Study on the influence of fertilizers on the yield and quality of barley and potatoes

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Abstract. Improved plant nutrition when applying organic and mineral fertilizers occurs due to nitrogen, phosphorus and potassium from fertilizers and soil. A significant part of them is fixed by soil. Depending on the amount of fertilizer applied and the mobility of soil nutrients, different conditions for the formation of the crop and its quality are created. Reproduction of soil fertility and increase in crop yields can only be achieved on the basis of the scientifically based use of fertilizers and other chemicals in crop rotations. Currently, the rational use of fertilizers, both organic and mineral, to increase productivity, quality of crops and improve soil fertility is of particular importance. Studying the effectiveness of various fertilizer systems in crop rotations and biologization of agriculture are currently becoming particularly important. Hence, this study highlights the comprehensive information on the influence of various fertilizer on the yield and quality of barley and potatoes.

1. Introduction

In nature, everything is interconnected. The green organs of plants and their root systems function according to this principle. If you limit the development of one of these parts, the other will inevitably suffer. The main function of above-ground organs is that they provide the root system with energy. Its source is sugars - a product of photosynthesis occurring in green tissues. In turn, the root system is a “pump” that pumps water and a complex of nutrients from the soil necessary for the development of the above-ground part [1]. If both the “tops” and the “bottoms” work according to the optimal scenario, the agronomist will be satisfied with the crop yields.

Nutrition is one of the regulated factors of plant life. The greatest plant productivity is achieved when plants are provided with nutrients in optimal proportions and sufficient quantities [2, 3]. Unbalanced nutrition leads to a decrease in yield, deterioration in product quality, and pollution of soil and water bodies [4]. The main technique that improves plant nutrition is the use of fertilizers. Their effectiveness depends on the soil-climatic conditions of the region, the biological characteristics of the cultivated crops, and the technologies used [5, 6]. A distinctive feature of the modern period is the development of new technologies adapted to modern land use conditions based on the maximum use of the biological factor.

Currently, with the increasing anthropogenic impact on agricultural systems, methods of biologization of agriculture, including the rational use of manure and other organic fertilizers, are becoming increasingly important. There is growing interest in alternative systems based on the application of organic fertilizers alone and the complete abandonment of mineral fertilizers. The main argument here is the possibility of obtaining clean products and protection from environmental pollution [7]. Recently, there has been a decrease in the volume of use of mineral fertilizers in a number of European countries, the USA, and Japan. But in these countries, even a 50% reduction in their consumption retains

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the use of 200 - 300 kg of NPK per hectare. In this regard, it is relevant to objectively characterize various systems: organic, mineral and organomineral - in a comparative study of their influence on productivity, product quality, soil fertility parameters, as well as on environmental indicators.

2. Biological features of barley

The productivity of barley is largely determined by its biological characteristics. Barley is a crop with a short development period, and it structure is shown in Figure 1. Its growing season in the Non-Chernozem zone ranges from 90-100 days. Barley is a cold-resistant crop. Barley seeds can germinate at a temperature of 1-2 C and sprout vigorously at a temperature of 4-5 C. Negative temperatures during germination have a harmful effect on the further growth of plants. During the tillering phase, the most favorable temperature is 10-12 C. In the subsequent period (before the heading phase, the optimal temperature is 15-17 C. During the period of filling and ripening of barley grains, it is easier to tolerate high temperatures. Temperatures below 13-14 C inhibit plant development. Barley is the most drought-resistant crop. Barley seeds during germination require less water (48-65% of the grain weight) than seeds of other varnishes. After germination, due to the poor development of the root system, it requires a large amount of moisture [8, 9]. The maximum amount of water of the plant is dissipated walk in the tillering - booting phase. Lack of moisture during this period causes an increase in the number of barren flowers. Despite the high adaptability of barley to various cultivation conditions, it is very demanding on soil fertility. In the Non-Black Earth zone, loamy soils are most suitable. Barley grows poorly on light sandy and sandy loam soils.

