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Dynamics of nutrients in the soil and spring barley yield depending on the rates of mineral fertilizers

Volodymyr Hanhur[1], Mykola Marenych[2], Irina Korotkova[3*], Valentina Gamayunova[4], Len Oleksandr[5], Liubov Marinich[1], Roman Olepir[6]

[1] Department of Plant, Faculty of Agro-Technology and Ecology, Poltava State Agrarian University, Poltava, Ukraine
[2] Department of Selection, Seed Growing and Genetics, Faculty of Agro-Technology and Ecology, Poltava State Agrarian University, Poltava, Ukraine
[3] Department of Biotechnology and Chemistry, Faculty of Agro-Technology and Ecology, Poltava State Agrarian University, Poltava, Ukraine
[4] Department of Agriculture, Geodesy and Land Management, Faculty of Agro-Technology, Mykolayiv National Agrarian University, Mykolayiv, Ukraine
[5] Poltava State Agricultural Research, Poltava, Ukraine
[6] Department of Agriculture and Agrochemistry, Faculty of Agro-Technology and Ecology, Poltava State Agrarian University, Poltava, Ukraine

Abstract
The study aim was to evaluate nitrogen, mobile phosphorus and exchangeable potassium efficiency from different mineral fertilizers applied to soil at the spring barley cultivation. The impact of fertilization systems with different doses and ratios of nutrients ($P_{45}K_{30}$, N_{45}; $N_{23}P_{23}K_{15}$; $N_{45}P_{45}K_{30}$; $N_{68}P_{68}K_{45}$) on the spring barley yield from 3-years of experiments in the Poltava (Ukraine) was analyzed. The study of doses and forms of mineral fertilizers influence on the main elements content of plant nutrition at all stages of spring barley organogenesis was carried out in the soil layer of 0–20 cm and at a depth of 20–40 cm. It was found the application of fertilizers with increased nutrients content at sowing provide an increase in their content in the soil compared to the control. The highest effect was observed when the fertilizers at a dose of $N_{68}P_{68}K_{45}$ was used. An increase in nitrogen content in the first stage of organogenesis (BBCH 01–02) in the soil layer of 0-20 cm was 17.6%, phosphorus 35.4%, potassium 19.8% compared to control. In the deeper layer of soil 20–40 cm, the content of these elements was much lower. A significant decrease of nutrients content in the soil was observed between stages III–XII of organogenesis, but no external signs of nitrogen, phosphorus and potassium deficiency were detected in spring barley plants. The application of $N_{68}P_{68}K_{45}$ kg ha^{-1} of active substance and full protection crops from pests, diseases and weeds resulted in the highest grain yield of spring barley 5.27 t ha^{-1}.

Keywords: spring barley, precursors, doses of mineral fertilizers, productivity, nitrogen, phosphorus, potassium

Introduction

Barley (*Hordeum vulgare L.)* is an important grain crop grown worldwide for food and feed production. In world agriculture, barley production ranks fourth after wheat, rice and corn. Barley grain yield depends on a number of factors, in particular differences in varieties, soil, climate and growing conditions. Low soil pH, lack of moisture, poor soil drainage and imperfect agricultural technologies are negative factors which affect yield [1]. The most important factor in regulating the yield and quality of barley grain is undoubtedly fertilizers. The share of a crop harvest formed by using fertilizers can reach 23-70%. Plant growth and yield are highly dependent on the ability of the soil to provide plants with sufficient amount of nitrogen. Nitrogen fertilizers play a potential role in the formation of soil nitrogen [2]. The effectiveness of nitrogen use by grain crops is influenced by the ability of root system to absorb nitrogen from the soil, assimilation of nitrogen in the plant and its redistribution from vegetative parts to grain. It is known that only 30–50% of the applied nitrogen fertilizers and 25% of phosphorus are absorbed by crops or tied up in soil organic pools, which include both microbial biomass and soil organic matter. The rest of the nitrogen is losses from denitrification, leaching and evaporation into the environment, which leads to the various negative ecological effects [3, 4]. To recoup the losses, it is necessary to apply nitrogen from 28.0 to 46.5%. To some extent, the amount of mineral fertilizers applied can reduce the use of inorganic growth stimulants [5] and bio stimulants [6].

In the process of growth, plants absorb not only the mineral nitrogen from the soil, but also nitrogen from organic fertilizers, the so-called mineralized nitrogen [7]. Plants use several forms of nitrogen in the natural soils. In most aerated soils, nitrate is a predominant form absorbed by plants from the soil, while ammonium may be the predominant form in some acidic and/or anaerobic environments [8].

The nitrogen uptake by the soil is low, which means that plants can only use about 50–75% of the nitrogen coming from fertilizers [9]. In general, the availability of nitrogen largely depends on the amount of water in the soil [10].

The impact of nitrogen on plant development can be comprehensive, including mechanisms that control seed germination [11, 12], flowering period [13], stomata movement [14], as well as the structure of roots and shoots [15, 16].

It should be noted that phosphorus has a significant and essential part in plant nutrition, especially at the early stages of growth, when the root system is not fully developed [17, 18]. It was found that crops, including barley, do not respond to nitrogen fertilizers when their phosphorus content is insufficient [19, 20]. However, small doses of nitrogen (30–50 kg ha^{-1}) are not able to change a P level in the soil, while high doses (150–250 kg ha^{-1}) can reduce the available P of the soil by about 35% [21]. So, it is important to monitor phosphorus levels in the soil, especially when intensification of nitrogen fertilization is considered.

