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THE INFLUENCE OF MINERAL FERTILIZERS ON THE DYNAMICS OF THE ACCUMULATION OF MAIN MACROELEMENTS IN THE SOIL AND IN WHEAT PLANTS

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Abstract

The experiment was carried out on chernozem during 2020-2021 in Dolj County, the wheat variety used is Glosa, an early autumn wheat, resistant to drought. The experiment was placed in the field according to the block method, in 4 repetitions with 8 variants. Following the use of different doses of fertilizers, the dynamics of nitric nitrogen, mobile phosphorus and mobile potassium in the soil, in the plant and in the grains were monitored at 3 determination dates, as well as the production obtained. After the analyzes carried out, it was found that the soil is rich in nitric nitrogen, ammoniacal nitrogen, the plants having at their disposal the nitrogen necessary for nutrition, and as regards the content of P and K, the soil is well supplied with these elements. Following the dynamics, the decrease in the content of main macroelements was observed, the younger the plants, the richer they are in these elements, and as the vegetative growth phase ends, the content decreases.

Key words*: fertilizers, wheat, protein, production.*

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important crops, having an important place in field crops (Li et al., 2020). It is one of the most widely cultivated cereal grains in the world, and also a staple food for many people, providing a valuable source of energy and nutrients for a healthy diet (Păunescu et al., 2016; Shiferaw et al., 2013).

Wheat flour is used in the bakery and pasta industry, and bran and third-grade wheat is used as concentrated fodder in animal feed. The secondary products - straw and chaff - are used either as coarse fodder mixed with other fodder, or as bedding for animals (Shewry, 2009).

In order to obtain a quality harvest, it is important to plant wheat varieties adapted to local conditions, to use natural or chemical fertilizers depending on the needs and to respect the work technology recommended for wheat cultivation (Reynolds & Borlaug, 2006).

Glosa wheat variety ranks first among the seeds of cultivated areas in Romania (22476.46 ha) followed by FDL Miranda (6444.72 ha), Izvor (3131.06 ha) and the area sown with the Glosa variety (1238 ha) in 2017 represents half of the total area cultivated with wheat in Romania (Băcanu (Șerban) et al., 2018).

The Glosa variety has a wide adaptability, being stable and constant in terms of production and less affected by the fluctuation of climatic conditions.

According to specialists in agriculture, it is an early variety, with good resistance to fall, wintering, drought and heat or ear germination (Dobre, 2015).

In conclusion, wheat is an essential crop for human and animal food, and the proper management of the crop can ensure obtaining a quality and profitable harvest.

By applying the right combination of nutrients at the right time and in the right amounts, farmers can ensure that crops have access to the essential elements they need for healthy growth. This can help maximize the use of resources like water, sunlight, and other nutrients while minimizing waste and environmental impact (Srivastav, 2020).

In addition, balanced fertilization can help improve soil composition by replenishing nutrients that have been depleted through previous cropping cycles. This can help maintain the productivity of the soil over time and reduce the need for costly inputs like pesticides and herbicides.

Overall, the balanced application of fertilizers is essential for sustainable agriculture practices that prioritize both crop productivity and environmental stewardship (Pandey et al., 2020).

Regarding the soil requirements, wheat is the most demanding grain, distinctly exceeding the requirements of the other grains (Singh, 2017). The most suitable soils for wheat must offer optimal conditions for plant growth and development (Salim & Raza, 2020). The fertility of the soils intended for wheat cultivation must be high, because the poorly developed and somewhat predatory root system of this plant is not capable of extracting even the last remnants of nutrients from the soil (Popovici et al., 2017). Wheat is part of the crops that are very pretentious to fertilizers, although it does not extract large amounts of nutrients from the soil (Salim & Raza, 2020).

