Influence of mineral fertilizers on the white lupine seeds yield under cultivation in the Central Black Earth region of Russia

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Abstract. The study results on using macro- and micronutrients in the cultivation of white lupine (Lupinus albus L.) in the soil and climatic conditions of the Central Black Earth region of Russia are presented. Field trials were carried out in 2018-2020 at the Department of Plant Growing, Breeding and Vegetable Growing in Belgorod State Agrarian University. The object of research is a high-intensity variety of white lupine Degas. The subject of research is the Aquamix microfertilizer of two brands – Aquamix-T (for seed treatment) and Aquamix-TV (for foliar dressing), macrofertilizers – potassium sulphate (K₂SO₄) and potassium monophosphate (KH₂PO₄). The weather conditions during the years of the experiments were unfavorable for the growth and development of lupine, since during the entire growing season of the plants an increased temperature regime was observed with a deficit of precipitation. The soil cover of the experimental field is represented by typical chernozem with an average content of basic nutrients. The accounting area of the plot is 18 m², the replication is fourfold, the placement is systematic. The experiment included seven options: 1) control (without fertilizers), 2) seed treatment with Aquamix-T micronutrient fertilizer, 3) seed treatment with Aquamix-T micronutrient fertilizer and foliar fertilization with Aquamix-TV micronutrient fertilizer, 4) seed treatment with Aquamix-Tilist micronutrient fertilizer solution potassium sulphate, 5) seed treatment with microfertilizer Aquamix-Tilist feeding with potassium monophosphate solution, 6) seed treatment with micronutrient Aquamix-Tilist fertilizer with a mixture of Aquamix-TV + potassium sulphate, 7) seed treatment with micronutrient fertilizer Aquamix-Tilist fertilization with potassium monophosphate mixture. Analysis of the data obtained showed that the highest yield of white lupine seeds was obtained on the variants with seed treatment with Aquamix-Tilist micronutrient fertilizer together with foliar dressing with Aquamix-TV micronutrient fertilizer in combination with K₂SO₄ or KH₂PO₄ macrofertilizers, which was 3.64 and 3.62 t/ha, respectively, which is 0.64 and 0.62 t/ha or 21.3 and 20.5% above the control variant.

1. Introduction
At the present stage of agro-industrial complex development in the Russian Federation, considerable attention is paid to the problem of meeting the needs of the livestock industry in fodder protein, as well as the search for effective ways to reduce its production cost. As you know, to successfully solve the deficiency problem of fodder vegetable protein, it is necessary to expand the acreage for grain legumes, including lupine. White lupine is distinguished by the highest nitrogen-fixing ability among annual legumes, accumulating in the biomass up to 300 kg/ha of symbiotic nitrogen [1, 2]. In addition, lupine has a powerful root system, which makes it undemanding to soil fertility. The lupine advantages also
include its high yield potential and high content of crude protein in seeds, balanced in amino acid composition [3, 4, 5]. Thus, the lupine cultivation not only contributes to obtaining a large amount of high-quality fodder vegetable protein, but also to an increase in soil fertility. However, to obtain high and sustainable seed yields in regions where lupine is not a traditional crop, it is necessary to develop a scientifically grounded technology for its cultivation in relation to specific soil and climatic conditions. The most effective and fast-acting way to increase the yield of agricultural crops and the quality of crop products are fertilizers [6, 7]. At the same time, to obtain the greatest positive effect, it is necessary to provide plants with optimal not only basic nutrients (macronutrients), but also microelements that are involved in many metabolic processes, including nitrogen fixation. The most accessible form for plants is chelated micronutrient fertilizers. They have biological activity and therefore are more quickly involved in physiological processes in plants. The same amounts of fertilizers can give very different economic returns, and if they are used irrationally, even the absence of a positive effect from their use is quite possible. Much here depends on fertilizing method, determining the optimal rate. Seeds enrichment with microelements using pre-sowing treatment is the most affordable way to intensify metabolic reactions, to activate germination processes and further plant development. To improve the nutrition of agricultural crops in certain periods of their development and to replace one or another nutrient that is missing in the soil, foliar fertilization of crops is usually carried out.

Many scientific works are devoted to lupine cultivation. However, the advisability question of using various types and doses of mineral macro- and micronutrient fertilizers, as well as their combinations on white lupine, has not been sufficiently studied. The use of mineral fertilizers significantly increases the yield and quality of lupine seeds, as well as the yield of crude protein and fat per hectare. In this regard, the purpose of the research was to study the effectiveness of pre-sowing seed treatment with micronutrient fertilizers, as well as foliar dressing with macro- and micronutrient fertilizers in the cultivation of white lupine.

