*Bulgarian Journal of Agricultural Science, 29 (No 1) 2023, 43–54*

# Increasing the efficiency of mineral fertilizers by their biological modification

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## Abstract

Mitrofanov, S. V., Orlova, N. V., Blagov, D. A., Teterin, V. S., Panferov, N. S. & Varfolomeeva, M. M. (2023). Increasing the efficiency of mineral fertilizers by their biological modification. *Bulg. J. Agric. Sci., 29 (1)*, 43–54

The article presents the results of a study of the efficiency of biomodified mineral fertilizers. Field experiments were carried out in 2021 in Ryazan region of the Russian Federation on dark gray forest soil. The object of the research was early maturing sunflower variety Aley. The scheme of the experiment included four variants: the control (without fertilizers); fertilizer mixture ($N_{65}P_{45}K_{65}$); $N_{65}P_{45}K_{65}$ treated with a working solution of Lignohumate AM, PEG 400 and water ($N_{65}P_{45}K_{65}$ + HumL); $N_{65}P_{45}K_{65}$treated with a working solution of Ecorost AM humate and PEG 400 ($N_{65}P_{45}K_{65}$ + HumEc). The results of the experiment showed that the use of mineral fertilizers treated with humic preparations had a significant impact on the dynamics of the vegetative weight of sunflower plants. The excess of the air-dry weight of the experimental variants over the control was 19% for $N_{65}P_{45}K_{65}$ + HumEc and 18.4% for $N_{65}P_{45}K_{65}$ + HumL. In addition, there was a significant increase in the average diameter of the sunflowers – by 19.3% and 27.6%, respectively. The pre-sowing application of $N_{65}P_{45}K_{65}$ also contributed to an increase in the weight of achenes by 26.9%, $N_{65}P_{45}K_{65}$ + HumEc caused 33.9% increase and $N_{65}P_{45}K_{65}$ + HumL had 37.1% increase. The largest weight of 1000 seeds was established on the variant with a fertilizer mixture biomodified with humic preparation Ecorost and PEG 400. The excess over the control variant was 16.1%. Experimental variants increased the biological yield of Aley sunflower. The introduction of N65P45K65 provided an increase in yield by 9.4 dt/ha (32.6%). On the variants with mineral fertilizers modified with humic preparations and PEG 400, the gains relative to the control were approximately equal: $N_{65}P_{45}K_{65}$ + HumEc – 43.8%, $N_{65}P_{45}K_{65}$ + HumL – 44.8%.

*Keywords:* sunflower; biomodified fertilizers; humic preparations; phenological and growth manifestations; seed productivity; seed quality.

## Introduction

The growing population of the Earth requires an appropriate amount of food. The population growth in 2005-2016 amounted to 1 billion people. According to UN estimates, by 2030 the projected population will be 8.5 billion, and by the end of this century it will be 11.0 billion people. Along with this, there is a tendency to reduce the sown area per person. If at present it is 0.18 ha, then by 2050 this figure will decrease to 0.15 ha, and by 2100 to 0.12 ha. In addition to the use of crop products for food purposes, there is an increase in their use for bioenergy production and other industries. All this dictates the need for a constant increase in crop production (Sychev et al., 2020).

World statistics show that over the past 40 years, mineral fertilizers have accounted for 40% of the increase in food production (Sychev et al., 2020; Efremov, 2019; Altuhov et al., 2019).

However, the scarcity and high cost of traditional forms of fertilizers makes it necessary to find and introduce into production techniques that increase the efficiency of their use.

Today, world science offers many methods to improve the efficiency of fertilizers, the most effective of which are their differentiated application, as well as their combined use with preparations increasing the utilization of nutrients.

One of the ways to improve the efficiency of mineral fertilizers is the use of technologies for the biological modification of mineral fertilizers. The essence of the biological modification of mineral fertilizers is that biological preparations are added to granular or liquid mineral fertilizers (and ameliorants) that have a complex of useful properties for plants, such as stimulation of plant growth, fungicidal and bactericidal activity, anti-stress effect, molecular nitrogen fixation, phosphate mobilizing activity.

Chemicals in the soil bind phosphorus compounds introduced with mineral fertilizers into a form inaccessible to plants. Microorganisms that are part of biological products, competing with soil microflora for food sources, significantly reduce the process of transferring phosphorus compounds to a form inaccessible to plants, and due to the active development of the root system and root hairs, they significantly increase the absorption capacity of the plant, which is especially important in the early phases of vegetation (Zavalin et al., 2011; Shurekov et al., 2011).

The protective properties of the preparations are due to the ability of the strains of microorganisms used to produce a complex of toxins, lytic enzymes and surfactants with a different mechanism of action, as well as to stimulate the production of phytoalexins (protective compounds) in the plant. Due to this, they have a wide range of fungicidal, bactericidal activity and do not cause resistance. Having populated the root system, the bacteria accompany the plant during the entire growing season and provide a long-term protective effect.

In addition, their use in conjunction with applied mineral fertilizers helps to increase the biological activity of soils by stimulating various groups of beneficial microorganisms and suppressing pathogenic soil microflora. They accelerate the process of decomposition of plant residues and humification (Chebotar et al., 2007).

One of the founders of the biological modification of mineral fertilizers in Russia is Academician of the Russian Academy of Sciences, Doctor of Agricultural Sciences Zavalin, A. A. Some studies were carried out on the biological modification of mineral fertilizers by using microbiological preparation “BisolbiFit”, created on the basis of *Bacillus subtilis* Ch-13 strain, and a technology for obtaining fertilizers of this type was developed (Chebotar et al., 2004)

A decrease in the solubility rate of mineral fertilizer granules combined with a bacterial preparation was experimentally established, compared to granules of untreated mineral fertilizers. The mineral elements in the composition of the granules treated with a bacterial preparation are in a more stable physicochemical state, less soluble and, therefore, more resistant to denitrification processes (transition to a gaseous state). Thus, the enrichment of mineral fertilizer granules with a biological product based on strain *Bacillus subtilis* Ch-13 contributes to plants’ more efficient assimilation of mineral substances that make up these fertilizers.