MATERIALS AND METHODS

The experiment was placed in the field according to the block method, in 4 repetitions with 8 variants, on a surface of 1600 m^2 (plot surface 10/5 m) located in the Segarcea area, Dolj county, on a clay- illuvial chernozem (SRCS 1980) or argic phaeozems (SRTS 2012) with the following profile and characteristics:

- Ap, Apt, A_m, AB, Bt_1, Bt_2, Bt_3, BC, Ck;
- subangular polyhedral structure, moderately compact, firm when wet, hard when dry, moderately plastic;
- medium clay loam texture on the Ap horizon and clay loam on the other horizons;
- weak acid reaction (pH = 6.10-6.56);
- the degree of nitrogen insurance is low to medium (Nt = 0.08-0.12%);
- well supplied with phosphorus accessible to plants: 55-61 ppm P and well provided with potassium (164-218 ppm K);
- humus content between 2.42-2.86%.

The treatments to which each variant was subjected are: V1 - unfertilized control, V2 - N_{60}, V3 - N_{100}, V4 - P_{40}, V5 - P_{80}, V6 - $N_{60}P_{40}$, V7 - $N_{100}P_{80}$, V8 - $N_{150}P_{100}$.

The fertilizers used to ensure the mentioned doses were ammonium nitrate with 34.5 N% and concentrated superphosphate with 40 P_2O_5%. The entire quantity of fertilizers was applied once at the beginning of October, before sowing, and was incorporated into the soil through a work with an agricultural combinator. On October 8, wheat of the Glosa variety was sown, the preceding plant was soybean - a leguminous crop that has the property of fixing nitrogen from the nodosity on the root.

Weather conditions during the experiment are summarized in Figure 1. The year 2020 was a favorable year for wheat cultivation, with precipitation and temperature values closer to the multiannual average. Thus, the precipitation exceeds the multi-year average exactly when it was necessary, namely in October, November, helping to good germination and growth, as well as in the months of May-June, helping to form the spike and the grain.

The temperatures were within accessible limits, registering slightly lower temperatures in the summer, thus helping the formation of the grain.

In 2021, higher temperatures were recorded in almost every month of the growing season except for May, which was 0.70°C lower. In June, during the formation of the grain, the temperatures were higher by 0.90°C, which led to its shrivelling.

Precipitation was also lower in 5 months out of the 9 months of the vegetation period, being very low at sowing, the sunrise did not occur on time, and 41.5 mm lower in April when the plants needed to form the spike.

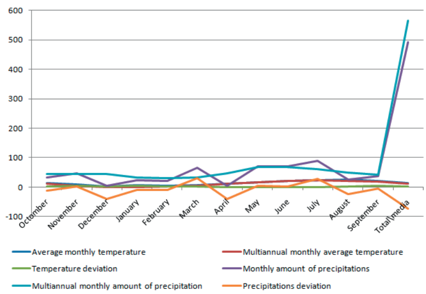

Figure 1. Temperatures and precipitations recorded during the wheat growing season in 2020-2021

The following determinations were made on the soil samples collected at a depth of 0-20 cm:

- determination of ammoniacal nitrogen from the soil by extraction in potassium sulphate and then by Nessler coloring, spectrophotometric determination at a wavelength of 525 nm,
- determination of nitric nitrogen by extraction in potassium sulphate and coloring with phenol

disulfonic acid, spectrophotometric determination at a wavelength of 420 nm,

- determination of mobile phosphorus in ammonium lactate acetate extract,
- determination of mobile potassium in ammonium lactate acetate extract by flamephotometry.

Regarding the plant samples, they were subjected to the following determinations: determination of total nitrogen, phosphorus and potassium in plants, by Kjedahl method modified by Gogoasa - disaggregation with sulphuric acid and perhydrol and then distillation.

Plant and soil samples were collected before heading stage, at heading and at harvest.

As part of the dynamics, chemical analyzes were carried out on the soil at a depth of 0-20 cm, in which nitric nitrogen, ammoniacal nitrogen, mobile phosphorus and mobile potassium were studied.