2. Materials and methods
The studies about the effect of pre-sowing seed treatment with Aquamix-T micronutrient fertilizer and foliar dressing with macro- and micronutrient fertilizers on the productivity of lupine plants were carried out in 2018-2020 in field experiments at the collection nursery of the Department of Plant Growing, Breeding and Vegetable Growing of Belgorod State Agrarian University. The research object was a high-intensity variety of white lupine Degas, the research subject were mineral macro- and micronutrient fertilizers.

The soil of the experimental field is typical chernozem with an average content of basic nutrients. The weather conditions during the years of the experiments were unfavorable for lupine growth and development, since, during the entire growing season of the plants, an increased temperature regime was observed with sediment deficit.

The experience included seven options: 1) control (without fertilizers), 2) seed treatment with Aquamix-T micronutrient fertilizer, 3) seed treatment with Aquamix-T micronutrient fertilizer and foliar application with Aquamix-TV micronutrient fertilizer, 4) seed treatment with Aquamix-T micronutrient fertilizer and leaf top dressing with a solution of potassium sulphate, 5) seed treatment with micronutrient fertilizer Aquamix-T and foliar fertilization with a solution of potassium monophosphate, 6) seed treatment with micronutrient fertilizer Aquamix-T, foliar dressing with a mixture of Aquamix-TV + potassium sulphate, 7) seed treatment with micronutrient fertilizer Aquamix-T and foliar dressing with a mixture Aquamix-TV + potassium monophosphate.

Field experiments were planed according to the existing methodological recommendations. The area of the registration plots is 18 m² with systematic placement. Sowing was carried out by warming up the sowing layer of soil to 6-7°C with seeding rate of 1.3 million pieces/ha of germinating seeds. Sowing method is ordinary with 15 cm row spacing. Foliar fertilizing was carried out during flower-bud formation. Fertilizers were used in the following doses: monopotassium phosphate – 3.0 kg/ha, potassium sulphate – 3.0 kg/ha, Aquamix - TV – 150.0 g/ha, Aquamix - T – 300.0 g/t.
3. Results and discussion
The level and weight of plants’ dry matter are the result of their interaction with environmental factors and make it possible to judge the conditions of growth and development, as well as the responsiveness of cultivated crops to the applied agrotechnical methods. Optimization of the plant nutrition system both by using mineral macrofertilizers and through micronutrients introduction has a positive effect on the linear growth and accumulation of dry plant biomass. Pre-sowing seeds treatment with micronutrient fertilizer Aquamix-T, both separately and in combination with foliar dressing, contributed to an increase in the height of white lupine plants in comparison with the control. In the flowering period, there was no noticeable difference in plant height between experimental options with pre-sowing seed treatment with micronutrient fertilizer Aquamix-T, either separately or in conjunction with foliar dressing with macro- and micronutrient fertilizers. However, in the pod formation period in the options with combined using Aquamix-T microfertilizer for pre-sowing seed treatment and macro- and micronutrient fertilizers for foliar dressing, the plant height exceeded not only the control, but also the option with pre-sowing seed treatment. The greatest influence on plant height was exerted by foliar dressing with a mixture of Aquamix-TV + K2SO4 and a mixture of Aquamix-TV + KH2PO4 against the background of pre-sowing seed treatment with micronutrient fertilizer Aquamix-T. In these experimental options, the height of lupine plants in the pod formation period was 54.7 and 54.0 cm, respectively, that is 5.7 and 6.4 cm more than in the control (Table 1).

Table 1. Influence of macro- and micronutrient fertilizers on linear growth and weight of air-dry matter of white lupine plants, 2018-2020

| No. | Experimental option                          | Average plant height by vegetative stage, cm | Average weight of one plant by vegetative stage, g |
|-----|---------------------------------------------|---------------------------------------------|--------------------------------------------------|
|     |                                             | Average weight of one plant by vegetative stage, cm |                                  |
|     |                                             | flowering | pod formation | flowering | pod formation |
| 1   | Control – no fertilizer                     | 43.4      | 48.3          | 12.0      | 23.3          |
| 2   | Seed treatment with Aquamix-T               | 47.3      | 51.5          | 13.0      | 24.0          |
| 3   | Aquamix-T + foliar dressing Aquamix-TV      | 47.0      | 53.1          | 13.2      | 25.4          |
| 4   | Aquamix-T + foliar dressing K2SO4           | 48.0      | 53.1          | 13.3      | 25.9          |
| 5   | Aquamix-T + foliar dressing KH2PO4          | 47.0      | 52.8          | 13.4      | 25.7          |
| 6   | Aquamix-T + foliar dressing with Aquamix-TV + K2SO4 | 47.6  | 54.0          | 14.8      | 28.0          |
| 7   | Aquamix-T + foliar dressing with Aquamix-TV + KH2PO4 | 48.0 | 54.7          | 14.5      | 27.8          |