In addition to forms and methods of fertilization, the determination of appropriate agronomic practices in order to increase barley production and yields, taking into account the ecological conditions of the regions or the growing technology is also important. Since barley is a crop with a short growing season, in some regions with cool and humid climates, early sowing is used to extend the growing season, which leads to grain yield increase. However, in this case, young plants are often exposed to low soil temperatures that limit the mobility of nutrients in the soil and reduce root growth, resulting in limited nutrient availability. To overcome nutrient deficiency, starter fertilizers (N-P-K: 12-5-15) are used at early sowing, then a basic dose of nitrogen (NPK: 24-4-5) in the amount of 100 kg ha^{-1} is applied [22].

One of the most important agronomic techniques of spring barley cultivation is the proper selection of a predecessor crop in combination with balanced mineral fertilizers for specific soil and climatic and production conditions. When testing a number of predecessor crops, such as sugar beets, soybeans, corn for silage and grain, sunflower, at various levels of mineral fertilizers, in the process of growing spring barley, soybeans and sugar beets turned out to be the most effective. The highest barley yield of 5.00 kg ha^{-1} was obtained after soybean and 5.28 kg ha^{-1} after sugar beet, which is 0.62 and 0.94 kg ha^{-1} higher than the control, respectively. After sunflower, spring barley yield was at a control level [23]. Incorporating legume crops (beans, peas) into the crop rotation increases the carbon and nitrogen content in the soil, so using suitable intercrops can replace or reduce the amount of mineral nitrogen fertilizer used [24].

The authors of the study [25] established a correlation between the efficiency of nitrogen used by barley plants and yield. Higher nitrogen content promotes intensive accumulation of chlorophyll in leaves and the photosynthesis increase, which is accompanied by the yield increase. It was found that the increase in chlorophyll content by 13.5% in the leaves is accompanied by the yield increase by 12.7%.

Mutual use of organic and mineral fertilizers is possible in order to solve the problem of insufficient fertility or soil depletion due to continuous cultivation of grain crops, removal of crop residues, leaching of nutrients as well as to sustainably increase barley yields [26]. Statistically identical grain yields can be obtained by applying 50% of the recommended doses of N and P (18-10 kg ha^{-1}) from mineral sources + 50% from compost (2.69 kg ha^{-1}), as well as by applying 33% NP (12 kg ha^{-1}) in the composition of Diammonium phosphate and urea + 33% from compost (1.97 kg ha^{-1}) + 33% from manure (0.68 kg ha^{-1}) [27].

The combination of NPK-containing fertilizers and humic acid has a significant impact on the biological yield of barley, as it leads to the growth in utilization coefficient of nutrients from mineral fertilizers (nitrogen, phosphorus, potassium) by increasing the permeability of cell membranes [28, 29].

In general, to further optimize the crops system fertilization, including spring barley, and develop practical recommendations for the use of fertilizers, it is necessary to establish which element or set of elements of nutrition determine their effectiveness and lead to the significant yield increase. The impact of fertilization systems with different doses and ratios of nutrients on the yield and quality of spring barley grain in the widespread short-rotation field crop rotations has not been studied sufficiently.

Therefore, the present study aim was to determine the impact of different rates of mineral fertilizers on the dynamics of the main nutrients content in the soil (easily hydrolysable nitrogen, mobile phosphorus and exchangeable potassium) and grain yield of spring barley.

Material and Methods

Field experiment was conducted in the period of 2018-2020 on the research field of Poltava State Agricultural Research Station named by M.I. Vavilov of the National Academy of Agrarian Sciences of Ukraine.

The soil of the experimental plots was typical low-humus hard loamy black soil with a humus content in the arable layer of 4.85%; pH_{KCl} = 6.0–6.5; hydrolytic acidity was 2.0 mg per 100 g of soil. The nutrient content was: easily hydrolysable nitrogen – 122.8–138.4 mg kg^{-1} of soil, mobile phosphorus – 79.6-88.1 mg kg^{-1} of soil, exchangable potassium – 139.8–148.1 mg kg^{-1} of soil.

The precursor crop was late-maturing soybean varieties. Tillage in volved breaking-up the soil after a predecessor crop being harvested with a Normandie 60 disc shelling machine to a depth of 8–10 cm.

The main tillage was carried out with a chisel aggregate AGH-2.5 to a depth of 25–27 cm in early October. Pre-sowing tillage was carried out in the first decade of April by combined aggregate AKPN-6 Podillia to a depth of 6-8 cm. After that, spring barley was sown by a continuous method with a row spacing of 15 cm with a SZ-5.4 seeder with minimum time gap.

‘Sviatohor’ barley grain was sown in the experiment. Seeding rate was 4.0 million of germinated seeds per hectare.

Experiment scheme included 6 fertilization variants, in particular:

- Without fertilizers (control);
- $P_{45}K_{30}$;
- N_{45};
- $N_{23}P_{23}K_{15}$;
- $N_{45}P_{45}K_{30}$;
- $N_{68}P_{68}K_{45}$.

Ammonium nitrate, granular superphosphate, and potassium chloride were used as mineral fertilizers.

The protection system provided seed treatment before sowing with the preparation Raxil Ultra (liquid concentrate of suspension Tebuconazole, 120 g l^{-1}) in the amount of 0.4 l t^{-1}. Crop protection against weeds was carried out by spraying the crops with Logran 75 WG herbicide (water-soluble granules of Triasulfuron, 750 g l^{-1}) at the rate of 0.01 kg ha^{-1} in the tillering phase before the phase of stem elongation (BBCH 21-29).