A number of researchers proved the efficiency of modifying mineral fertilizers with the help of humic preparations (Mitrofanov, 2015; Volotin et al., 2016; Garmash et al., 2013; Levin et al., 2015).

The authors studied the effect of humic and bacterial preparations, liquid complex microfertilizers and their mixtures on the phenology and production processes of spring barley during the growing season, the yield and quality of the harvest of this crop against various backgrounds of mineral nutrition (Mitrofanov, 2015; Mitrofanov & Novikov, 2020).

It was established that the use of mineral fertilizers treated with liquid humate Ecorost, regardless of methods of pre-sowing seed treatment, increases the air-dry weight of plants in tillering and earing phases, productive tillering and yield of spring barley.

The use of mineral fertilizers treated with a humic preparation, on average, according to variants for seed treatment, provided an increase in barley yield by 0.46 t/ha (20.0%).

According to professor of Moscow State University Named after Lomonosov, Doctor of Chemistry Perminova, I.V., increasing the efficiency of mineral fertilizers when processed with Ecorost can be explained by the fact that humic substances can enter into a wide range of various interactions with various classes of organic compounds, form complexes with metals and complex soil minerals (Perminova, 2008). This is confirmed by the research of scientists of Federal Rostov Agrarian Research Center (Polienko et al., 2020; Lyhman et al., 2019; Popov et al., 2018; Lyhman & Polienko, 2017).

Field studies were also carried out to study the effect of humic preparations on the microbial community of gray forest medium loamy soils of Ryazan region of the Russian Federation.

Studies of microorganisms of various ecological and trophic groups of gray forest medium loamy soil of the studied crop rotation using generally accepted methods showed that the preparations and their complexes used in pre-sowing seed treatment had an impact on the number of soil microorganisms and biological activity. The use of the metagenomic approach in research made it possible to take into account, along with cultivated, non-cultivated microorganisms.

An analysis of the results obtained on experimental variants using humic preparation Ecorost made it possible to establish that the main share of the microbiome in these variants was formed by bacteria of *Actinobacteria* group, the major component of which was the bacteria of *Micrococcaceae* family, causing the transfer of hard-to-reach nutrients, such as urea, into a more accessible for plants ammonia form. On the experimental variants, a large proportion of diazotrophic bacteria of *Proteobacteria* group was also noted (Mitrofanov et al., 2021).

In this regard, the purpose of the research was to study the effectiveness of the use of mineral fertilizers biologically modified by the use of humic preparations obtained from various raw materials.

## Material and Methods

Field experiments were carried out in 2021 in Ryazan region on dark gray forest soil. The climate of Ryazan region of the Russian Federation is moderately continental, not characterized by extremeness and sudden changes in meteorological elements. The climate of the region is quite balanced, with moderately cold winters and hot summers.

Ryazan region is characterized by dry years, frequent winter thaws and ice-covered ground, early spring and late autumn frosts, thunderstorms and strong winds in the warm season.

The average annual temperature in the region ranges from +3.9 to +4.6°C. The average monthly temperature in January is from -11.5°C to -10.5°C.

The period of active vegetation of plants increases from north to south from 144 to 152 days, the average duration of the frost-free period is 130-149 days. In recent decades, there has been a trend of increasing temperatures in January and April.

Ryazan region is located in a zone of sufficient moisture. The annual amount of precipitation is 500-600 mm per year. Evaporation in the north is less than 500 mm and it is more than 500 mm in the center and in the south. The moisture factor is thus equal to one. This sufficient moisture contributes to the development of the production of a wide range of crops (https://www.nbcrs.org/ regions/ryazanskaya-oblast/klimat).

The distribution of precipitation throughout the region during the year is uneven. During the warm period it is 70% of the annual precipitation falls in most of the region. In the south and southwest this figure can be even higher. The maximum precipitation occurs in July and the minimum amount occurs in March-April. In the beginning and up to the middle of summer, thunderstorms are frequent in the evenings, while August is usually dry and hot.

In 2021, during the growing season, the temperature regime and the distribution of precipitation were quite contrasting (Table 1).

Thus, in May, prior to sowing, the temperature regime was close to the long-term average. The average monthly temperature was 14.9°C, while the average monthly temperature in May was 14.0°C. The amount of precipitation was 50 mm at a norm of 40 mm, the excess over the norm was 27%. Such weather conditions quite favorably affected the germination of crops in June.

May gave way to hot June-August. In June, the mean monthly air temperature (20.1°C) exceeded the long-term average data (17.4°C) by 2.7°C. The amount of precipitation in June was 87.0 mm, with a norm of 64.0 mm, which was 136.0% of the norm. However, the distribution of precipitation was uneven. Almost 84% of the precipitation fell between June 9 and 15.

July and August were characterized as extremely dry months. The average monthly temperatures were higher than the long-term averages, but there was a shortage of precipitation, so in July the amount of precipitation was 33.0 mm, and in August it was 23.0 mm, which was 42% of the norm.

In September, according to observational data, the actual temperature was 10.3°C, while the average monthly temperature was 12.2°C. Precipitation amounted to 60 mm, while the amount of precipitation in September was 51 mm, which was 118% of the norm.

The field experiment was laid on a site with a calm relief (slope 1, southern exposure). The soil was gray forest light

**Table 1. Weather conditions of the growing season**

| Parameter | May | June | July | August | September |
|---|---|---|---|---|---|
| Average monthly temperature, °C | 14.9 | 20.1 | 21.9 | 21.2 | 10.3 |
| Deviation from the norm, +/− | +0.9 | +2.7 | +2.3 | +3.5 | –1.9 |
| Precipitation actual, mm | 50.0 | 87.0 | 33.0 | 23.0 | 60.0 |
| In % of the norm | 127.0 | 136.0 | 42.0 | 42.0 | 118.0 |

loamy. The agrochemical analysis of soil samples made it possible to establish that the reaction of the soil environment (KCl) was close to neutral and equal to 5.8-6.1 pH units, the content of mobile phosphorus was very high (660-825 mg/kg), the content of exchangeable potassium was in the range of increased and high (145-228 mg/kg), the availability of exchangeable ammonium stabilized at the level of 1.0-1.7. The content of nitrate nitrogen was high. It was in a wide range of variation from 35.1 mg/kg of soil to more than 100 mg/kg of soil.