The most important criteria for predicting productivity are the aboveground biomass of plants, which reflects the soil and climatic conditions of growth, the level of agricultural technology, and others. Observations of biomass formation dynamics by vegetative stages of white lupine showed that with an increase in plant nutrition, its increase is observed. Thus, the largest mass of air-dry matter of lupine plants was observed in the options with pre-sowing seed treatment with Aquamix-T micronutrient fertilizer in combination with foliar dressing with a mixture of macro- and micronutrient fertilizers. In the flowering period of air-dry matter in the option with Aquamix-T + foliar dressing with Aquamix-TV + K2SO4 was 14.8 g, in the pod formation period – 28.0 g, and in the option with Aquamix-T + foliar dressing with Aquamix-TV + KH2PO4 – 14.5 g and 27.8 g, which is 2.8 and 4.7 g, 2.5 and 4.5 g, respectively, higher than the control.

As is known, using certain fertilizers will be effective if they contribute to the creation of an optimal leaf area, better illumination of the leaf apparatus and an increase in the duration of its vigorous activity. One of the main factors of high plant productivity is the size of the assimilation surface, which depends on the growth rate and duration of active leaf functioning. Crop yield is closely related to leaf area. The
macro- and micronutrient fertilizers studied in our experiment had a significant effect on the leaf surface formation. Pre-sowing seed treatment with micronutrient fertilizer Aquamix-T promoted an increase in leaf area, which was noticeable already at the early stages of development. Foliar dressing with macro- and micronutrient fertilizers, carried out in the bud-formation period, enhanced the effect of pre-sowing seed treatment with micronutrient fertilizer Aquamix-T and led to an even greater leaf area increase in the flowering period and the pod formation period compared to the control. Thus, in the pod formation period, the largest leaf area was observed in the options with pre-sowing seed treatment with Aquamix-T in combination with foliar dressing with a mixture of Aquamix-TV + potassium sulphate and Aquamix-TV + potassium monophosphate, which amounted to 31.2 and 30.7 thousand m²/ha, respectively, which is higher than the control by 6.9 and 6.4 thousand m²/ha. In other experimental options, the leaf area in this period varied from 25.6 to 29.1 thousand m²/ha, which is 1.6-4.8 thousand m²/ha more than in the control.

Table 2. Leaf area of white lupine plants depending on macro- and micronutrient fertilizers, thousand m²/ha, 2018-2020

| No. | Experimental option                                | Average on one plant by vegetative stage |                 |                 |                 |
|-----|---------------------------------------------------|----------------------------------------|-----------------|-----------------|-----------------|
|     |                                                   |                                        | tillering       | flowering       | pod formation   |
| 1   | Control – no fertilizer                           | 8.2                                    | 16.4            | 24.3            |                 |
| 2   | Seed treatment with Aquamix-T                     | 9.7                                    | 17.8            | 25.6            |                 |
| 3   | Aquamix-T + foliar dressing Aquamix-TV            | 9.7                                    | 20.5            | 28.5            |                 |
| 4   | Aquamix-T + foliar dressing K₂SO₄                 | 9.9                                    | 21.3            | 29.1            |                 |
| 5   | Aquamix-T + foliar dressing KH₂PO₄               | 9.8                                    | 21.0            | 28.8            |                 |
| 6   | Aquamix-T + foliar dressing with Aquamix-TV + K₂SO₄ | 9.8                                    | 22.4            | 31.2            |                 |
| 7   | Aquamix-T + foliar dressing with Aquamix-TV + KH₂PO₄ | 9.9                                    | 22.4            | 30.7            |                 |

The productivity of white lupine depends on many factors, the most important of which is the activity of symbiotic relationships between lupine plants and nodule bacteria. With a better supply of plants with symbiotic nitrogen, photosynthetic potential, accumulation of dry matter by all plant organs, the yield and protein productivity of crops increase. The size of the symbiotic apparatus of lupine plants can be judged primarily by the number and mass of active nodules.

The peak formation of active nodules on lupine roots falls on the flowering period, then the intensity of their formation gradually decreases. From the flowering period to the pod formation period, the number of active nodules increases slightly, and their weight increases by one and a half times. Pre-sowing seed treatment with Aquamix-T micronutrient fertilizer and foliar dressing with Aquamix-TV micronutrient fertilizer, potassium sulphate and potassium monophosphate had a positive effect on the number and weight of active nodules on the roots of lupine plants.