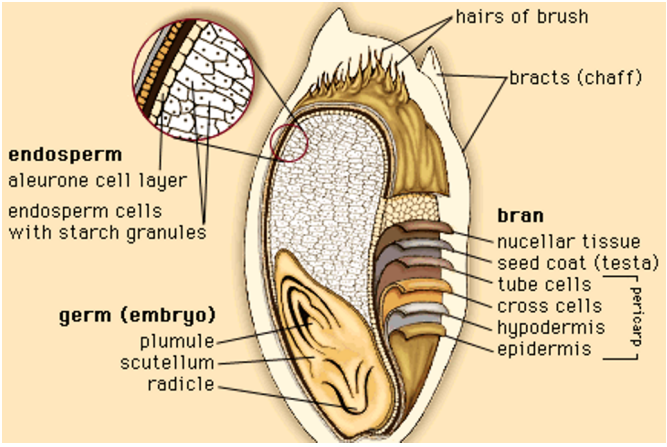

Fig. 1. Structure of Barley

When cultivating barley on soddy-podzolic soils, fields with pH = 6-6.5 [10], humus content of at least 2%, mobile phosphorus and exchangeable potassium of 15-20 mg/100 g of soil are preferred. With the pre-sowing application of full mineral fertilizer in such areas, the yield of intensive varieties can reach 5.5t/ha.

Barley develops quickly during the growing season. It begins to use nutrients immediately after emergence, using nitrogen and potassium most quickly, and using phosphorus at a slower rate. Thus, the main part of the potassium (87%) and nitrogen (74%) of the total removal is used to exit into the tube, and all the nitrogen and potassium are used by the maximum period (during the heading phase). A good phosphorus regime is necessary until the end of the growing season. The climatic conditions of the Non-Chernozem Zone are generally favorable for the normal growth of barley. However, weather deviations from the norm in some years lead to significant fluctuations in the harvest. High yields of barley when applying fertilizer in the zone are formed at an average daily air temperature during the sowing-tillering period within 13-15 0C, sufficient (80-100 mm) precipitation during the period of intensive growth and moderate moisture during filling grains (50-60 mm of precipitation in July).

3. Biological features of potatoes

Potatoes are one of the most important agricultural crops which outer and inner structure is shown in Figure 2. They are rightly called the second bread. Potato tubers contain about 25% dry matter, including 14...22% starch, 1.4...3% protein, about 1% fiber, 0.2...0.3% fat and 0.8...1.1% ash substances. Potatoes are a source of vitamins C, A, B1, B2, B6, P and K. Young tubers are especially rich in vitamins [11, 12]. The entire period of potato growth is conventionally divided

into three parts. The first period is from germination to the beginning of flowering. At this stage, the mass of tops mainly increases. The growth of tubers is insignificant.
The second period covers flowering and continues until the tops stop growing, almost until they begin to wilt. At that time, the most intensive growth of tubers occurs. The third period is from the cessation of growth of tops to its natural withering. The growth of tubers continues, but less intensively than in the second period. The second period is the most important in the formation of tubers, during which time up to 65...75% of the final harvest accumulates. The weather conditions prevailing during that period determine the level of the harvest.
For potato plants, the temperature regime is very important, so at 10...12 ^{0}C in moderately moist soil they sprout on the 25...27th day, at 14...16 ^{0}C - on the 18...22nd day. The best temperature for germinating tubers in the middle zone is 18...22 ^{0}C. The combination of good soil moisture supply and optimal temperature during germination contributes to the accelerated emergence of seedlings [13, 14]. The most favorable temperature for tuber formation is 15...20 ^{0}C. At a temperature of 6 ^{0}C and above 23 ^{0}C, tuber growth is delayed, and at 26...29 ^{0}C, tuber formation stops.
Potato is a light-loving plant. Therefore, the choice of optimal standing density is of great importance. The most appropriate density is such that, under specific plant growth conditions, the formation of about 40 thousand m2 of leaf surface per 1 hectare is ensured; this corresponds to an average fertilizer application rate of 230...250 thousand stems per 1 hectare for food and 250... 270 thousand stems for seed potatoes.