To study the efficiency of biomodified mineral fertilizers, a small-plot field experiment was laid.

The object of research in the field experiment was early maturing sunflower variety Aley. The variety was bred by SPA Altai LLC from early maturing oilseed variety Sur by the method of multiple individual selection of early maturing biotypes, followed by evaluation by progeny. It has complex resistance to Fusarium rot, downy mildew, sunflower moth, broomrape, phomopsis. Harvesting is possible without desiccation.

Agronomic characteristics of the variety were as follows: ripeness group – early ripening, plant height – 155-170 cm, potential yield – 30-32 c/ha, oil content 52-54% (https://www. sibagrocentr.ru/produktsiya/podsolnechnik/alej).

Experimental scheme includes four variants:

- Control (no fertilizer);
- $N_{65}P_{45}K_{65}$;
- $N_{65}P_{45}K_{65}$, treated with a working solution of Lignohumate AM, PEG 400 and water ($N_{65}P_{45}K_{65}$ + HumL);
- $N_{65}P_{45}K_{65}$, treated with a working solution of Ecorost humate and PEG 400 ($N_{65}P_{45}K_{65}$ + HumEc).

Fertilizers were introduced as fertilizer mixtures which included such components as ammonium sulfate, ammoniated superphosphate and potassium sulfate.

Ammonium sulfate contained not less than 21% of nitrogen by mass fraction in terms of dry matter; 0.2% of water; no more than 0.03% of sulfuric acid.

Ammonized superphosphate contained not less than 9% of nitrogen by mass fraction in terms of dry matter and 30% of phosphorus.

Potassium sulfate contained 50% potassium by mass fraction in terms of dry matter and 17% of sulfur. The choice of sulfur-containing fertilizer is due to the fact that sunflower, like other oilseeds, is demanding on sulfur in the soil.

Fertilizers were applied locally to the row area as a seedbed fertilizer. According to research (Tishkov, 2003; Boldisov, 2017) this method of applying fertilizers for sunflower is the most optimal and versatile.

The norm of mineral fertilizers was taken based on recommendations for sunflower fertilizer in the Non-Chernozem zone of the Russian Federation (Gavrilov et al., 1983). According to the recommendations of the authors, the average norm of mineral fertilizers for sunflower was $N_{90}P_{60}K_{90}$. However, due to the fact that fertilizers were applied locally, which made it possible to reduce fertilizer doses by 25-30% compared to the broadcast method, fertilizers were applied at a dose of $N_{65}P_{45}K_{65}$.

The following preparations were used as bio modifiers.

Ecorost humic preparation, which is a dark brown or brown liquid, is obtained on the basis of humic acids, odourless with pH close to neutral (6.5-7.5) and 54 g/l of the active substance (humic acids). It is hazard class 4 (low-hazardous product). TU 0392-001-26688910-2014.

Lignohumate AM is a powdered organomineral fertilizer based on humic compounds, potassium, sulphur and trace elements (Table 2).

**Table 2. Composition of Lignohumate AM**

| Parameter | Value of parameter, dimension |
|---|---|
| Active ingredient content | 900 g/kg |
| Salts of humic substances | 81 % |
| Humic acids | 50 % |
| Fulvic acids | 25 % |
| Potassium (K) not less than | 9 % |
| Sulphur (S), not less than | 3 % |
| Iron (Fe) | 0.18 % |
| Manganese (Mn) | 0.11 % |
| Copper (Cu) | 0.11 % |
| Zinc (Zn) | 0.11 % |
| Molybdenum (Mo) | 0.0135 % |
| Selenium (Se) | 0.0045% |
| Bor (B) | 0.135% |
| Cobalt (Co) | 0.11% |

Processing of mineral fertilizers took place by fine spraying with the addition of low molecular weight polyethylene glycol (PEG 400). This ensured the penetration of the solution into the structure of the mineral base of the fertilizer, forming an osmotically active shell around the granules, which in turn made it possible to reduce adhesion and the loss of water-soluble mineral fertilizers.

Polyethylene glycol (PEG)-400 is a polymerization product of ethylene oxide with ethylene glycol. Polyethylene glycols – $H(O-CH_2-CH_2)$ n-OH are compounds with a molecular weight less than 20 000 g/mol. PEG 400 is soluble in water, methanol, benzene, dichloromethane, but do not dissolve in diethyl ether and hexane. PEG 400 refers to low molecular weight polymers, the average value of molecular weight is in the range of 380-440 g/mol and the number of moles of ethylene oxide is 8. It is used as a moisture regulator (in papermaking), emulsifier, antistatic agent, dispersant, detergent in textile and leather industry, coolant component, thickener in hydraulic fluids, binder in cosmetics and pharmaceuticals.

The experiment was laid in accordance with the Methodology of the State Variety Testing of Agricultural Crops (Fedina, 1983).

Sowing was carried out on May 06, 2021. The area of the experimental plot was 25 $m^2$, the replication was six-fold. The seeding rate was 60 thousand seeds per hectare. Row spacing was 70 cm. The depth of seeding was 4-6 cm. Agrotechnics corresponded to regional recommendations.

Observations and studies were carried out in the following phenological stages:

- the stage of fully germinated sunflowers, when about 75% of evolute cotyledonary leaves appeared on the soil surface;
- the stage of complete formation of the sunflower (budding), when not less than 75% of plants formed sunflowers, the diameter of which reached 2 cm;
- the stage of mass flowering with 75% of flowering plants. Plants are considered flowering if they have semiflorets and tubiform florets begin to open in the first tiers of the sunflower;
- the stage of pickling ripeness, when the sunflower back sides of 75% of plants became brown.