To protect crops from pests, insecticide Karate Zeon 050 CS (microencapsulated aqueous suspension of Lambda-cyhalothrin, 50 g l^{-1}) was applied in a dose of 0.15 l ha^{-1}. To protect crops from diseases fungicide Alto Super 330 EC (emulsion concentrate of cyproconazole, 80 g l^{-1} + Propiconazole, 250 g l^{-1}) in a dose of 0.5 l ha^{-1} was applied at the beginning of earing phase (BBCH 37-51). The sown area of the land plot was 100 m^2, the accounting area was 80 m^2. Barley was sown in four repetitions. Placement of variants was randomized.

Spring barley yield was harvested separately by the method of direct harvesting with the combine harvester SAMPO-500. Grain from each experimental plot was weighed and corrected for moisture content (standard moisture content is 14%) and contamination with impurities was converted for yield in t ha^{-1}. Analysis of yield structure was carried out in the test sheaves selected from two non-contiguous replications.

The indicators of precipitation and air temperature during the growing season of spring barley had significant deviations from the average long-term data over the research years (Fig. 1, 2).

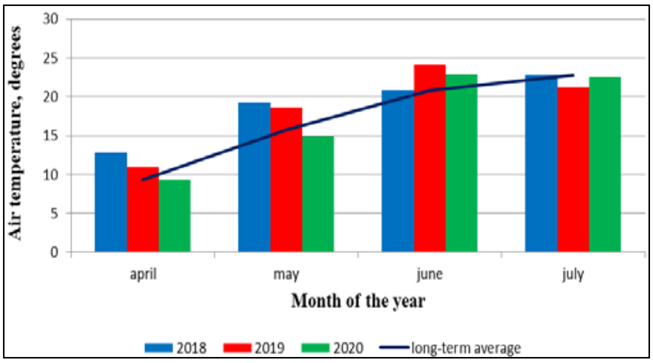

Fig 1: Average monthly air temperature for 2018-2020 spring barley vegetation seasons (Poltava, Ukraine)

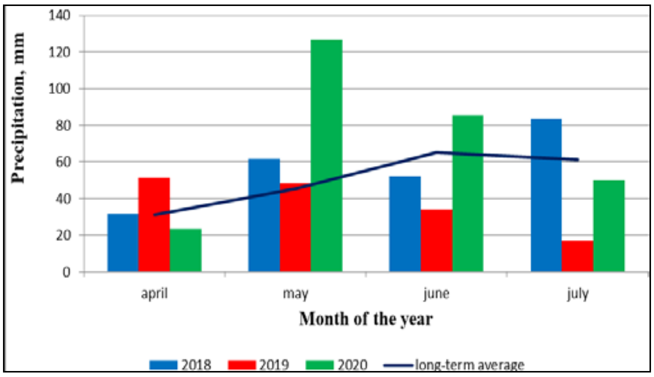

Fig 2: Monthly total rainfall for 2018-2020 spring barley vegetation seasons (Poltava, Ukraine)

The most favorable temperature regime was recorded in 2018, when the average air temperature during the crop growing season was 18.9 °C, which is 1.7 °C higher than the average long-term indicator. During the growing season, the amount of precipitation was 229.2 mm, which is 26.2 mm or 12.9% higher than the norm.

The weather conditions of the growing season 2020, were also quite favorable for the barley crop, both in terms of air temperature and precipitation. However, the distribution of precipitation according to the vegetation periods was uneven. Thus, in May and June the excess of the average monthly norm of precipitation was 178.2 and 31.1%, respectively, and in April and July there was a deficiency at a level of 25.6 and 17.8%, respectively.

2019 year was characterized by a prolonged persistent drought, which was observed in June and July, that is, during the period of grain formation and filling. The deficit of precipitation in these months was respectively 47.5 and 72.0% compared to the long-term norm.

Statistical processing of the experiment results was carried out by methods of dispersion analysis, correlation and regression analyses using STATISTICA 6.0 (7.0, 10.0) software.

Results and Discussion

Productivity of crops is the most variable and integral indicator of their vitality, which accumulates their genetic potential, soil fertility, weather conditions and elements of cultivation technology. Barley intensively assimilates nutrients within a short period of time - from the tillering phase to the beginning of heading (25-30 days), therefore it responds well to the application of mineral fertilizers and their aftereffect. Among the main nutrients, barley reacts most intensively to nitrogen. Therefore, the system of applying fertilizers for barley cultivation, first of all, should be aimed at optimizing the crop nitrogen nutrition.

In this research, the impact of mineral fertilizers doses and forms on the easily hydrolyzable nitrogen content in the upper soil layer of 0-20 cm and at a depth of 20-40 cm at all stages of spring barley organogenesis was studied. The experiment results are presented in Table 1.

As can be seen from the above data, depending on the spring barley organogenesis stage, the easily hydrolysable nitrogen content in the soil changed depending on the dose of fertilizer applied (Tab. 1). Thus, at the first stage of organogenesis (BBCH 01-02) in the soil layer of 0-20 cm both on the control plot (without fertilizers) and on the plot with the application of $P_{45}K_{30}$ and $N_{23}P_{23}K_{15}$, nitrogen content was quite low and was 137.1 and 149.1 mg kg^{-1} of soil, respectively.