The chemical analyzes of the soil are particularly important, given the fact that only with their help, it is possible to determine the extent to which the plants use the fertilizers administered for fertilization. In order for the results to be as real as possible, 5 soil samples were taken from each experimental variant, from which an average sample was then made.

To determine the degree of supply of plants with assimilable nitrogen, it is necessary to determine the forms of nitrogen in the soil.

The samples of wheat grains were analyzed as follows:

- determination of nitrogen, phosphorus and potassium from wheat grains by Kjedahl method, disaggregation with concentrated H_2SO_4 and perhydrol, then distillation.
- interpretation of the data regarding the grain yield obtained in the year 2020/2021.

RESULTS AND DISCUSSIONS

Nitrogen is the most important nutritional element in the life of plants, it contributes to the increase of agricultural production (Sala, 2011), being able to affirm that without nitrogen there is no life, but also the lack of phosphorus and potassium in soil creates an improper environment for their development.

Following the dynamics of the formation of soluble nitrogen compounds, it is found that in general in the early spring the amount of nitric nitrogen is very small, then increases as the weather warms up to reach a maximum usually in April, May, so that afterwards decreases in summer during the dry period and increases again towards the beginning of autumn (Figure 2).

Due to the fact that the content of organic matter is higher in phaeozems, as well as the almost weak reaction, favorable conditions are created for the downgrading of the nitrification process, leading to an increase in the amount of nitric nitrogen.

During the vegetation period, the accumulation of nitrates in the soil does not occur at the same time as the plants' requirements, and for this reason, the application of chemical fertilizers is required to ensure the necessary nutrients for plant growth.

Wheat needs nitrogen in the spring for the completion of germination and for vegetative growth, or during this time it often happens that the soil has a small amount of nitrogen.

Analyzing the data obtained, it can be seen that, following the applied fertilizers, the nitric nitrogen in the soil during the heading stage (from 05.05 to 06.12.2021) is in sufficient quantity. On May 5, the NO_3^- content varied between 64-147 kg NO^{-3} /ha.

The highest amount of nitric nitrogen is recorded when it is applied $N_{150}P_{100}$ - 147 kg NO_3^-/ha and when N_{100} is applied - 141 kg NO_3^- /ha, situations when large amounts of nitrogen were used for fertilization.

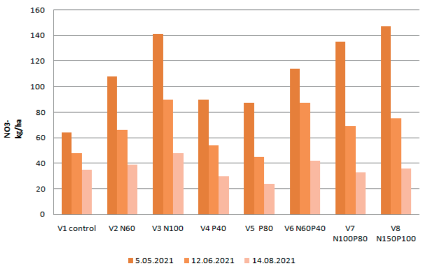

Figure 2. Nitric nitrogen content in the soil during the vegetation period

Moderate values of the nitric nitrogen content in the soil are also recorded in the situation where nitrogen was not used, but only phosphorus: P_{40}, P_{80}, respectively 90 kg NO_3^- /ha, respectively 87 kg NO_3^-/ha, due to the phosphorus-nitrogen interaction in the soil which has the ability to increase nitrogen efficiency, the contents recorded in nitric nitrogen are higher compared to the unfertilized control (V1 - 64 kg NO_3^- /ha).

On 12.06.2021, the date when the heading stage ended, the NO_3^- content of the soil decreases in all variants, between 45-90 kg NO_3^-/ha. This decrease is normal because the wheat plants needed large amounts of nitric nitrogen for nutrition.

The highest amount of nitrogen was registered at V3 (N_{100}), V6 ($N_{60}P_{40}$) and V8 ($N_{150}P_{100}$), variants where high doses of nitrogen were used for fertilization.

Except for the unfertilized control, in all other variants, the nitric nitrogen content in the soil, even if it has decreased compared to 05.05.2021, indicates a normal and good soil supply state.