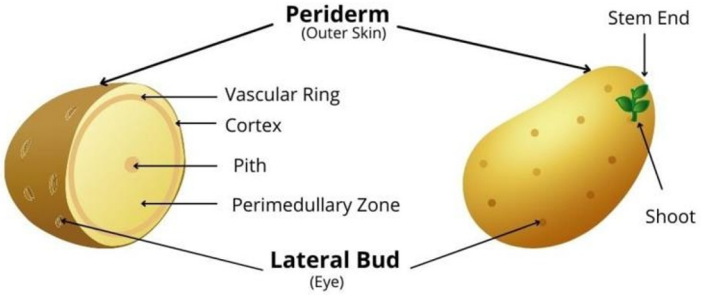

Fig. 2. Outer and inner structure of potato

Potatoes place high demands on the air regime of the soil. In order to have a sufficient amount of oxygen in loamy soil, it is necessary to keep it in a loose state with a bulk density of at least 0.9...1.2 g/cm3. Potatoes are a plant that requires soil moisture. The most favorable conditions for potato growth and the formation of a high yield of tubers are created when soil moisture is from 60% PPV to 100% PPV. A decrease in soil moisture to 40% of the MPV in the middle zone reduces the yield by 40% or more.
To ensure high potato yields in the middle zone, it is necessary that at least 300 mm of precipitation fall during the growing season. Potatoes have specific requirements for root nutrition; an important biological feature here is determined by an underdeveloped root system. For normal growth, development and harvest accumulation, potatoes require more nutrients than many other field crops [15, 16]. With 1 t of tubers and the corresponding number of tops (0.4 t) and root residues, kg: N-5...6, P2O5 - 1.5...2, K2O - 7...10 [17].
Nitrogen is supplied to potato plants throughout the growing season, but most of it is consumed during the period of budding - flowering. At the same time, a good supply of nitrogen in the early stages of growth contributes to a faster and more powerful formation of the vegetative mass. Thanks to this, plants use spring moisture reserves in the soil more productively and better form a tuber crop.
Potatoes consume phosphorus throughout the growing season; During the period of budding and flowering, phosphorus absorption increases. During the formation of tops, potassium is intensively supplied. The ratio of nutrients N: P2O5: K2O in crops is 1: 0.3: 1.4, and this ratio shows that potatoes are a potassium-loving crop [17].

4. The effect of fertilizers on the yield and quality of barley

In the Non-Chernozem Zone, the most common fertilizer system is a combined one. It combines mineral fertilizers and lime materials with the use of bedding manure, peat manure composts and green fertilizers in crop rotation. The application of physiologically acidic mineral fertilizers on sod-podzolic soils for crops that require environmental reaction has a negative effect on the yield.
Liming changes the nutritional regime, which in turn changes the conditions for the effective use of fertilizers. Before sowing barley on acidic soils, liming is carried out, which gives an increase of at least 3-5 c/ha of grain. Lime is applied

under plowing or plowing in full doses (according to hydrolytic acidity) in the form of dolomite flour or other forms. Proper use of fertilizers is a means of improving plant nutrition and increasing barley yield [18]. In addition, when growing barley on organic soils, a fertilizer regimen may need to include copper (Cu). These recommendations are limited to organic (peat) soils. It is currently not advised to apply copper when growing barley on mineral soils. Table 1 shows copper recommendations for barley cultivated on organic soils.

Table1. Copper recommendations for barley cultivated on organic soils

Copper, ppm	Broadcast, copper	Broadcast, copper sulfate	Foliar spray, copper	Foliar spray, copper sulfate
0-2.5 (low)	6-12 lb/acre	24-48 lb/acre	0.3 lb/acre	1.2 lb/acre
2.6-5.0 (marginal)	6	24	0.3	1.2
More than 5.0 (adequate)	0	0	0	0

In our country and abroad, the application of manure and other organic fertilizers directly to barley is practiced quite rarely. Barley is mainly cultivated in field crop rotations. It uses the aftereffects of organic fertilizers applied to previous crops. With the aftereffect of moderate rates of manure (8-10 tons) on average, and the yearly barley yield increased by 6-10 c/ha or more, protein content, as a rule, did not change [19].

When eliminating excess soil acidity and applying phosphorus-potassium fertilizers in most soil and climatic zones of the country, nitrogen fertilizers have the greatest impact on the yield, protein content and other quality indicators of barley grain. Therefore, at present, when the problem of barley grain quality is especially acute, much attention is paid to nitrogen fertilizers: optimal rates, forms, timing and methods of their application are identified.

Under favorable weather conditions, the application of moderate rates (40-60 kg/ha) of nitrogen fertilizers can increase the barley grain yield by 10-15 c/ha.