Table 1: The balance of easily hydrolyzable nitrogen in the soil at the spring barley cultivation with various fertilization systems on average for 2018–2020 (mg kg^{-1} of soil)

Fertilizers dose, kg ha^{-1} of active substance	Stages of spring barley organogenesis			
	I (Germination, BBCH 01-02)	III (Tillering, BBCH 28-29)	VIII (Heading, BBCH 51-52)	XII (Full ripeness, BBCH 89-92)
Soil layer of 0-20 cm				
Without fertilizers	137,6	136,9	127,7	114,4
$P_{45}K_{30}$	137,1	136,0	127,3	116,9
N_{45}	155,8	155,0	129,3	121,1
$N_{23}P_{23}K_{15}$	149,1	148,0	130,7	122,8
$N_{45}P_{45}K_{30}$	155,3	154,6	130,0	120,7

$N_{68}P_{68}K_{45}$	161,8	160,8	130,1	121,1
$HIP_{0,95}$	3,2			
Soil layer of 20-40 cm				
Without fertilizers	119,4	119,4	117,9	106,5
$P_{45}K_{30}$	120,6	120,6	115,8	107,0
N_{45}	142,5	143,5	117,7	115,7
$N_{23}P_{23}K_{15}$	136,2	136,2	119,3	114,9
$N_{45}P_{45}K_{30}$	140,0	140,0	125,3	115,6
$N_{68}P_{68}K_{45}$	146,4	146,4	125,3	119,0
$HIP_{0,95}$	4,8			

Fertilizer application during sowing with increased of nutrition elements content provided increase of easily hydrolysable nitrogen content in comparison with control by 12.9% ($N_{45}P_{45}K_{30}$); by 13.2% (N_{45}); by 17.6% ($N_{68}P_{68}K_{45}$). In the period from the third (BBCH 28–29) to the eighth (BBCH 51–52) stage of organogenesis, a decrease of the nitrogen content in this soil layer was observed for all variants of mineral fertilizers application by 6.4–19.1%. During stages VIII–XII of organogenesis, the largest decrease of the easily hydrolyzable nitrogen content in the soil was observed on the control plot by 10.4% and with the use of only phosphorus-potassium fertilizers in a dose of $P_{45}K_{30}$ by 8.2%.

The reduction of nitrogen content varied in the range of 6.3-6.9% on all other variants in this period. Significant decrease of nitrogen content in the soil between the stages III-XII of organogenesis may be connected with the intensive nitrogen consumption by barley plants in order to form the vegetative mass and grain, while between the stages I-III of organogenesis, the use of this nutrient was less.

Thus, the nitrogen content in the soil layer of 0-20 cm gradually decreased, but remained by 2.2-7.3% higher on the fertilized variants compared with the control.

In the deeper soil layer of 20-40 cm, the easily hydrolysable nitrogen content at the stage I of organogenesis was significantly lower (by 13.2%) compared to the soil layer of 0-20 cm on the plots without fertilization and by 12% on the plots where 45 kg ha^{-1} active ingredient of phosphorus and 30 kg ha^{-1} active ingredient of potassium fertilizers were applied. The content of nitrogen in the soil layer of 20-40 cm relatively to the layer of 0-20 cm under the fertilizer variants N_{45} and $N_{23}P_{23}K_{15}$ and $N_{45}P_{45}K_{30}$ and $N_{68}P_{68}K_{45}$ was lower by 8.5-8.7% and 9.5-9.9%, respectively. The application of mineral fertilizers increased the content of easily hydrolysable nitrogen in the soil of the given layer (20-40 cm) compared to the control from 14.1% with the fertilizer dose of $N_{23}P_{23}K_{15}$ to 22.6% using $N_{68}P_{68}K_{45}$. The maximum decrease of this nutrient was observed in the period between the stages III-VIII of organogenesis by 4.0% on the plots where potassium-phosphorus fertilizers in a dose of $P_{45}K_{30}$ were applied and by 14.4% on the plots where $N_{68}P_{68}K_{4}$ were applied.

Control plot (without fertilizers) in the period of VIII-XII organogenesis stages provided the greatest decrease of easily hydrolysable nitrogen in both the soil layer of 0-20 cm (by 10.4%), and the soil layer of 20-40 cm (by 9.7%). This may also be connected with its intensive consumption by the plant for the crop formation. At the stage XII of organogenesis, the lowest easily hydrolysable nitrogen content in the soil layer of 20-40 cm was recorded on the control plot (106.5 mg kg^{-1}), which is 0.5% less than on the plots with the application of phosphorus-potassium fertilizers $P_{45}K_{30}$ and 10 5% less than on the plots with the maximum rate of fertilizer $N_{68}P_{68}K_{45}$.

Phosphorus is the second most important element of plant nutrition after nitrogen. It ensures energy processes in plant cells, affects the development of the root system, and increases crop yields. Barley, as a crop with a short growing season, is particularly sensitive to the lack of phosphorus at the early stages of development during root system formation. Since the plants are least protected and require additional nutrition at this stage, and providing with phosphorus at later stages cannot compensate it.

As can be seen from Table 2, the mobile phosphorus content at the stage I of organogenesis in the soil layer of 0–20 cm both on the control plot (without fertilizers) and on the plot with the application of only nitrogen fertilizers in a dose of N_{45} was almost the same and was 87.4 and 87.0 mg kg^{-1} of soil, respectively. Application of phosphorus with mineral fertilizers at the time of spring barley sowing increased its content in the arable soil layer compared with the control by 24.0% ($N_{23}P_{23}K_{15}$ dose), and by 28.6% ($N_{45}P_{45}K_{30}$ dose). The application of phosphorus-potassium fertilizers in a dose of $P_{45}K_{30}$ and $N_{68}P_{68}K_{45}$ provided the greatest effect and as a result, the phosphorus content increased compared to the control plot, by 34.9% and 35.4%, respectively.