Table 3. Number and weight of active nodules on the roots of white lupine plants, depending on the macro- and micronutrient fertilizers, 2018-2020

| No. | Experimental option                                | Average on one plant by vegetative stage |                 |                 |
|-----|---------------------------------------------------|----------------------------------------|-----------------|-----------------|
|     |                                                   |                                        | flowering       | pod formation   |
|     |                                                   |                                        | number, weight, | number, weight, |
|     |                                                   |                                        | pcs. mg         | pcs. mg         |

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The largest number and weight of active nodules on one lupine plant were observed in the options with pre-sowing seed treatment with Aquamix-T in combination with foliar dressing with a mixture of Aquamix-TV + potassium sulphate and Aquamix-TV + potassium monophosphate, which amounted to 26.2 pcs. and 123.4 mg, 25.8 pcs. and 122.4 mg, respectively, which is higher than the control by 4.2 pcs. and 11.1 mg, 3.8 pcs. and 10.1 mg.

Table 4. Yield of white lupine seeds depending on macro- and micronutrient fertilizers

| No. | Experimental option | Yielding ability, t/ha | + to the control |
|-----|---------------------|------------------------|-----------------|
|     |                     | 2018 | 2019 | 2020 | average | t/ha | %     |
| 1   | Control – no fertilizer | 3.06 | 3.02 | 2.93 | 3.00 | - | - |
| 2   | Seed treatment with Aquamix-T | 3.13 | 3.10 | 3.01 | 3.08 | 0.08 | 2.6 |
| 3   | Aquamix-T + foliar dressing Aquamix-TV | 3.54 | 3.43 | 3.24 | 3.40 | 0.40 | 13.3 |
| 4   | Aquamix-T + foliar dressing K₂SO₄ | 3.57 | 3.47 | 3.28 | 3.44 | 0.44 | 14.5 |
| 5   | Aquamix-T + foliar dressing KH₂PO₄ | 3.57 | 3.44 | 3.25 | 3.42 | 0.42 | 13.8 |
| 6   | Aquamix-T + foliar dressing with Aquamix-TV + K₂SO₄ | 3.78 | 3.66 | 3.48 | 3.64 | 0.64 | 21.3 |
| 7   | Aquamix-T + foliar dressing with Aquamix-TV + KH₂PO₄ | 3.80 | 3.64 | 3.41 | 3.62 | 0.62 | 20.5 |

HCP<sub>0.05</sub>0.13 0.15 0.23

In other experimental options, the number and weight of nodules were higher than in the control, but inferior to the experimental options with pre-sowing seed treatment with micronutrient fertilizer Aquamix-T together with foliar dressing with Aquamix-TV + potassium sulphate (K₂SO₄) and Aquamix-TV + potassium monophosphate (KH₂PO₄) (table 3).

Pre-sowing treatment of lupine seeds with chelated micronutrient fertilizer Aquamix-T together with foliar dressing with the mixture of a highly concentrated complex of microelements Aquamix-TV with potassium sulphate (option 6) and potassium monophosphate (option 7) had a significant effect on the crop yield which averaged 3.64 over three years and 3.62 t/ha, which is 0.64 and 0.62 t/ha or 21.3 and 20.5% higher than the control (table 4). High yield of lupine was also noted during pre-sowing seed treatment with chelated micronutrient fertilizer Aquamix-T together with foliar dressing Aquamix-TV (option 3) – 3.40 t/ha, together with foliar dressing with potassium sulphate solution (option 4) – 3.44 t/ha and with foliar dressing with potassium monophosphate solution (option 5) – 3.42 t/ha, which is 0.40 t/ha, 0.44 and 0.42 t/ha higher than in the control. Pre-sowing treatment of lupine seeds with Aquamix-T (option 2) did not lead to a significant increase in the yield.

4. Conclusion

As a result of our studies, we assessed the effect of pre-sowing seed treatment with chelated micronutrient Aquamix-T, both separately and in combination with foliar fertilization with macro- and micronutrient fertilizers, on white lupine growth, development and seed productivity. The results
obtained indicate that foliar dressing of lupine crops with Aquamix-TV micronutrient fertilizer, potassium sulphate and potassium monophosphate against the background of pre-sowing seed treatment with Aquamix-T micronutrient fertilizer are a justified element of the technology, since they contribute to increasing in height, aboveground weight, size of the symbiotic apparatus of plants and high seeds yield. The greatest positive effect was obtained in the options with pre-sowing seed treatment with micronutrient fertilizer Aquamix-T together with foliar dressing with the mixture of Aquamix-TV + potassium sulphate and Aquamix-TV + potassium monophosphate, where the seed yield was 3.64 and 3.62 t/ha, respectively, that is 0.64 and 0.62 t/ha or 21.3 and 20.5% higher compared to the control.

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