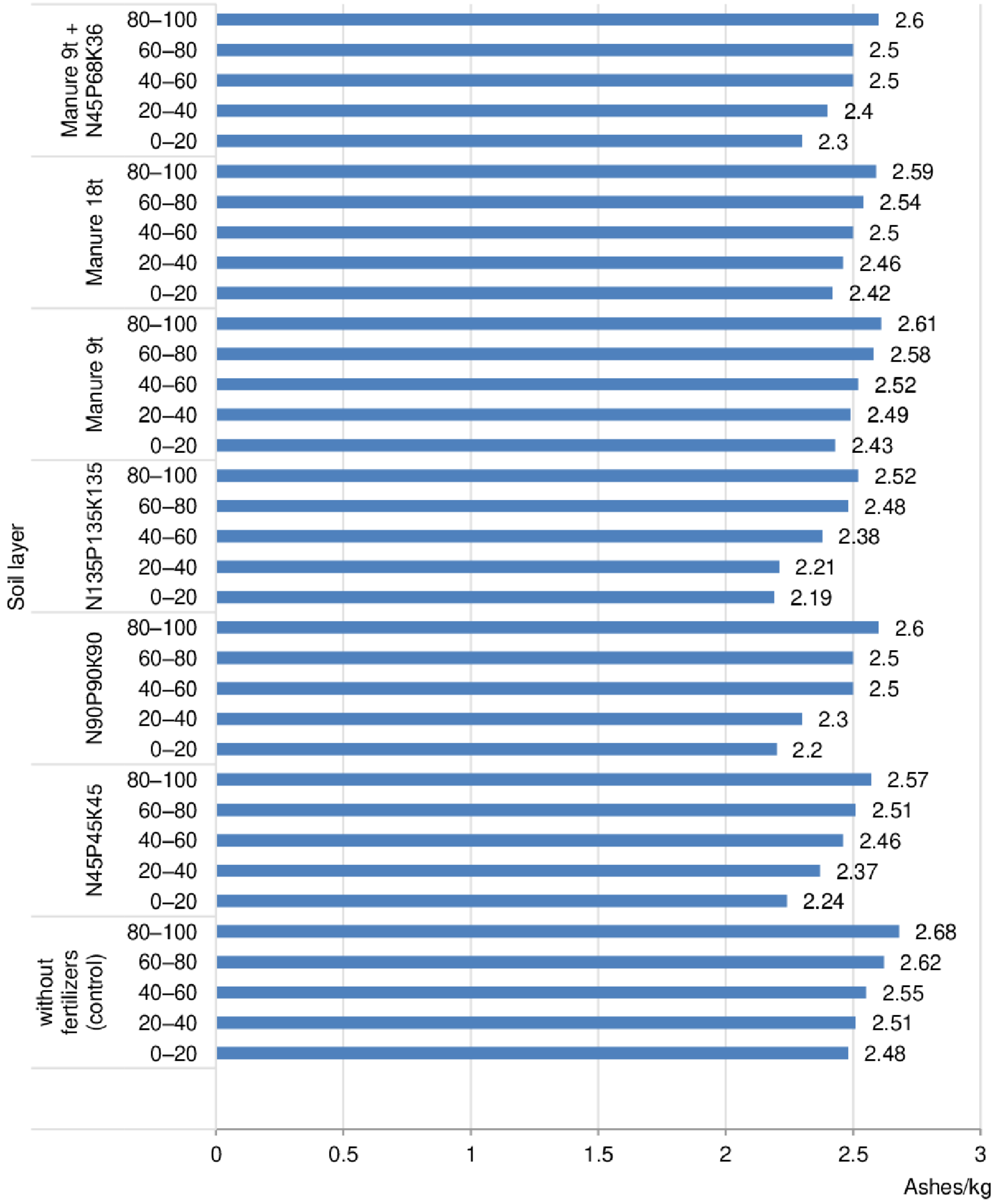

Figure 3. The change of exchangeable Mg^{2+} content in ashed black soil after continuous (1965–2023) fertilizer usage in field crop rotation.

in a smaller number of larger aggregates. It provides a larger air space in the soil and better water infiltration [Markoski, 2018].