Table 2: The mobile phosphorus content in the soil by the development stages of spring barley depending on the fertilizers rate, on average for 2018-2020 (mg kg^{-1} of soil)

Fertilizers dose, kg ha^{-1} of active substance	Stages of spring barley organogenesis			
	I (Germination, BBCH 01-02)	III (Tillering, BBCH 28-29)	VIII (Heading, BBCH 51-52)	XII (Full ripeness, BBCH 89-92)
Soil layer of 0-20 cm				
Without fertilizers	87,4	87,0	79,2	68,3
$P_{45}K_{30}$	117,9	117,6	97,3	80,0
N_{45}	87,0	86,2	79,7	71,2
$N_{23}P_{23}K_{15}$	108,4	107,2	92,7	75,1
$N_{45}P_{45}K_{30}$	112,4	111,8	97,4	75,3
$N_{68}P_{68}K_{45}$	118,3	114,6	102,6	74,1
$HIP_{0,95}$	2,4			
Soil layer of 20-40 cm				

Without fertilizers	79,1	78,5	67,7	65,2
$P_{45}K_{30}$	95,5	95,2	78,9	71,6
N_{45}	78,4	78,2	67,0	64,3
$N_{23}P_{23}K_{15}$	91,4	91,0	84,7	69,6
$N_{45}P_{45}K_{30}$	94,3	94,0	82,2	68,5
$N_{68}P_{68}K_{45}$	97,0	96,7	84,0	70,3
$HIP_{0,95}$	3,1			

As barley plants assimilated phosphorus, its content in the soil of this layer decreased. On the plots, where phosphorus-potassium fertilizers were applied in a dose of $P_{45}K_{30}$, reduction of phosphorus content in the soil at the stages III-VIII and VIII-XII of organogenesis occurred almost evenly and averaged 17.5%. It should be noted that application of $N_{23}P_{23}K_{15}$; $N_{45}P_{45}K_{30}$ and $N_{68}P_{68}K_{45}$ reduced phosphorus content in soil at the stages III-VIII of organogenesis by 13.5; 12.9 and 10.5%, respectively. However, during the last stages of organogenesis (VIII-XII), the need of barley plants for phosphorus increased, which was reflected in a significant decrease of its content in the soil of plots with $N_{23}P_{23}K_{15}$ – by 19.0%; $N_{45}P_{45}K_{30}$ – by 22.7%; $N_{68}P_{68}K_{45}$ – by 27.8%.

In the soil layer of 20–40 cm, the mineral fertilizers application also increased the mobile phosphorus content at the use of $N_{23}P_{23}K_{15}$ by 15.5%; $N_45P_{45}K_{30}$ – by 19.2%; $P_{45}K_{30}$ – by 20.7%; and $N_{68}P_{68}K_{45}$ – by 22.6% in comparison to control (without fertilizers). In the process of organogenesis, a regular decrease of mobile phosphorus in the soil was observed, which was the maximum between the stages III–VIII, and on the plots with fertilizer use amounted to 6.9–17.1%.

At the stage XII of organogenesis, the this nutrient content was significantly higher on the plots where mineral fertilizers were applied in a dose of $N_{23}P_{23}K_{15}$; $N_{45}P_{45}K_{30}$; $P_{45}K_{30}$; $N_{68}P_{68}K_{45}$ of the active ingredient compared to the control and with applying only nitrogen fertilizers in a dose of N_{45}.

Potassium is also an important element of plant nutrition, because this macroelement is involved in metabolic processes (respiration, photosynthesis), as well as increases the speed of nitrogen uptake. Table 3 presents the results of the potassium content determination in the arable layer of soil and at a depth of 20–40 cm at all stages of barley organogenesis.

Table 3: The exchangable potassium content in the soil by the development stages of spring barley depending on the fertilizers rate, on average for 2018-2020 (mg kg^{-1} of soil)

Fertilizers dose, kg ha^{-1} of active substance	**Stages of spring barley organogenesis**			
	I (Germination, BBCH 01-02)	**III (Tillering, BBCH 28-29)**	**VIII (Heading, BBCH 51-52)**	**XII (Full ripeness, BBCH 89-92)**
Soil layer of 0-20 cm				
Without fertilizers	148,0	147,9	127,0	115,6
$P_{45}K_{30}$	171,8	170,2	144,4	135,9
N_{45}	148,1	147,8	123,8	120,0
$N_{23}P_{23}K_{15}$	164,0	164,8	132,9	126,9
$N_{45}P_{45}K_{30}$	174,3	173,8	145,1	127,0
$N_{68}P_{68}K_{45}$	177,3	176,7	147,6	130,7
$HIP_{0,95}$	2,2			
Soil layer of 20-40 cm				
Without fertilizers	138,9	138,4	122,3	114,7
$P_{45}K_{30}$	156,5	155,6	137,8	132,4
N_{45}	139,1	138,4	121,0	116,5
$N_{23}P_{23}K_{15}$	146,6	145,7	131,8	125,6
$N_{45}P_{45}K_{30}$	156,1	153,5	136,1	124,6
$N_{68}P_{68}K_{45}$	160,9	160,1	137,2	126,9
$HIP_{0,95}$	4,1			

The control plot provided the lowest amount of exchangable potassium (148.0 mg kg^{-1} of soil) in the soil layer of 0–20 cm during the first stage of spring barley organogenesis. Application of mineral fertilizers in a dose of $N_{23}P_{23}K_{15}$ increased the exchangable potassium content compared to the control by 10.8%; $N_{45}P_{45}K_{30}$ – by 17.8%; $P_{45}K_{30}$ – by 16.1%, and $N_{68}P_{68}K_{45}$ – by 19.8% in this layer of soil (Tab. 3). In the deeper layer of the soil (20–40 cm), the application of these fertilizers in noted doses increased potassium content only by 5.5% ($N_{23}P_{23}K_{15}$); 12.4% ($N_{45}P_{45}K_{30}$); 12.7% ($P_{45}K_{30}$) and 15.8% ($N_{68}P_{68}K_{45}$).