Until the heading stage, wheat has the greatest need for nitrogen, after which the requirements decrease. The nitrogen in the soil decreases after this period, reaching at harvest (14.08) a nitric nitrogen content of the soil between 24 kg NO_3^-/ha (V5) - 48 kg NO_3^-/ha (V3), indicating a poor supply of the soil in nitric nitrogen, respectively a mediocre state of the soil in nitric nitrogen.

In conclusion, it can be observed, at all 3 determination dates, that the soil is well supplied with nitric nitrogen, the plants having the necessary nitrogen available for growth and development.

Nitric nitrogen is found in high quantities in the soil both due to the use of chemical fertilizers and the fact that the preceding plant was soybean, but also due to the increase in soil temperature which actively stimulates microorganisms and implicitly nitrifying bacteria.

Analyzing the obtained data as a result of the application of fertilizers, the ammoniacal nitrogen in the soil varies between 19.8-82.5 kg NH_4^+/ha on 05.05.2021, the condition of the soil's supply of ammoniacal nitrogen being very good, until heading stage, wheat has enough NH_4^+ which can be converted into nitrates (Figure 3).

The richest variant in ammoniacal nitrogen is V3 to which the dose of N_{100} was applied and V8 to which the dose of $N_{150}P_{100}$ was applied, with 75 kg NH_4^+/ha and, respectively, 82.5 kg NH_4^+/ha.

Until 12.06.2021, NH_4^+ is continuously decreasing in all variants, and the lowest NH_4^+ content is recorded at control - 9 kg NH_4^+/ha, the variant to which no fertilizers were applied. We can conclude that the plants had at their disposal a sufficient amount of ammoniacal nitrogen to later transform into nitrates.

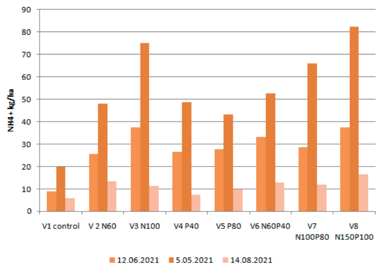

Figure 3. Ammoniacal nitrogen content in the soil during the vegetation period

Ammoniacal nitrogen decreases after heading stage, but in a smaller proportion than before heading stage. At harvest, the NH_4^+ content of the soil is low and is between 6-16.5 kg NH_4^+/ha, the soil having a weak to mediocre supply of ammoniacal nitrogen. This decrease is due to nitrification of ammoniacal nitrogen and consumption by plants.

The variant with the lowest content is unfertilized control -6 kg NH_4^+/ha, the highest content being recorded at the variant where $N_{150}P_{100}$ was applied -16.5 kg NH_4^+/ha.

In general, it is considered that the acidic environment favors the absorption of nitric nitrogen and the neutral and alkaline one favors the absorption of ammoniacal nitrogen (Tisdale et al., 1993; Lixandru et al., 1990).

Phosphorus in the soil, in an easily assimilable form, has a regime that fluctuates less during the vegetation period than that of nitrogen (Table 4). In the soil layer, usually, the total content of the soil in phosphorus is lower compared to nitrogen.

Before heading stage (May 5), the phosphorus content in soil varied within fairly large limits, recording from the control to V8 between 168 - 396 kg P/ha, the soil being well - very well supplied with phosphates accessible to plants and excessively supplied only for V8 variant.

At variants in which phosphorus is applied together with nitrogen, the highest phosphorus contents are registered, which oscillate between 254 and 396 kg P/ha, the supply of the soil with this element is very well and respectively excessive.