Scientists have found out that the main article of expenditure part of calcium balance is caused by its washing out of the soil as a result of atmospheric precipitation. Apart from that, a continuous application of physiologically acid mineral fertilizers, in higher doses in particular, causes growing acidity of the soil as well as leaching calcium and magnesium, which create fertility, out of its upper horizons [Hospodarenko et al., 2013] that is proven with the results of the conducted research. The research results reveal that the higher fertilizer dose, the higher exchangeable calcium content is which is conditioned by the fact that it is used in high doses of granulated superphosphatus.

K^+ cations contained in potassium fertilizers and which are absorbed by the soil oust equivalent amount of Ca^{2+} cations out of it [Hospodarenko, 2015]. This pattern is confirmed with the results of the conducted studies, as the variants of mineral fertilizer system were characterized by the lowest calcium content, while the highest exchangeable calcium one was in the fertilizer variants with manure usage.

When assessing plants root nutrition provision with magnesium and potassium, a great

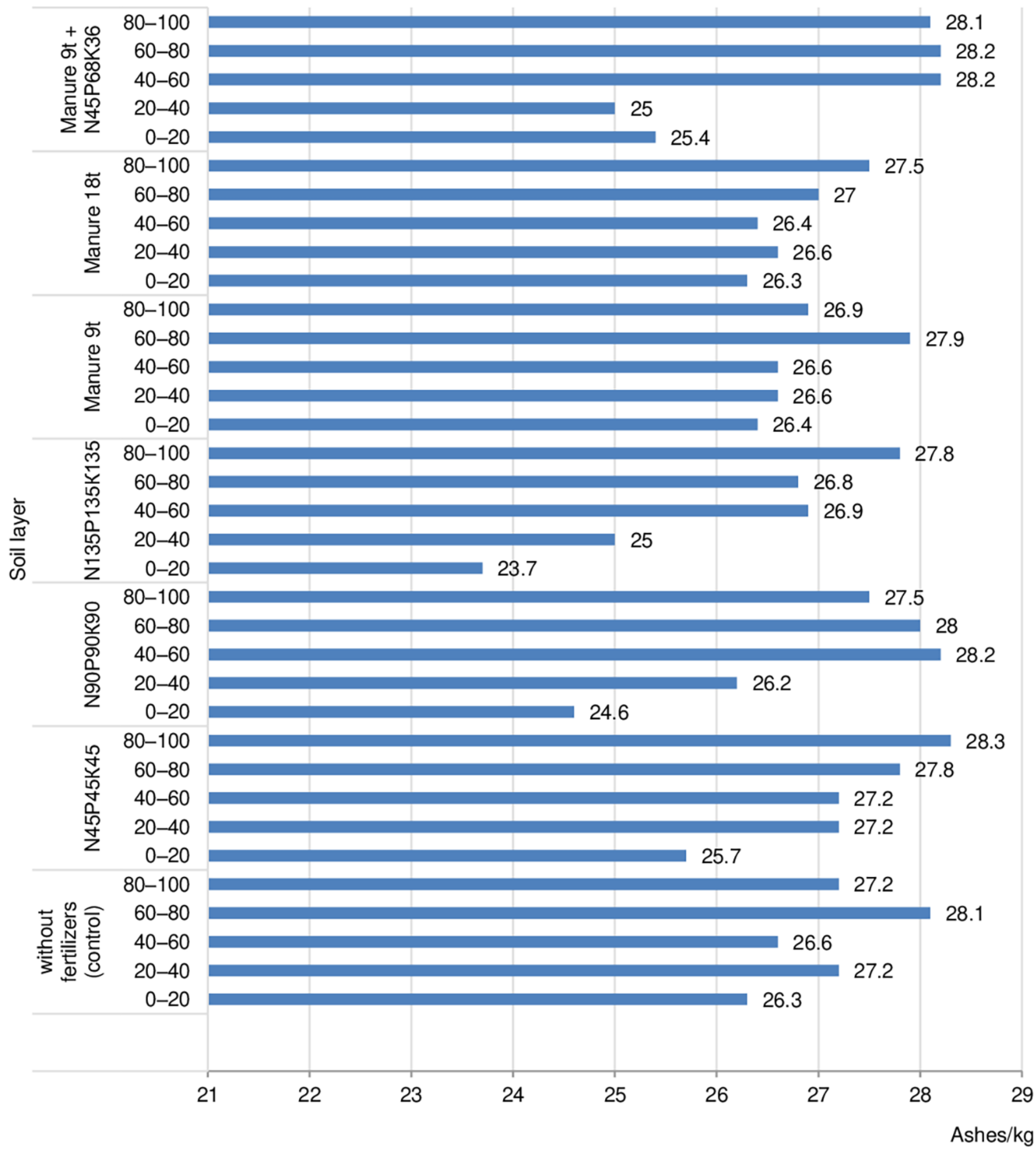

Figure 4. The change of exchangeable Ca^{2+} content in ashed black soil after continuous (1965–2025) fertilizer usage in field crop rotation

attention is given to the ratio between them in the structure of capacity of cation soil exchange. When potassium only is used with fertilizers, its content in the soil increases. As a result magnesium content changes to a lesser degree while potassium and magnesium balance is upset. The optimal ratio is Mg : K = 2–5. If the ratio is lower than 2, then magnesium deficit is observed, when it is more than 5, potassium deficit is observed [La Techniche di coltivazione Delle Principali colture agroindustriali, 1995].

The studies have revealed that even if using potassium with fertilizers (45–135 kg/ha K_2O yearly using different fertilizer systems) continuously, the ratio between these two important nutrients in soil intake complex for plants in a soil layer 0–20 cm is within optimal boundaries 2.6–3.6 (Figure 5).

On the plots where fertilizers were not used, the ratio was Mg : K = 4.2. Thus, when potassium fertilizer is used continuously, a problem of additional magnesium usage arises.

In the 20–40 cm deep soil layer, when fertilizers are used, an optimal ratio of the elements 3.3–4.5 is preserved. Deeper to the soil profile, magnesium and potassium ratio was approaching a critical one, that is potassium deficit was revealed.

Hence, the content of the moving compounds of calcium or magnesium in the soil is not always an objective indicator of their provision level of plants. Potassium and magnesium provision