There was no significant difference between the exchangable potassium content in the soil layers of 0-20 and 20-40 cm between the stages I-III of spring barley organogenesis. This may be connected to the insignificant development of vegetative mass of barley plants and, consequently, low requirements of the crop for this nutrient.

The maximum decrease in the amount of exchangeable potassium in the soil layer of 0–20 cm was observed in the period between the stages III–VIII of spring barley organogenesis by 14.1% on the control plot and by 15.2–19.4% after the mineral fertilizers application.

The decrease of exchangable potassium content during this period in the layer of 20-40 cm was less and amounted to 9.5-14.3% depending on the fertilizer variant, which can be explained by a significant increase of the spring barley dry matter and, accordingly, by the growing needs of plants for this nutrient.

During the stage XII, the exchangeable potassium content in the soil layers of 0-20 cm and 20-40 cm on the control plots was almost the same and higher on the variants, where mineral fertilizers in the doses of $N_{23}P_{23}K_{15}$; $N_{45}P_{45}K_{30}$; $P_{45}K_{30}$ and $N_{68}P_{68}K_{45}$ of the active ingredient were applied.

According to the research results, the application of potassium with mineral fertilizers improved the soil potassium regime in layers of 0–20 and 20–40 cm under spring barley plants. On the plots where nitrogen was applied in a dose of 45 kg ha^{-1}, the potassium content remained at a control level. Thus, the use of mineral fertilizers increased the degree of nutrient supply of soils depending on the fertilizers dose, and had a positive effect on the growth, development and productivity of spring barley plants.

Different rates of mineral fertilizers used in the experiment ensured soil enrichment with easily movable forms of nutrition elements and positively affected the yield formation of spring barley grain (Tab. 4).

Table 4: Spring barley yield depending on the mineral fertilizers rate

Fertilizers dose, kg ha^{-1} of active substance	Yield, t ha^{-1}			
	2018	2019	2020	Average for 2018-2020
Without fertilizers	3,64	3,41	3,52	3,52
$P_{45}K_{30}$	4,12	4,09	4,16	4,12
N_{45}	4,81	4,70	4,72	4,74
$N_{23}P_{23}K_{15}$	5,04	4,82	4,93	4,93
$N_{45}P_{45}K_{30}$	5,21	5,07	5,09	5,12
$N_{68}P_{68}K_{45}$	5,37	5,16	5,28	5,27
HIP $_{0,95}$	0,06	0,08	0,07	–

Yield of spring barley grain varied depending on both the peculiarities of weather conditions of the vegetation period (Fig.1, 2) and type and doses of mineral fertilizers applied (Tab. 4). To assess the role of weather conditions in the yield formation over the research years, we can use the data of the control plots where mineral fertilizers were not applied. Thus, significant amount of precipitation (229.2 mm) during the barley growing season in 2018 contributed to the highest crop yield over the research years, which was 3.64 t ha^{-1}. The lack of moisture in April-May 2019 of 47.5 and 72.0% compared to the long-term norm negatively affected the barley grain yield. The yield decreased by 6.3% compared to 2018 and amounted to 3.41 t ha^{-1}. Sufficient amount of precipitation, but uneven distribution over the growing seasons in 2020 contributed to the yield of 3.52 t ha^{-1}, which is 3.3% less than in 2018, and 3.1% higher than in 2019 year.

The composition and mineral fertilizers doses played a significant role in the yield formation. Thus, applying only phosphorus-potassium ($P_{45}K_{30}$) fertilizers increased the grain yield by 0.6 t ha^{-1} (17%), compared with the control. Barley was also positive response to nitrogen fertilizers (N_{45}) application in the form of ammonium nitrate, which provided the yield increase in comparison to control at a level of 34.7% (1.22 t ha^{-1}).

Significant effect was observed on the plots where mineral fertilizer $N_{45}P_{45}K_{30}$ was applied, and barley yield exceeded the control by 40%. With the application of half the dose of fertilizers from the above rate, there was a decrease in grain yield by 0.19 t ha^{-1} or 3.7%.

The highest level of the genetic potential realization of ‘Sviatohor’ spring barley productivity was observed when mineral fertilizers in a dose of $N_{68}P_{68}K_{45}$ was applied and the complex protection system against weeds, pests and diseases was used. The increase in grain yield compared to the variant without fertilizers was 1.75 t ha^{-1} or almost 50%.

So, the obtained results allow us to conclude that all fertilizers doses, which were studied in this research, are able to provide a significant increase in barley grain yield compared to the variant without their application. The proposed fertilizers doses do not exceed their threshold value, at which the barley crop shows depression and slightly increases the yield.

Analysis of the data concerning the content and dynamics of easily hydrolysable nitrogen, mobile phosphorus and exchangeable potassium in soil layers of 0–20 cm and 20–40 cm in spring barley cultivation shows that mineral fertilizers help to improve the soil nutrient regime. The nitrogen, phosphorus and potassium content in the soil significantly changed depending on the different fertilizers doses. Therefore, the smallest amount of investigated forms of nitrogen, phosphorus and potassium in the soil layer of 0–20 cm at the stage I was determined on the control plot, where fertilizers were not applied. The easily hydrolysable nitrogen content was 137.6 mg kg^{-1} of soil, mobile phosphorus was 87.4 mg kg^{-1} of soil and exchangeable potassium was 148.0 mg kg^{-1} of soil.