The duration of the growing season was calculated from the emergence of full seedlings to pickling ripeness.

Before harvesting, 25 out of 100 plants were counted according to the following characteristics:

- The height of plants from the soil surface to the point of attachment of the sunflower, cm.
- The weight of achenes of one sunflower. 25 sunflowers are threshed, after cleaning the achenes are weighed and divided by the number of sunflowers.
- The weight of 1000 seeds.
- The achene huskiness.

The indicator was determined in accordance with GOST 10855-64 by manual caving (2006). To do this, two test portions weighing 10.0 ± 0.01 g were taken from the average achenes from the plot, previously cleared of impurities. The seeds of each test portion were crushed with tweezers. The fruit shells (husks) separated from the seed (kernel) were weighed with an accuracy of 0.01 g. The huskiness was presented in % to the weight taken to analyze achene samples. The average of the two determinations was taken as the huskiness of the achene sample. The difference between parallel determinations was allowed no more than ± 0.1%. Otherwise, determining was repeated.

- The incrustation was determined by the steaming method. For each variant, average samples of 200 g were selected, from which two samples of 1000 typical seeds were isolated for analysis. The seeds were placed in cups and filled with boiling water so that they were covered with it. After 20 min, achenes were selected that had a darkened shell layer, almost black in color. At the same time, shell-less, on the contrary, brightened and became light gray.
- The biological yield. The indicator was determined by the following formula:

$$Y_b = \frac{10\,000}{S_{sample}}\left(R_{plant} \cdot \frac{m_n}{N_{plant}}\right) / \, 100\,000, \quad (1)$$

where $Y_b$ is biological yield, dt/ha;

10 000 is the area of 1 ha, $m^2$;

$S_{sample}$ is the area from which sampling was carried out, $m^2$;

$R_{plant}$ is the arithmetic mean number of plants from the sampling point, pcs.;

$m_n$ is the yield weight of selected plants, g;

$N_{plant}$ is the number of selected plants, pcs.;

100 000 is the conversion factor of crop weight from grams per hectare to centners per hectare.

- The chemical analysis of seeds. Samples weighing 0.7 kg were taken for analysis. The analysis was carried out in an accredited laboratory of FSBI "SAS "Ryazanskaya".

The data of the field experiment were mathematically processed using Excel add-in for statistical evaluation and analysis of the results of field and laboratory experiments Agcstat, developed by Federal State Budgetary Scientific Institution "North Caucasian Federal Scientific Agrarian Center" based on the methods described in the manual (Dospehov, 1985).

## Results and Discussion

Field germination is one of the parameters that ensure high yield of crops. Seed germination is formed in the process of growing and largely depends on soil and climatic conditions, growing technology, methods of pre-sowing seed treatment. Under the conditions of the experiment, the value of field germination varies slightly according to variants (Table 3). Differences are not significant.

**Table 3. Field germination of Aley sunflower, %**

| Variant | Field germination of sunflower, % |
|---|---|
| Control | 84.0 |
| $N_{65}P_{45}K_{65}$ | 85.8 |
| $N_{65}P_{45}K_{65}$ + HumEc | 87.2 |
| $N_{65}P_{45}K_{65}$ + HumL | 86.9 |
| $HCP_{05}$ | 3.0 |

The obtained results can be explained by the fact that the development of the seed in the initial stages of ontogenesis primarily occurs due to nutrients that make up its composition, as well as growth substances: phytohormones, amino acids, purines, etc. In this connection, the application of fertilizers before sowing can give a potential effect only in the later stages of plant development.

The study of the rates of stages of plant growth and development made it possible to establish a clear effect of mineral fertilizers (Table 4). In variants with mineral fertilizers, a decrease in the length of interstage periods and the growing season as a whole was established. This fact has both positive and negative implications.

On the one hand, this makes it possible to avoid a decrease in the quality of the resulting crop, caused by sunflower diseases, for example, gray and white rot, which is typical for a number of territories of the Russian Federation in the autumn period, characterized by excessive precipitation and low average daily air temperatures.

On the other hand, a decrease in the duration of the growing season increases the load on harvesting equipment and grain farming, since harvesting occurs at the beginning of September, when post-harvest processing of grain and leguminous crops takes place.

In all variants of the experiment, shoots of weeds appeared simultaneously with sunflower shoots. Infestation was of a mixed nature with a predominance of *Chenopodium album*, *Amaranthus retroflexus*, *Convolvulus arvensis* and *Agropyron repens* (Table 5).

In experimental variants, a larger number of weeds was found, which was due to the fact that applied mineral fertilizers are an additional source of nutrition not only for sunflowers, but also for weeds. There was no significant difference between the experimental variants in terms of the species composition of weeds and their number. For weed control, inter-row treatment and treatment with Select herbicide, EC (120 g/l) at a consumption rate of 1.6 l/ha took place.

**Table 4. The duration of the phenological stages of sunflower development depending on the background of mineral nutrition, days**

| Variant | Development stages | | | | Vegetation period length |
|---|---|---|---|---|---|
| | Sowing – full shoots | Budding | Mass flowering | Mass flowering – pickling ripeness | |
| Control | 9 | 39 | 29 | 42 | 110 |
| $N_{65}P_{45}K_{65}$ | 9 | 38 | 27 | 42 | 107 |
| $N_{65}P_{45}K_{65}$ + HumEc | 9 | 36 | 24 | 40 | 100 |
| $N_{65}P_{45}K_{65}$ + HumL | 9 | 37 | 24 | 41 | 102 |

**Table 5. Species composition of weeds on Aley sunflower crops, pcs/m²**

| Weed type | Variant | | | |
|---|---|---|---|---|
| | Control | $N_{65}P_{45}K_{65}$ | $N_{65}P_{45}K_{65}$ + HumEc | $N_{65}P_{45}K_{65}$ + HumL |
| *Chenopodium album* | 8 | 6 | 7 | 6 |
| *Amaranthus retroflexus* | 4 | 5 | 5 | 6 |
| *Convolvulus arvensis* | 5 | 5 | 3 | 3 |
| *Agropyron repens* | 3 | 3 | 4 | 4 |
| *Cirsium arvense* | 2 | 5 | 3 | 2 |
| *Setaria* | 2 | 3 | 2 | 4 |
| *Sonchus arvensis* | 2 | 4 | 4 | 4 |
| Total | 26 | 31 | 28 | 29 |