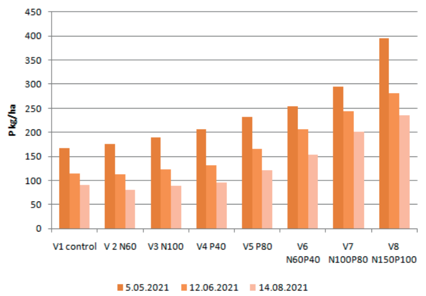

Figure 4. Phosphorus content in the soil during the vegetation period

At heading stage (12.06.2021) the phosphorus content of the soil registers lower values, being between 113 and 282 kg P/ha.
The highest level of phosphorus in the soil at this time, is observed for V8 - 282 kg P/ha to which $N_{150}P_{100}$ was applied; V7 - 243 kg P/ha and V6 - 207 kg P/ha, the soil in these variants being very well supplied with phosphorus.
At harvest, the phosphorus content is lower than the other two determinations, as expected, because the plants needed this element in their nutrition. It has values between 81 kg P/ha (where N_{60} is applied) and 236 kg P/ha (where $N_{150}P_{100}$ is applied). The phosphorus supply status of the soil is good for variants V5-V7, very good for V8 and medium supplied for V1-V4.
The dynamics of phosphorus in the soil for the 3 data analyzed highlights the fact that the chemical fertilizers used have an effect on its mobilization. Phosphorus mobilization as a result of the applied treatments was different depending on the administration of phosphorus as fertilizer.
Analyzing the data dynamics, it can be observed that the soil is medium and well supplied with phosphorus, providing the plants with the necessary phosphorus for their growth and development.
The potassium in the soil in easily assimilable forms has a regime during the vegetation period in which the fluctuations characteristics of nitrogen are absent (Figure 5). Due to the chemical and biological processes in the soil, it passes from the mineral form to the soil solution.
Analyzing the obtained data, it can be observed that the soil is medium supplied with potassium, its content oscillating between 143 kg K /ha (V1) on 14.08. and 296 kg K/ha (V8) on 05.05.

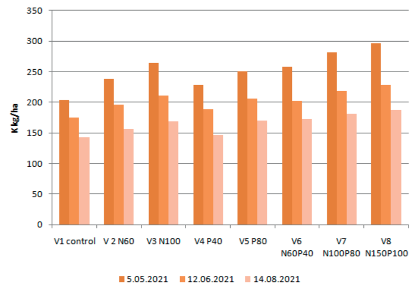

Figure 5. Potassium content in the soil during the vegetation period

From the data contained in Figure 5, it appears that the soil is medium supplied with potassium, its content varying between 203 and 296 kg K/ha at the first determination date (5.05.2021), regardless of the treatments applied, the soil providing potassium necessary for the growth and development of plants. The application of fertilizers with both nitrogen and phosphorus lead to an increase in the potassium content of the soil as a result of the nitrogen - phosphorus - potassium interaction, reaching 282-296 kg K/ha.
At heading stage, a weak supply of soil in potassium is recorded for V1-V2-V4 and medium supply for the other variants, the content oscillating between 202 kg K/ha (V6) and 228 kg K/ha (V8).
At harvest potassium content registers values between 143 kg K/ha (V1) and 188 kg K/ha (V8) which indicates a poor supply of soil in potassium for all 8 variants. This low content is due to consumption by the wheat plants during the vegetation period.
The content of nitrogen, phosphorus and potassium determined in all variants over the course of the vegetation period shows a variation of these elements. The dynamics of the main nutritional elements (N, P, K) in wheat plants is presented in the Figure 6.

The total nitrogen content of plants changes to a rather large extent under the influence of fertilizers.

Along with the growth of the plants, the nitrogen, phosphorus and potassium content decreases, eventually reaching the lowest content in the straw at harvest, due to the increase in the vegetative mass of the plants.

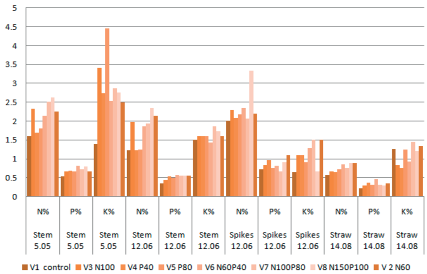

Figure 6. Dynamics of N, P, K accumulation in wheat plants

The maximum consumption of nitrogen is recorded at heading stage, after which a movement of a considerable part of nitrogenous substances is observed from the respective organs (stems, spikes) to the grain, where most of it is represented by protein compounds.