Compared with the stages I-III of organogenesis, the easily hydrolysable nitrogen content in the soil at the stages VIII-XII of spring barley organogenesis decreased by 14.7–25.2% in the soil layer of 0–20 cm and by 9.0–17.1% in the soil layer of 20–40 cm, mobile phosphorus decreased by 21.8–37.4% and 10.8–18.7%, exchangeable potassium decreased by 21.9–26.3% and 17.4–21.1%, respectively, due to the intensive use by mineral nutrients in order to form the generative organs and promote assimilation processes, which result in the biological synthesis of organic substances and their transportation to the caryopsis.

The statistical analysis of the research results confirmed the correlation between a level of yield and the nutrients content in the soil with the corresponding correlation coefficients.

Therefore, a direct correlation dependence with strong relationship was established between a yield level and the easily hydrolysable nitrogen content in the soil layers of 0-20 cm and 20-40 cm, which is confirmed by correlation coefficients, which were $r = 0.90$ and $r = 0.86$ at the stage III of organogenesis; $r = 0.91$ and $r = 0.68$ at the stage VIII; and $r = 0.91$ and $r = 0.91$ at the stage XII in the soil layers of 0-20 cm and 20-40 cm, respectively.

The average and high correlation dependence was established between an yield level and the phosphorus content in the soil layers of 0–20 and 20–40 cm, which was characterized by coefficients $r = 0.57$ (for soil layer of 0-20 cm) and $r = 0.75$ (for soil layer of 20-40 cm) at the stage III, correlation coefficients for both soil layers were almost the same – $r = 0.71$ and $r = 0.77$, respectively.

The average and weak correlation between an yield level and phosphorus content in the soil layers of 0–20 cm and 20–40 cm was observed at the stage XII of barley crop organogenesis with correlation coefficients $r = 0.44$ and

0.33, respectively. It should be noted that a level of barley grain yield was in the average dependence on the potassium content in the soil, which is confirmed by the correlation coefficients r = 0.49, and r = 0.59 for all stages of organogenesis.

A two-factor dispersion analysis was conducted in order to evaluate the fertilizers effect on soil quality parameters and barley crop yield. The effect of both individual research factors (year, fertilizers) and their interaction were evaluated.

Dispersion analysis of the research results showed that the main factors of impact on barley yield are mineral fertilizers and plant protection system, their shares are 41% and 35%, respectively. Interaction of these factors was also statistically reliable, but their share in total was 13%. It should be noted that due to the mineral fertilizers application and protection crops from pests, the share of the impact of growing years was reduced to 10%.

Thus, thanks to the used agronomic practices, yield control reached the level of 89%, which is certainly a high value in a view of the planned yield obtaining (Fig. 3).

Equation of dependence of barley yield was obtained by multiple regression method:

$$Yield=1098,234+118536X-33,964Y-0,0634X^2+0,015XY+0,016Y^2$$, where:

X – Fertilizers, kg of active substance per hectare;

Y – Gradations of crops protection.

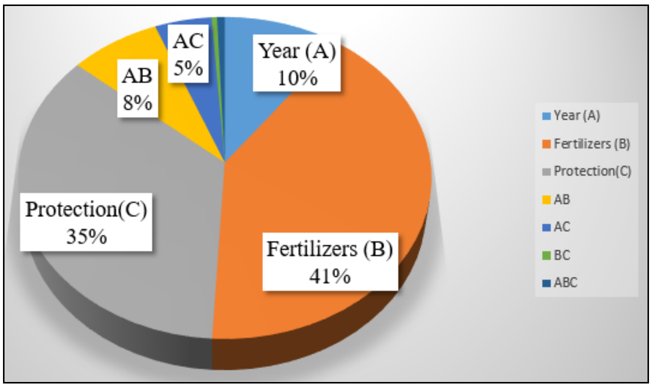

Fig 3: The effect of cultivation factors on the barley yield, %

The effect of the studied mineral fertilizers doses and barley crop protection system is presented graphically in Figure 4.

The regression graph (Fig. 4) shows that the application of fertilizers can reduce yields in case of excessive rates, and the improvement of crop protection system has a direct effect – yields increase.

Therefore, the research found that the best conditions for growth and development of plants, as well as the reproductive organs formation and the grain yield formation of spring barley variety 'Sviatohor' at a level of 4.93–5.27 t ha^{-1} are created by applying mineral fertilizers in doses of $N_{23}P_{23}K_{15}$; $N_{45}P_{45}K_{30}$; $N_{68}P_{68}K_{45}$ kg ha^{-1} of active substance and using integrated crop protection. Against the background of application of such fertilizers doses, barley grain yield increased compared to the control by 40.1; 45.5; 49.7%, respectively.

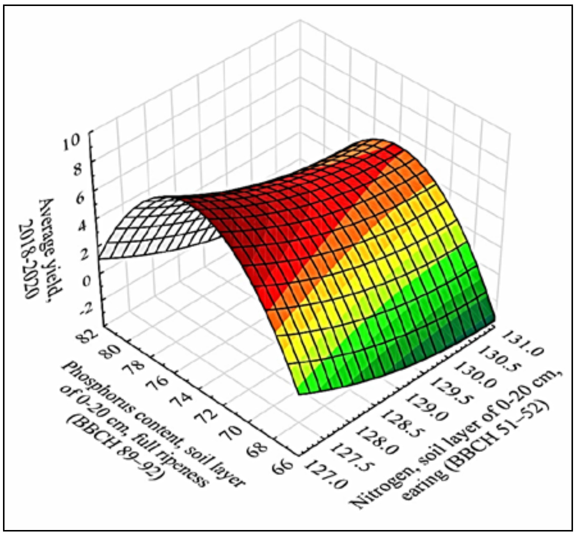

Fig 4: The yield dependence on the fertilization variant and the crop protection level

The main role in this belongs to nitrogen in the layer of 0–20 cm (r = 0.86–0.82), but this dependence exists only in at the certain period – from germination to earing (BBCH 01–52). Correlation analysis shows that under the current level of intensification of barley grain production, the optimization of crop nutrition has not been achieved yet. The correlation coefficients between the nutrients content in the soil and yield are in the range of 0.83–0.98, which indicates a strong dependence. This dependence is observed regardless of the phase of crop development. The main role belongs to nitrogen in the layer of 0-20 cm (r = 0.86–0.82), but this dependence exists only in a certain period – from sprouting to earing (BBCH 01–52).