**Table 6. Density and safety of sunflower plants**

| Variant | Number of plants, pieces/m² | | | Plant safety, % | | |
|---|---|---|---|---|---|---|
| | full shoots | mass flowering | pickling ripeness | full shoots – mass flowering | mass flowering – pickling ripeness | full shoots – pickling ripeness |
| Control | 5.04 | 4.34 | 4.30 | 86.11 | 99.07 | 85.32 |
| $N_{65}P_{45}K_{65}$ | 5.15 | 4.54 | 4.50 | 88.16 | 99.12 | 87.38 |
| $N_{65}P_{45}K_{65}$ + HumEc | 5.23 | 4.64 | 4.62 | 88.72 | 99.57 | 88.34 |
| $N_{65}P_{45}K_{65}$ + HumL | 5.21 | 4.58 | 4.55 | 87.91 | 99.34 | 87.33 |

Throughout the growing season of sunflower, plant death was observed due to interspecific competition with weeds, lack of moisture and other factors, especially in the first half of the growing season (Table 6). However, by the flowering stage, the plant density stabilized.

Greater preservation of plants during the growing season was observed in variants with mineral fertilizers, which was due to their high preservation in the period from shooting to flowering.

Variants of fertilizers had a significant impact on the dynamics of the vegetative mass of sunflower plants during the growing season (Table 7). The excess of the air-dry weight of the experimental variants over the control in the stage of mass flowering was 15.1% with $N_{65}P_{45}K_{65}$, 19.0% with $N_{65}P_{45}K_{65}$ + HumEc, 18.4% with $N_{65}P_{45}K_{65}$ + HumL. Given this fact, it is possible to use biomodified fertilizers when growing sunflower for green fodder and silage.

**Table 7. The dynamics of air-dry weight of sunflower plants, g/m²**

| Variant | Stage of development | |
|---|---|---|
| | Mass flowering | Pickling ripeness |
| Control | 4 942 | 1 689 |
| $N_{65}P_{45}K_{65}$ | 5 689 | 1 823 |
| $N_{65}P_{45}K_{65}$ + HumEc | 5 882 | 1 884 |
| $N_{65}P_{45}K_{65}$ + HumL | 5 850 | 1 863 |
| $LSD_{05}$ | 644 | 121 |

This trend continued to pickling ripeness but the excess over the control was somewhat lower: $N_{65}P_{45}K_{65}$ – 7.9%, $N_{65}P_{45}K_{65}$ + HumEc – 11.5%, $N_{65}P_{45}K_{65}$ + HumL – 10.3%. A decrease in parameters indicated a higher moisture content in the vegetative mass of sunflower in the stage of mass flowering in experimental variants.

Studies showed that the applied fertilizers did not have any positive effect on the plant height. So, in the control variant (without fertilizers), the height of plants averaged 140.6 cm (Table 8).

**Table 8. The height of plants from the soil surface to the sunflower articulation point, cm**

| Variant | Parameter | Difference with the control |
|---|---|---|
| Control | 140.6 | – |
| $N_{65}P_{45}K_{65}$ | 145.6 | 5.0 |
| $N_{65}P_{45}K_{65}$ + HumEc | 132.4 | – 8.2 |
| $N_{65}P_{45}K_{65}$ + HumL | 139.5 | – 1.1 |
| $LSD_{05}$ | 7.5 | |

The introduction of fertilizer mixture contributed to the growth of plants up to 145.6 cm (3.6%), but this value was not statistically significant. Variant $N_{65}P_{45}K_{65}$ + HumL was at the control level. The variant with a fertilizer mixture treated with Ecorost humate had a 5.8% decrease in the average height of plants.

The data obtained showed that the height of Aley sunflower plants practically did not depend on the background of mineral nutrition. At the same time, the stems in the control variant were thinner. Part of the sunflower stems, unable to withstand the mass of the sunflower, deviated, and therefore, moisture accumulated on the back side of the sunflowers, which in some cases led to the development of the sunflower rot, and as a result, a decrease in the yield of seeds.

An analysis of the elements of the crop structure made it possible to identify the dependence of the diameter of sunflower on applied fertilizers (Table 9).

**Table 9. The diameter of sunflowers, cm**

| Variant | Parameter | Difference with the control |
|---|---|---|
| Control | 14.5 | – |
| $N_{65}P_{45}K_{65}$ | 16.4 | 1.9 |
| $N_{65}P_{45}K_{65}$ + HumEc | 17.3 | 2.8 |
| $N_{65}P_{45}K_{65}$ + HumL | 18.5 | 4.0 |
| $LSD_{05}$ | 1.2 | |

The average diameter of the sunflower in the control was 14.5 cm. The application of fertilizer mixture $N_{65}P_{45}K_{65}$ provided a significant increase in the average diameter of the baskets by 13.1%, $N_{65}P_{45}K_{65}$ + HumEc by 19.3% and $N_{65}P_{45}K_{65}$ + HumL by 27.6%, respectively.

At the same time, variants with fertilizers treated with humic preparations had a large proportion of sunflowers of a convex shape.

According to the research of an employee of the All-Russian Scientific Research Institute of Oilseeds Named after V. S. Pustovoita Bochkarev, B. N. it was found that the convex-shaped sunflowers are characterized by a lower friability in comparison with flat and shapeless sunflowers.

The weight of the achenes had a direct correlation with their diameter (Table 10).

The smallest weight of one sunflower was in the control variant equal to 66.9 g. The sowing application of $N_{65}P_{45}K_{65}$ contributed to an increase in this indicator by 26.9%, $N_{65}P_{45}K_{65}$ + HumEc by 33.9% and $N_{65}P_{45}K_{65}$ + HumL by 37.1%.