Based on the determinations made on the plants, it can be seen that before heading stage (5.05) the nitrogen content of the plants varies between 1.605% (control) and 2.631% (V8).

At heading stage, analyzes were done separately for spikes and analysis for stem + leaves (plant without spikes).

A higher content of total nitrogen is observed in the spikes than for stem + leaves, which indicates that the nitrogen has started to migrate into the spikes.

For stem + leaves, the total nitrogen varies between 1.221 % (control variant) and 2.34% (V8), while in spikes the nitrogen content varies between 2.013 % (control) and 3.341% (V8).

At harvest, the nitrogen content is very low compared to the content recorded for the plants before and after heading stage. At harvest, the nitrogen content varies between 0.564% (control) and 0.889% (V8). A higher value of the nitrogen content in the plants is observed in the variants where fertilization was done with nitrogen and phosphorus, the increase being due to the interaction between nitrogen and phosphorus.

The phosphorus content of the wheat plants decreases with the growth of the plants, leaving the phosphorus to be assimilated more intensively in the second part of the vegetation.

The application of nitrogen fertilizers increases the phosphorus content in plants. The phosphorus content drops significantly for straws, because it moves towards the grain to participate in the synthesis of protein substances, the desorption phenomenon being very little obvious for phosphorus.

Before heading stage, the phosphorus in the plants oscillates between 0.54% (control) and 0.81% (V6). It was observed that the phosphorus content was much higher in the spikes than in straws. For straws, the content varied between 0.35 (control) and 0.58 (V6). At harvest, the phosphorus content of the straws varied 0.21 at (control) and 0.46 (V6).

In terms of potassium dynamics, in the first phases of vegetation the largest amount accumulates at an accelerated and intense rate, observing an obvious decrease at the end of the vegetation period due to the desorption phenomenon.

The amount of potassium in the plants analyzed before heading stage oscillates between 1.4% (control)-4.45% (V5). At heading stage, the potassium content decreases both in straws and in spikes, straws having a higher content than spikes. For straws, the potassium content is between 1.5% (control) and 1.86% (V7), and in spikes between 0.65% (control) and 1.51% (V7).

At harvest, the potassium content of the straw is, in most variants, lower than the potassium content of the straw at the time of heading stage and higher than that of the spice at the time of heading stage.

In wheat grains, the N/P ratio registers higher values compared to plants, due to the fact that both elements are in large quantities compared to plants, and the N/K ratio has lower values in grains than in plants, because nitrogen has been accumulated in grains in increased quantities, while potassium was returned to the soil through the desorption phenomenon (Figure 7).

It can be stated that the application of phosphorus fertilizers increases the degree of use of nitrogen from fertilizers and from the soil, and thus contributes to achieving significant increases in production.

The nitrogen content of the grains has a direct influence on their quality, and is influenced by the amount of fertilizer applied to the variant.

The nitrogen content oscillates between 1.95% (control)-2.351% (V6) and the phosphorus content oscillates between 0.64% (control) and 1.02 % (V8).

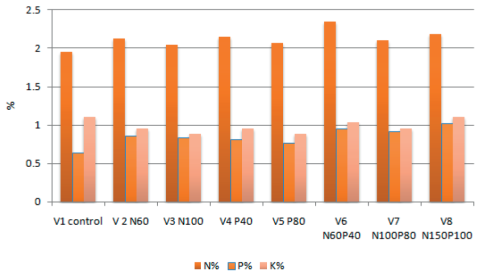

Figure 7. Accumulation of N, P, K in wheat grains

Regarding potassium, it oscillated between 0.89% (V3, V5) - 1.1% (V1, V8).