At the time of grain ripening, the correlation between nitrogen content and yield disappears, but it remains with other nutrients (especially phosphorus content) (Fig.5).

Average yield (2018-2020) = $3736.2183-68.273X+20,0277Y+0,2618X^2-0,0045XY-0,1312Y^2$

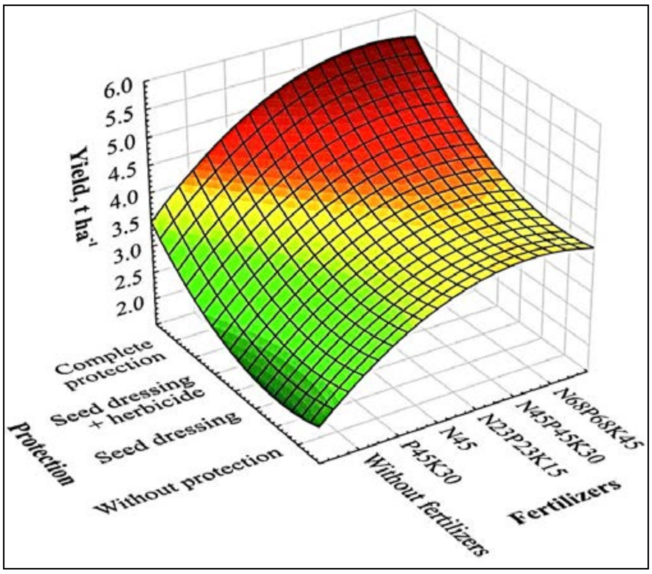

Fig 5: The yield dependence on average over the study years on the nitrogen and phosphorus content in the soil layer 0-20 cm

The research findings correlate very accurately with study results of [30], where the author indicated that the application of only phosphorus and potassium fertilizers in a dose of 60 and 30 kg active substance per hectare does not increase the barley yield, and nitrogen has a leading role. The application of $N_{60}P_{60}K_{30}$ fertilizer provided the the maximum yield increase of 32-50 %. The systematic mineral fertilizers application at the same dose can lead to the yield increase up to 54%.

At the same time, with a sufficient phosphorus and potassium content in the soil, it is possible to use only nitrogen fertilizers. For example, in a study [31], the authors analyzed the effectiveness of 33% NH_4NO_3 in doses from N_{50} to N_{200} while growing 10 barley varieties. It was found that each variety has its own effective dose, which can also vary depending on the regions environmental conditions. So, the use of nitrate fertilizers N_{100} for some varieties and N_{150} for some others can lead to the yield increase by 1.85-2 times.

However, some researchers claim that the yield increase can be 25-30% [32], which agrees with our results.

Our research scheme in one of the variants was to study the impact of pure ammonium nitrate N_{45} on barley yields. As the nitrogen content in the soil can be regarded as low (137.6 mg kg^{-1} soil), application of nitrogen fertilizer N_{45} increased nitrogen level by 11.7%, which resulted in increasing barley yield by 25.7% compared to the control plot, but this yield was 10% lower than in the plot where $N_{68}P_{68}K_{45}$ was applied.

We believe that the dose of ammonium nitrate N_{45} is considered to be effective for the barley cultivation on soils with sufficient phosphorus and potassium content.

The precursor crop is very important for determining the applied fertilizers doses, especially nitrogen fertilizers. Its choice should be guided by the degree and nature of the impact on the subsequent crop, which is determined by its morphological and biological characteristics. In our research, a precursor crop was soybean. Soybean is able to effectively absorb atmospheric nitrogen, and as a result its content in the soil significantly increases [33], which, in turn, leads to the yield increase, as shown in this research by 40.1-49.7% depending on the fertilizer dose.

A significantly lower yield increase compared to the plots without fertilizers was obtained by the authors [23] when $N_{68}P_{68}K_{45}$ was applied - by 14%, and when $N_{70}P_{70}K_{70}$ was applied - by 20% with soybean as a precursor crop, which may be due to the barley varietal characteristics.

Conclusions

The application of mineral fertilizers in the doses of N_{45}; $N_{45}P_{45}K_{30}$ and $N_{68}P_{68}K_{45}$ kg ha^{-1} of the active substance increased a level of plants nitrogen supply at the stage III of organogenesis (tillering, BBCH 28-29). The application of $N_{23}P_{23}K_{15}$ and $P_{45}K_{30}$ and the variant without fertilization did not significantly change the soil nitrogen supply in comparison with the content at the sowing period. It was found that on all fertilized variants except control, spring barley plants did not show any external signs of phosphorus and potassium deficiency during the growing season, which indicates that the soil is sufficiently supplied with these mineral nutrients.

The highest spring barley yield of 5.27 t ha^{-1} was formed due to the application of $N_{68}P_{68}K_{45}$ kg ha^{-1} and full implementation of the crops protection from pests, diseases and weeds. The reduction of the fertilizer dose to $N_{45}P_{45}K_{30}$ and $N_{23}P_{23}K_{15}$ was accompanied by a decrease in grain yield by 2.8 and 6.5%, respectively.

Conflict of Interest Statement

We declare that we have no conflict of interest

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