The weight of 1000 seeds is one of the most important elements of the structure of the sunflower yield when studying the effect of agrotechnical methods of cultivation on crop

**Table 10. The weight of achenes in a sunflower, g**

| Variant | Parameter | Difference with the control |
|---|---|---|
| Control | 66.9 | – |
| $N_{65}P_{45}K_{65}$ | 84.9 | 18.0 |
| $N_{65}P_{45}K_{65}$ + HumEc | 89.6 | 22.7 |
| $N_{65}P_{45}K_{65}$ + HumL | 91.7 | 24.8 |
| $LSD_{05}$ | 10.7 | |

**Table 11. The weight of 1000 seeds, g**

| Variant | Parameter | Difference with the control |
|---|---|---|
| Control | 63.4 | – |
| $N_{65}P_{45}K_{65}$ | 71.6 | 8.2 |
| $N_{65}P_{45}K_{65}$ + HumEc | 73.6 | 10.2 |
| $N_{65}P_{45}K_{65}$ + HumL | 66.2 | 2.8 |
| $LSD_{05}$ | 7.5 | |

productivity. It was found that the sowing fertilizer application had an impact on this parameter (Table 11).

The largest weight of 1000 seeds was 73.6 g in the variant with a fertilizer mixture biomodified with a solution of humic preparation Ecorost and PEG 400. The excess over the control variant was 10.2 g (16.1%).

The introduction of $N_{65}P_{45}K_{65}$ contributed to an increase in the weight of 1000 achenes by 8.2 g (12.9%). Variant $N_{65}P_{45}K_{65}$ + HumL had 2.8 g (4.4%) excess over the control, but it was not statistically significant. This is explained by the fact that in this variant, with an increase in the diameter of sunflowers, the number of smaller seeds located in the central part of the sunflower increased.

The huskiness of seeds is one of the parameters characterizing the quality of the sunflower crop. It largely determines the yield of oil from seeds and, as a result, the amount of oil obtained from the sown area. The content of husks in various varieties of oilseed sunflower varies within 22-42%.

The analysis made it possible to establish that in the control variant the huskiness of seeds was 29.4% (Table 12).

**Table 12. The huskiness content of sunflower achenes, %**

| Variant | Parameter | | | Difference with the control |
|---|---|---|---|---|
| | I | II | Cp. | |
| Control | 29.3 | 29.5 | 29.4 | – |
| $N_{65}P_{45}K_{65}$ | 40.3 | 39.9 | 40.1 | + 10.7 |
| $N_{65}P_{45}K_{65}$ + HumEc | 25.2 | 24.8 | 25.0 | – 4.4 |
| $N_{65}P_{45}K_{65}$ + HumL | 35.4 | 34.8 | 35.1 | + 5.7 |
| $LSD_{05}$ | 0.78 | | | |

The introduction of $N_{65}P_{45}K_{65}$ sharply increased the huskiness of the seeds by 10.7%. This fact is consistent with the data obtained in the research (Nizamov et al., 2019), devoted to the study of the efficiency of agrochemicals in the technology of sunflower cultivation in the forest-steppe zone of the Middle Volga region of the Russian Federation.

A decrease in huskiness of achenes was noted in experimental variants with complexly mixed fertilizers modified by treatment with mixtures of humic preparations and PEG 400 relative to $N_{65}P_{45}K_{65}$ variant. Thus, in $N_{65}P_{45}K_{65}$ + HumL variant, the excess over the control was 5.7%, and in $N_{65}P_{45}K_{65}$ + HumEc variant, the huskiness was lower than in the control variant by 4.4%. However, the results obtained for this parameter may be erroneous due to the imperfection of the method used.

Incrustation is one of the qualities that determine the resistance of seeds to diseases and pests, in particular sunflower moth. The incrustation layer is formed from sclerenchyma cells and consists of 70% carbon. It is black and very dense. Incrustation is one of the parameters required in breeding and seed production processes. All breeding varieties of oilseed sunflower have high incrustation in the range of 93-100%.

In the course of the analysis carried out by the method of steaming, it was found that the incrustation of seeds in all variants was 100% and was determined by the genetic potential of the variety. It was not possible to identify discolored seeds in any of the studied samples. In this regard, it is impossible to judge the nature of the effect of applied fertilizers.

Experimental variants increased the biological yield (excluding losses during harvesting) of Aley sunflower (Table 13).

**Table 13. Biological yield of sunflower depending on the use of various types of fertilizers, dt/ha**

| Variant | Parameter | Control gain |
|---|---|---|
| Control | 28.8 | – |
| $N_{65}P_{45}K_{65}$ | 38.2 | 9.4 |
| $N_{65}P_{45}K_{65}$ + HumEc | 41.4 | 12.6 |
| $N_{65}P_{45}K_{65}$ + HumL | 41.7 | 12.9 |

The introduction of $N_{65}P_{45}K_{65}$ provided an increase in yield by 9.4 c/ha (32.6%). In variants with mineral fertilizers modified by treatment with mixtures of humic preparations and PEG 400, the gains are approximately equal relative to the control: $N_{65}P_{45}K_{65}$ + HumEc – 43.8% and $N_{65}P_{45}K_{65}$ + HumL – 44.8%.

At the same time, the biological yield in the control variant was at the level of the average actual yield of the variety equal to 28-32 c/ha. And it was 40-42 c/ha in variants with biomodified mineral fertilizers that was within the potential yield of a variety.

Data on changes in the agrochemical parameters of the soil under the influence of sunflower Aley and the studied nutritional backgrounds are presented in Table 14.

As can be seen from the data in the table, a decrease in the nitrogen content of nitrates was observed in all variants of the experiment. The greatest loss of 48.3 g/kg was established in the control variant. In the variant with $N_{65}P_{45}K_{65}$ the decrease was 22.9 g/kg. In variants with biomodified fertilizers, this parameter relative to the fertilizer mixture was somewhat lower, but not so significantly: $N_{65}P_{45}K_{65}$ + HumL – 21.3 g/kg, $N_{65}P_{45}K_{65}$ + HumEc – >20.8 g/kg. Based on this, it is possible to conclude that humic preparations do not have a pronounced effect on the processes of nitrogen nitrification.