However, such rates of nitrogen fertilizers mainly increase the size of the yield, and they have little effect on the protein content. The increase in protein content, as a rule, does not exceed 1-1.5%. It is possible to sharply increase the protein content of barley grain, which is especially important when using it as feed, only with the use of increased and high rates of nitrogen fertilizers.

Thus, the optimal norms of nitrogen fertilizers for Belarus, as well as for the Central, Volga-Vyatka regions of the Non-Chernozem Zone, which produce a significant amount of barley grain, under weather conditions close to the long-term average, are in the range of 80-120 kg/ha [20].

5. The effect of fertilizers on the yield and quality of potatoes

Potatoes are a crop that is highly demanding of organic and mineral fertilizers. High potato yields are obtained by applying organic and mineral fertilizers, as well as liming. Potato productivity mainly depends on the humus content in the soil of mobile forms of phosphorus and potassium. The problem of maintaining a deficit-free humus balance is solved differently depending on the zone, the presence of perennial grasses, green manure, and irrigated crops in the crop rotation [21]. In the Non-Chernozem Zone, for example, high-quality prepared organic fertilizers are applied per 1 hectare of arable land in the following quantities:

• in specialized potato crop rotations that do not contain perennial grasses or siderites, on sod-podzolic loamy soils - 15...18 tons, on soddy-podzolic loamy soils - 18...20 tons;

• in specialized potato crop rotations containing perennial grasses or siderites, on sod-podzolic loamy soils - 10...12 t, on sod-podzolic sandy loam soils - 13...15 t.

The practice of advanced farms indicates that in various soil-climatic zones, the application of manure or compost in the amount of 30...60 t/ha is an effective means for obtaining high and sustainable yields of seed and ware potatoes. As the rates of manure for potatoes increase, the yield increases, and only when applying more than 100 t/ha, an increase in yield is often not observed. In this case, there is a powerful development of plant tops to the detriment of the accumulation of tubers; such potatoes are more susceptible to diseases and damaged by pests.

For potatoes, especially early varieties, only rotted or semi-rotted manure is applied, as well as well-prepared peat manure composts. It is better to use organic fertilizers on loamy soils in the fall, before fall plowing, and on sandy and sandy loam soils in early spring, before plowing the fallow land. When developing a potato fertilizer system, it is necessary to take into account the early maturity of the variety. Early varieties are more responsive to mineral fertilizers; they use nutrients more intensively in a short period. Late-ripening varieties absorb soil and manure nutrients better. When the norm of mineral fertilizers is established for specific conditions of potato cultivation, it is necessary to take

into account the reserves of soil nutrients and nutrients added with organic fertilizers. In the experiments of G. M. Nochaikina, the greater the net income, profitability and recoupment of production costs were obtained with the joint application of 40 t/ha of peat-manure compost and NPK for the planned harvest at the level of 30 t/ha [22]. The high efficiency of the combined use of organic and mineral fertilizers is evidenced by the experiments of N. M. Belous [23]. Optimal doses of nitrogen for mid-season and late-ripening potato varieties range from 120 to 150 kg/ha, provided they are balanced with other nutrients. When applying 120 kg of nitrogen per 1 ha with fertilizers, on average 50-60 kg of tubers are obtained per 1 kg of nitrogen. On light sandy loam soils with sufficient moisture, the efficiency may be higher. If nitrogen fertilizers are used against the background of bedding manure (40-50 t/ha), then the dose of nitrogen can be reduced to 80-90 kg/ha. According to Baniuniene and Zekaite's research [24], nitrogen was found to be the most essential component for potatoes. Fertilizer combinations including nitrogen produced the best production increases (3.8-6.0 t ha-1) (Figure 3). The yield was only slightly boosted by the addition of only PK. The tubers of crops fed with mineral fertilizers as opposed to organic ones collected the largest levels of dry matter and starch.