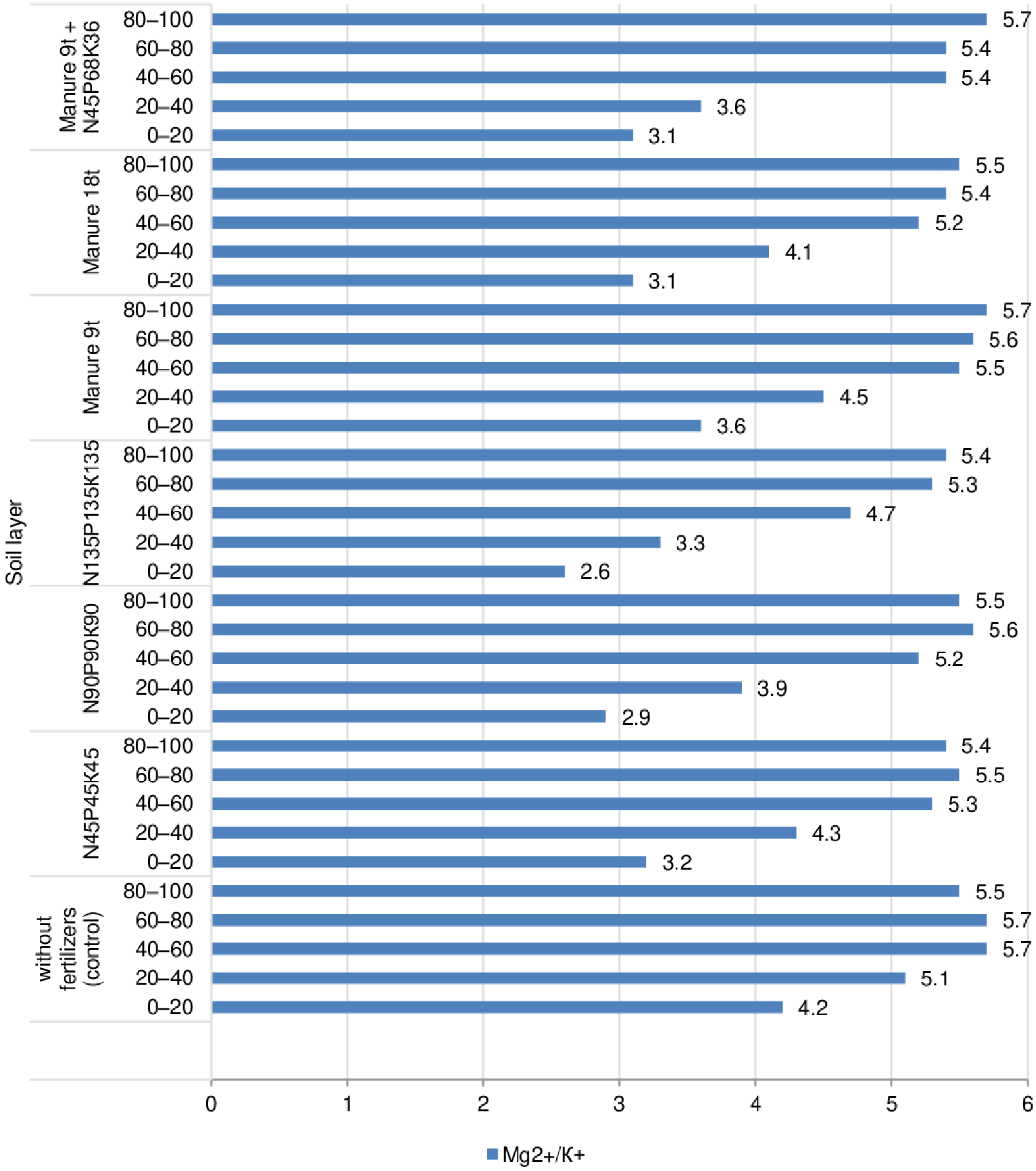

Figure 5. The change of Mg^{2+}/K^{+} ratio in the ashed black soil after continuous (1965–2023) fertilizer usage in field crop rotation

should be estimated in complex as they have an antagonistic impact on the absorption by plants. It is known that these nutrients compete for reaching plant root system. Potassium deficit will manifest itself more clearly when magnesium content in soil is higher and potassium fertilizer usage doses are low.

A continuous growing of agricultural crops in field crop rotation without fertilizer usage leads to gradual increase in ratio Mg : K in soil intake complex (SIC) up to 4.2 which proves the importance of potassium content in fertilizer usage system. Under fallows this index makes up 3.5.