However, in all experimental variants, an increase in the content of ammonium nitrogen was established, while the highest values were in variants with fertilizers modified with a solution of humic preparations and PEG 400: the control had 1.8 g/kg of soil: the control had 1.8 g/kg of soil, $N_{65}P_{45}K_{65}$ had 4.4 g/kg, $N_{65}P_{45}K_{65}$ + HumL had 4.8 g/kg and $N_{65}P_{45}K_{65}$ + HumEc had 6.8 g/kg.

The increase in the content of ammonium nitrogen in the control variant can be explained by an increase in the processes of ammonification of the organic matter of the soil of the experimental plot, while in the variant with mineral fertilizers it is due to the content of ammonium sulfate in the mixture. At the same time, it can be concluded that humic preparations used as a modifier enhanced ammonification process.

The data obtained on the effect of humic substances on soil nitrogen are positive. Humates do not have a pronounced effect on processes of nitrogen nitrification, while enhancing ammonification processes.

**Table 14. The dynamics of agrochemical parameters of the soil**

| Parameter, dimension | Before field experiment | | After harvest | | Difference between observations |
|---|---|---|---|---|---|
| | actual value | test method error | actual value | test method error | |
| Control | | | | | |
| pH (KCl), units pH | 5.8 | ± 0.1 | 5.9 | ± 0.1 | + 0.1 |
| Mobile potassium, mg/kg | 288 | ± 43 | 152 | ± 23 | – 136 |
| Mobile phosphorus, mg/kg | 665 | ± 133 | 650 | ± 130 | – 15 |
| Nitrate nitrogen, mg/kg | 54.6 | ± 10.9 | 6.3 | ± 1.9 | – 48.3 |
| Ammonium nitrogen, mg/kg | 1.7 | ± 0.3 | 3.5 | ± 0.5 | + 1.8 |
| $N_{65}P_{45}K_{65}$ | | | | | |
| pH (KCl), units pH | 5.9 | ± 0.1 | 5.8 | ± 0.1 | – 0.1 |
| Mobile potassium, mg/kg | 166 | ± 25 | 112 | ± 17 | – 54 |
| Mobile phosphorus, mg/kg | 660 | ± 132 | 660 | ± 132 | 0 |
| Nitrate nitrogen, mg/kg | 35.1 | ± 7.0 | 12.2 | ± 2.4 | – 22.9 |
| Ammonium nitrogen, mg/kg | 1.0 | ± 0.1 | 5.4 | ± 0.8 | + 4.4 |
| $N_{65}P_{45}K_{65}$ + huml | | | | | |
| Ph (kcl), units ph | 6.1 | ± 0.1 | 5.8 | ± 0.1 | – 0.3 |
| Mobile potassium, mg/kg | 145 | ± 22 | 139 | ± 21 | – 6 |
| Mobile phosphorus, mg/kg | 685 | ± 137 | 650 | ± 130 | – 35 |
| Nitrate nitrogen, mg/kg | 35.1 | ± 7.0 | 13.8 | ± 2.8 | – 21.3 |
| Ammonium nitrogen, mg/kg | 1.3 | ± 0.2 | 6.1 | ± 0.9 | + 4.8 |
| $N_{65}P_{45}K_{65}$ + HumEc | | | | | |
| pH (KCl), units pH | 5.8 | ± 0.1 | 5.2 | ± 0.1 | – 0.6 |
| Mobile potassium, mg/kg | 151 | ± 23 | 194 | ± 29 | + 43 |
| Mobile phosphorus, mg/kg | 825 | ± 165 | 610 | ± 122 | – 215 |
| Nitrate nitrogen, mg/kg | > 100 | – | 79.2 | ± 15.8 | > 20.8 |
| Ammonium nitrogen, mg/kg | 1.0 | ± 0.1 | 7.8 | ± 1.2 | 6.8 |

Nitrates are the main source of significant losses of soil nitrogen and fertilizers due to denitrification and leaching by precipitation, which causes great damage to agriculture. Nitrates, unlike ammonium, are easily washed out of the root layer of the soil into groundwater, rivers and reservoirs. Second, plants use more $NH_4^+$, than $NO_3$. Third, nitrates can almost unlimitedly enter plants and, at their high content in products, make them dangerous for human and animal health.

An analysis of the reaction of the soil environment made it possible to establish that in the control variant and in $N_{65}P_{45}K_{65}$ variant, this parameter does not practically change (it lies within the error of the measurement method).

In variants with biomodified fertilizers, the fact of soil acidification was established: $N_{65}P_{45}K_{65}$ + HumL had 0.3 pH units and $N_{65}P_{45}K_{65}$ + HumEc had 0.6 pH units. This fact can be explained by the influence of humic substances on processes of nitrogen conversion in the soil – a decrease in the loss of nitrate nitrogen and an increase in the growth of ammonium, which, as a result, leads to the release of ammonia and nitric acid.

An analysis of the dynamics of mobile potassium revealed the following trend. In the control variant (without fertilizes), a decrease in the content of mobile potassium in the soil (-136 mg/kg of soil) was naturally established. When $N_{65}P_{45}K_{65}$ was applied, the deficit was somewhat lower (54 mg/kg). In variants with $N_{65}P_{45}K_{65}$ + HumL a non-deficient content of mobile potassium was observed, and in variant $N_{65}P_{45}K_{65}$ + HumEc an increase of 43 mg/kg of soil was established. Based on this, it can be concluded that humic substances enhance metabolic processes in the soil, converting fixed forms of potassium into mobile (metabolic) ones.