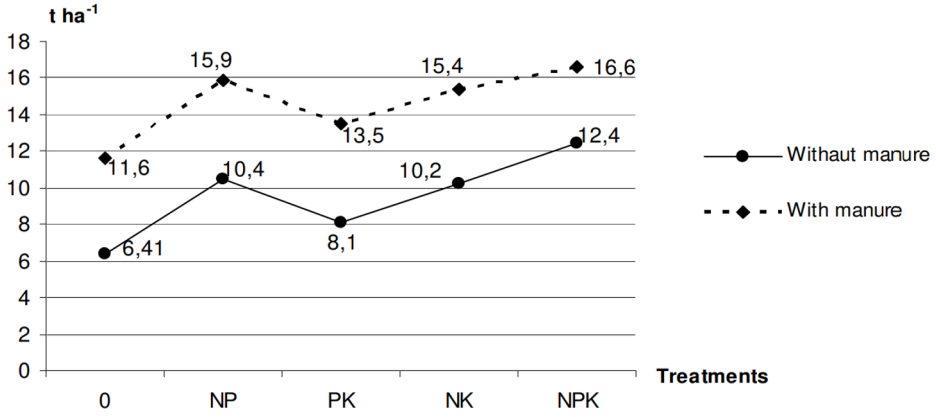

Fig. 3. The effect of organic and mineral fertilizers (manure) on potato tuber yield, t ha^{-1} [24]

When developing potato fertilization systems, it is necessary to take into account the early maturity of the variety. Early varieties are more responsive to mineral fertilizers; they use nutrients more intensively in a short period. Late-ripening varieties absorb soil and manure nutrients better. When establishing standards for mineral fertilizers for specific potato cultivation conditions, it is necessary to take into account the supply of soil nutrients and nutrients added with organic fertilizers. In the experiments of G.M. Nochaikina, the highest net income, profitability and cost recovery from products were obtained with a joint application of 40 t/ha of peat manure compost and NPK for a planned harvest of 30 t/ha [22]. The high efficiency of the combined use of organic and mineral fertilizers is evidenced by the experiments of N.M. Belous [23].

Optimal doses of nitrogen for mid-ripening and late-ripening potato varieties range from 120 to 150 kg/ha, provided they are balanced with other nutrients. When applied with fertilizers 120 N per 1 ha, on average, 50-60 kg of tubers are obtained per 1 kg of N. On light sandy loam soils with sufficient moisture, the efficiency may be higher. If nitrogen fertilizers are used against the background of bedding manure (40-50 t/ha), then the share of nitrogen can be reduced to 80-90 kg/ha [17].

The increase in yield from mineral fertilizers is affected by the cultivation of the soil. According to Avdonin N.S. and Soloviev G.A. the increase in yield of potato tubers from full mineral fertilizer on poorly cultivated soil is 2 times lower than on average and well-cultivated soils. Unilateral application of nitrogen fertilizers reduced the starch content in potato tubers [25]. The effectiveness of mineral fertilizers when used together with organic fertilizers depends both on the doses of organic fertilizers used and on their type. In the experiments of N.M. Belous, on soddy-slightly podzolic sandy soil for potatoes, it is advisable to use high doses of bedding-free manure without additional application of full mineral fertilizer [26].

Potatoes react negatively to insufficient phosphorus and potassium nutrition. Phosphorus promotes faster formation of tubers and improves their quality. Under its influence, the starch content in tubers increases. Doses of phosphorus-containing fertilizers, as well as the ratio between fertilizers, depend on the level of soil supply with mobile phosphorus. All forms of phosphorus fertilizers can be used for potatoes. Doses for potatoes also depend on the content of mobile potassium in the soil and on the purpose for which the tubers are intended. It is better to use chlorine-free potassium

fertilizers for potatoes. If chlorine-containing fertilizers are used, it is recommended to apply them in the fall [27]. The lack of the above elements already in the first period of growth disrupts normal metabolism, inhibits plants and sharply reduces the yield and its quality.

Starch is the main nutrient in potatoes, so much research has been devoted to studying the effect of fertilizers on starch content. To establish the effect of fertilizers on the starchiness of tubers, the results of 89 experiments conducted on soddy-podzolic soil of the Non-Chernozem Zone were summarized. Nitrogen fertilizers containing NPK at an application rate of N 120 against the background of manure significantly reduced the starch content of tubers [28].

Other scientists have come to similar conclusions. The use of increased doses of nitrogen fertilizers also leads to a powerful development of the above-ground mass, the assimilation apparatus of plants. In this regard, the outflow of plastic substances from the leaves to the accumulating organs weakens, and the intensity of starch accumulation decreases. Nitrogen fertilizers enhance the growth of tops, which lengthens the growing season and delays ripening [29, 30].