Along with potassium, natrium (0.1–0.2%) is contained in plant textures almost always. It is an optional macroelement: it is a ballast in most cases, though its availability makes plants grow better. The potassium and natrium ratio in earth's crust approaches 1. According to its chemical qualities natrium is similar to potassium, but its ions unlike the ions of potassium, calcium and magnesium can not be fixed and are slightly held by soil colloids [Hospodarenko, 2015]. As you can see from the data and Figure 6, a slight increase in gross natrium content in 0–20 cm – 0.75 % soil layer occurs after continuous fertilizer usage only in variants with high doses mineral fertilizer usage. Its content on the land plots without fertilizer usage is 0.66 %. In 20–40 cm deep soil layer its content was increasing 0.1% only with mineral

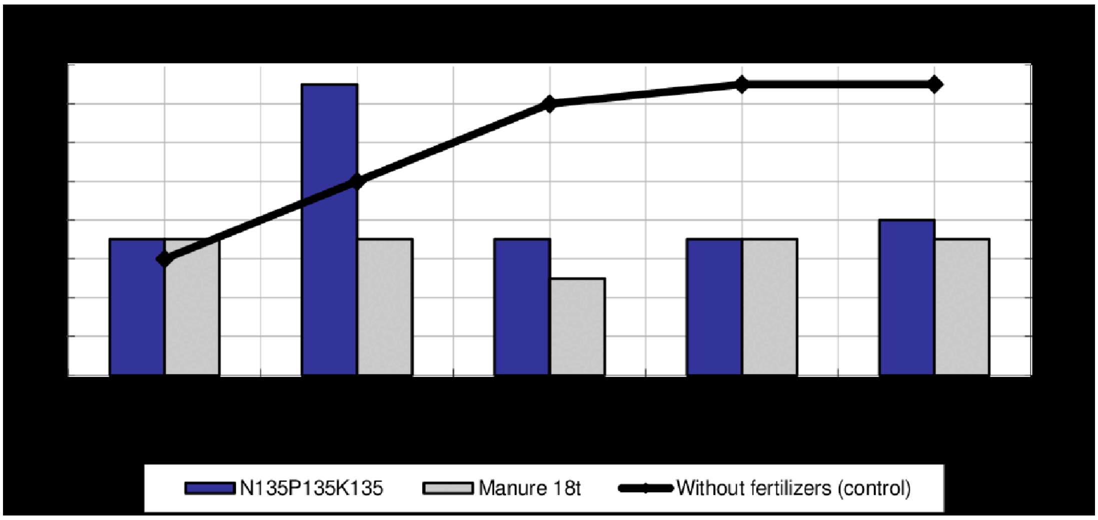

Figure 6. Gross sodium (Na_2O),% content in soil after continuous (1964–2023) fertilizer usage in field crop rotation

fertilizer system when using 135 kg K_2O/ha of crop rotation square. It can be explained by the fact that during the first four crop rotations potassium fertilizers were used as mixed potassium salt which contained 20% Na_2O.

A slight increase in the sodium content in soil can be explained by several reasons. First, by its considerable removal with sugar beet and maize yields for silage. Second, by the increased consumption of sodium by plants and the lack of potassium, as well as its migration beyond root containing soil layer.

CONCLUSIONS

As a result of ecological and agrochemical assessment of continuous mineral fertilizer usage in the field crop rotation, one can draw the following conclusions:

- fertilizer chlorine does not form stable compounds in the soil and migrates considerably in its profile. According to literature review, the chlorine fraction of fertilizers is still unstudied, which is an important point in terms of agrochemistry as well as ecology. Therefore, the issue of chlorine, especially its absorption by plants, migration to the subsoil, its penetrating into water sources, and its balance, should be assessed with the application of landscape and agrochemical approach. Fertilizer application in the field crop rotation in a dose of 45–135 kg of K_2O/ha does not enable chlorine content to increase in 1.5 m deep physiologically active soil layer.
- with continuous fertilizer usage in the ashed black soil, substantial changes of its intake complex occurred and the quantity of calcium and magnesium exchangeables has decreased, which causes the worsening of physical and chemical qualities and as a result can entail a lower fertility level.

The magnesium and potassium ratio in soil intake complex drops to 2.6–3.6 as a result of continuous usage of potassium with fertilizers when the control index without fertilizers is 4.2, which corresponds to the optimal ratio Mg : K = 2–5 ratio.

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