The study of the dynamics of the content of mobile phosphorus showed that in most variants in the cultivation of Aley sunflower, this parameter remained at the level of a deficit-free balance. Some reductions were observed, but they were within the margin of the test method error. However, in $N_{65}P_{45}K_{65}$ + HumEc variant, a significant decrease in this parameter was observed and it was about 26% of the content before the experiment was started. This fact can be explained both by an increase in the removal of available phosphorus compounds by plants under the action of Ecorost humic preparation obtained from milled lowland peat, and by the possible binding of mobile forms of phosphorus by it.

Even though sunflower is an oil crop, it is often used as animal feed. Meal and cake are also used for feed, obtained when processing for oil achenes with crude protein of up to 40%.

To conduct a chemical analysis of sunflower seeds, samples weighing 700 g were taken and submitted to certified laboratory "Station of the Agrochemical Service" Ryazanskaya", where the following nutritional parameters were studied: dry matter, organic matter, crude protein, digestible protein, crude fat, crude fiber and crude ash (Table 15).

The analysis performed showed that $N_{65}P_{45}K_{65}$ and $N_{65}P_{45}K_{65}$ + HumL variants had a lower content of dry and organic matter. Variant $N_{65}P_{45}K_{65}$ + HumEc was at the control level. The highest content of crude and digestible protein was found in sunflower seeds of $N_{65}P_{45}K_{65}$ + HumEc variant. The content of crude protein increased relative to the control by 0.78% and digestible protein by 0.67%. A decrease in these parameters was found in variants $N_{65}P_{45}K_{65}$ and $N_{65}P_{45}K_{65}$ + HumL. The content of crude protein in $N_{65}P_{45}K_{65}$ variant was less than the control by 0.81%, and that of digestible one by 0.68%. Lower values of the parameter were noted in $N_{65}P_{45}K_{65}$ + HumL variant, where a decrease relative to the control for crude protein was 2.19% and 1.86% for digestible one.

As for the content of crude fat in sunflower seeds, the highest content of 0.81% compared to the control was found in $N_{65}P_{45}K_{65}$ + HumL variant. This, in turn, makes it possible to recommend the introduction of fertilizer mixtures treated with Lignohumate AM to increase the fat content of achenes. A decrease in the content of crude fat in achenes was found in variants $N_{65}P_{45}K_{65}$ and $N_{65}P_{45}K_{65}$ + HumEc.

A wide variation in the content of crude fiber (± 5%) was established in experimental variants. The variant with the fertilizer mixture treated with Ecorost humic preparation was at the control level. The highest content was found in $N_{65}P_{45}K_{65}$ + HumL variant, where this parameter was 6.5%

**Table 15. Chemical composition of sunflower seeds, %**

| Variant | Dry matter | Organic matter | Crude protein | Digestible protein | Crude fat | Crude fiber | Crude ash |
|---|---|---|---|---|---|---|---|
| Control | 92.1 | 88.51 | 18.97 | 16.12 | 52.48 | 15.48 | 3.59 |
| $N_{65}P_{45}K_{65}$ | 91.3 | 87.45 | 18.16 | 15.44 | 50.49 | 20.23 | 3.85 |
| $N_{65}P_{45}K_{65}$ + HumEc | 92.3 | 88.61 | 19.75 | 16.79 | 51.32 | 15.42 | 3.69 |
| $N_{65}P_{45}K_{65}$ + HumL | 90.8 | 86.95 | 16.78 | 14.26 | 53.29 | 21.98 | 3.85 |

**Table 16. The calculation of the economic efficiency of biologically modified mineral fertilizers**

| Variant | Fertilizer costs, ruble/ha | Economic efficiency of biologically modified mineral fertilizers on a sown area of 100 ha, million rubles |
|---|---|---|
| $N_{65}P_{45}K_{65}$ | 12137.0 | 1.66 |
| $N_{65}P_{45}K_{65}$ + HumEc | 13348.7 | 2.46 |
| $N_{65}P_{45}K_{65}$ + HumL | 12678.8 | 2.60 |

higher than the control. The content of crude fiber was 4.75% higher in $N_{65}P_{45}K_{65}$ variant than that in the control. Increasing the level of crude fiber was negative, as it made it difficult to absorb nutrients at high levels.

The applied fertilizers did not have a significant effect on the content of crude ash.

The calculation of the economic efficiency of biologically modified mineral fertilizers was carried out in comparison with the control (Table 16).

Since within the framework of the field experiment, fertilizers were applied before sowing, the costs of fertilizing include the costs of fertilizers and their transportation to the place of application. However, as part of a small-plot field experiment, the biological yield was determined, which did not take into account yield losses that occurred when harvesting. According to the research (Kapustin & Kunakova, 2004), losses during sunflower harvesting ranged from 10 to 20%. In this connection, when calculating the economic effect, a correction factor was used that took into account this factor. As a result, the economic effect from mineral fertilizers when growing oilseed sunflower Aley on a sown area of 100 ha was as follows: 1.66 million rubles for $N_{65}P_{45}K_{6}$, 2.46 million rubles for $N_{65}P_{45}K_{65}$ + HumEc and 2.6 million rubles for $N_{65}P_{45}K_{65}$ + HumL.

## Conclusions

The conducted field studies confirmed the expediency of biological modification of solid mineral fertilizers with humic preparations as an effective way to increase their efficiency. Experimental variants increased the biological yield of Aley sunflower. The introduction of $N_{65}P_{45}K_{65}$ provided an increase in yield by 9.4 c/ha (32.6%). The gains relative to the control were approximately equal in variants with mineral fertilizers modified with humic preparations and PEG 400: 43.8% for $N_{65}P_{45}K_{65}$ + HumEc and 44.8% for $N_{65}P_{45}K_{65}$ + HumL. The economic effect of mineral fertilizers when growing oilseed sunflower Aley on a sown area of 100 hectares was 1.66 million rubles for $N_{65}P_{45}K_{6}$, 2.46 million rubles for $N_{65}P_{45}K_{65}$ + HumEc and 2.6 million rubles for $N_{65}P_{45}K_{65}$ + HumL.

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*Received*: **April, 11, 2022**; *Approved*: **June, 08, 2022**; *Published*: **February, 2023**