The potassium content in grains registers a normal decrease, being smaller than in straw, potassium having an auxiliary role in the formation and decomposition of the main substances in the grain, a good part of the potassium being returned to the soil.

Table 1. Grain wheat production (kg/ha)

Variant	Productions kg/ha	Difference compared to the average production	Significance	Difference from control	Significance	Yields kg a.s/kg
V1 control	5466	-1117	0	-	-	-
V2 N_{60}	6340	-243	0	+874	xxx	14.5
V3 N_{100}	6861	+278	0	+1395	xxx	13.9
V4 P_{40}	6121	-462	0	+655	xx	16.3
V5 P_{80}	6325	-258	0	+859	xxx	10.7
V6 $N_{60}P_{40}$	6525	-58	0	+1059	xxx	10.6
V7 $N_{100}P_{80}$	7181	+598	xx	+1715	xxx	9.5
V8 $N_{150}P_{100}$	7850	+1267	xxx	+2384	xxx	9.5

LSD 5% 404.7; LSD 1% 560.5; LSD 0.1% 773.3; Average production 6583 kg/ha

The productions obtained varied depending on the doses of fertilizers applied (Table 1). Thus, they varied between 5466 kg/ha for the unfertilized control and 7850 kg/ha when $N_{150}P_{100}$ was applied. The fairly high production obtained for control of 5466 kg/ha, is due to the previous years' fertilization of the soil and the previous crop - soybeans. The application of a moderate dose of nitrogen N_{60} leads to an increase in production to 6340 kg/ha, and a high dose of N_{100} leads to productions of 6861 kg/ha.

The moderate doses of phosphorus P_{40}, P_{60} also lead to higher production compared to the control 6121-6325 kg/ha, with a yield of 655 kg/ha and 859 kg/ha, due to the direct action of the applied phosphorus, but also due to the interaction nitrogen-phosphorus from the soil.

The highest productions are obtained after the use of doses of $N_{100}P_{80}$-7181 kg/ha and $N_{150}P_{100}$-7850 kg/ha.

Analyzing the productions obtained compared to the average productions, only the variants in which the above doses were applied are significant ($N_{100}P_{80}$) and distinctly significant when $N_{150}P_{100}$ is applied, with an increase in production compared to the average of 598 kg/ha and 1267 kg/ha. The application of NP fertilizers leads to higher wheat productions, these results are similar to Fana et al. (2012) and Kashif et al. (2023).

Compared to the control, all 7 variants in which chemical fertilizers were used in different doses are distinctly significant and only the variant in which the dose of 40 kg P/ha was applied is statistically significant.

The application of fertilizers leads to important increases in production per kg of active fertilizing substances. Nitrogen doses N_{60} and N_{100} lead to yields of 14.5 and 13.9 kg/ha a.s.

Overall, the use of organic and inorganic fertilizers in combination plays a crucial role in enhancing the growth and yield of crops by providing essential nutrients, due to the efficient transfer of carbon synthesis products and the storage of carbohydrates and proteins in grains (Ramadhan, 2022).

CONCLUSIONS

Analyzing the dynamics of the contents of $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, P and K in the soil during the research carried out, it is generally found that the soil is well supplied with these elements.

Along with the growth of the plants, the nitrogen, phosphorus and potassium content decreases, eventually reaching the lowest content in the straw at harvest, due to the increase in the vegetative mass of the plants.

Following the dynamics of the accumulation of N, P, K in wheat plants, a decrease in the percentage content of main macroelements was observed, the younger the plants, the richer in N, P and K, and as the vegetative growth phase ends, the content decreases. This decrease is slower at N and P and faster at K.

At the end of vegetative growth, along with the heading stage, the content of N, P and K in wheat plants is relatively constant until maturity.

Chemical fertilizers with nitrogen and phosphorus administered alone or together led to increases in production, the most significant increases in production were recorded when the fertilizers were administered together (V7 and V8).

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