However, in early potato varieties, as a rule, a decrease in starchy content is not observed, since the plants have time to finish the growing season before harvesting. V.A. Sukhoivanov believes that it is necessary to use increased doses of nitrogen fertilizers for potatoes, taking into account varietal characteristics and weather conditions [29]. Research has established that under the influence of nitrogen fertilizers in potato tubers, the nitrogen and protein content increases and protein collection increases [30, 31].

So in the experiments of V.I. Ponasina et al. studied the effect of nitrogen fertilizers with different rates (background) on soddy-podzolic soils. Although nitrogen fertilizers increase the relative content of crude protein in tubers, the biological value of protein from the nitrogen fertilizer rates applied to potatoes decreases [32, 33]. Increasing the nitrogen rate negatively affects the culinary quality of potatoes, such as darkening of the tubers. According to N.P. Kukresh, the application of more than 120 kg/ha of nitrogen to potatoes on soddy-podzolic soils led to darkening of the tubers and deterioration in taste in wet years [34].

The starchiness of tubers largely depends on the supply of phosphorus to the plants, which takes part in photosynthesis. With insufficient phosphorus nutrition, the starch content in potatoes drops sharply [30]. The effect of phosphorus on the starchiness of potatoes is largely determined by the nitrogen-potassium background of fertilizers. When summarizing the results of 89 experiments conducted on soddy-podzolic soils of the Non-Black Earth Region, it was found that phosphorus fertilizers increase the starch content in potato tubers or do not change it [28]. Phosphorus fertilizers promote maximum utilization of monosaccharides and a low level of their content, which is an indicator of high-quality potatoes [30]. The darkening of the pulp of potato tubers under the influence of phosphorus fertilizers was either minimal or absent [35]. The addition of phosphorus improved the culinary qualities of potatoes and reduced the content of nitrites and nitrates [33].

The effect of potash fertilizers on potato starchiness is largely determined by the form of the potassium fertilizer applied. When using chlorine-containing potassium fertilizer for potatoes, chlorine adversely affects the growth and development of potatoes, which affects the yield and its quality. At the same time, the starch content decreased [35]. The use of potassium fertilizers that do not contain chlorine leads to an increase in the starchiness of tubers. According to experiments conducted on soddy-podzolic soils, potassium sulfate and phyotational calcite should be used to increase the starch content in tubers [36]. Under the influence of potassium fertilizers, the protein content in potato tubers decreased or did not change significantly. Moreover, potassium fertilizers improve the biological value of potato proteins, because the content of reducing sugars decreased [30]. By reducing enzymatic browning, potassium fertilizers improve the appearance and culinary qualities of potatoes [37].

Thus, on soddy-podzolic loamy soils of the Non-Black Earth Region, in order to obtain a high yield of potatoes with good qualities, it is necessary to use a fertilizer system with the ratio of nutrients: $N:P:K = 1;1,5;1,2$ [38].

6. Conclusions

a) Nitrogen fertilizers have the greatest influence on the yield and quality of barley grain. Doses of nitrogen should be differentiated depending on soil and climatic conditions, agricultural technology, and varietal characteristics.
b) When the content of available phosphorus and exchangeable potassium in the soil is low, phosphorus-potassium fertilizers increase the yield and quality of barley grain.
c) The size and quality of the barley harvest depend on the level of soil fertility.
d) With a higher level of soil fertility, the yield and protein content of barley grain increases.

e) Obtaining a high potato yield depends on the content of humus and mobile forms of phosphorus and potassium in the soil. The problem of maintaining a deficit-free humus balance is solved differently, depending on the zone.
f) A great effect is achieved by combining organic and mineral fertilizers for potatoes. Moreover, doses of fertilizers are set in accordance with the supply of nutrients in the soil.
g) The increase in yield from mineral fertilizers is influenced by soil cultivation, agricultural technology, as well as varietal characteristics of potatoes.
h) Lack of phosphorus and potassium negatively affects the formation of the yield of potato tubers, as it disrupts metabolism and inhibits the plant.
i) High doses of seasonal fertilizers reduce the starchiness of tubers.

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