The influence of micronutrients on the productivity of corn during cultivation on green mass in the southern zone of Amur region

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Abstract. The following paper reviews the results of 2017-2019 studies of the influence of types and methods of micronutrient fertilizers application: zinc sulfate, cobalt sulfate and ammonium molybdate on the growth, development and productivity of corn. The studies were conducted in the southern agricultural zone of Amur region on the experimental field of Far Eastern State Agrarian University, located in the village of Gribskoye (Blagoveshchensk district). The object of research was a hybrid Mashuk 175MV (FAO 170) - an early-ripening three-linear hybrid of universal use. Treatment of seeds and plants of corn by microfertilizers was carried out using a solution with a concentration of 0.1%. As a result of studies, it was found that the use of microfertilizers during plants vegetation more effectively affects the accumulation of dry matter than seeds treatment and double treatment of seeds and vegetative plants. When seeds treatment, the most effective variant is the combined use of microelements and when treatment during vegetation is the variant with using cobalt. The use of microfertilizers showed a significant increase in leaf surface area for all variants relative to the background variant. The greatest effect was shown by the variant with the use of cobalt in the seeds treatment and spraying vegetation of plants. The combined use of microfertilizers in the seeds treatment and spraying during vegetation has shown a good increase the yield of green mass of corn. The greatest effect was shown in seeds treatment by cobalt and spraying the plants during vegetation.

1. Introduction
Livestock farming development, corn grain export and optimization of crop rotation together contribute to an increase in sown area of corn in Amur region. Mineral nutrition plays a prominent role in increasing the production of grain and green mass of corn, as well as in improving the quality parameters of the crop. The proper use of micronutrient fertilizers, along with the use of macro fertilizers, helps to increase the yield and quality of many crops [1]. Despite the small amount of micro elements (Fe, Mn, Zn, Cu, B, Mo, Co, Ni, etc.) in the consumption of corn, they play no less important role than macro elements (N, P, K, S, Mg, Ca). Trace elements are of great importance in the physiology of the mineral nutrition of corn. All processes of synthesis and transformation of substances in plant cells go on with the help of enzymes, which include trace elements [2].

Microelements participating in the most important biochemical processes stimulate photosynthetic activity of plants, shorten the ripening of fruit and seeds, increase productivity, improve product quality, as well as increase plant resistance to adverse environmental factors [3, 4, 5].
Among all trace elements, corn plants need zinc most of all, which is a part of many enzymes and is involved in chlorophyll formation, and contributes to vitamin synthesis. This element plays an important role in oxidation-reduction processes; therefore, zinc supplementation enhances the growth of corn plants [2, 4].

Molybdenum is often called a trace element of nitrogenous metabolism, since it is part of nitrate reductase and nitrogenase, and is involved in protein formation. Regular metabolism is impaired with a deficiency of this microelement, and the growth of corn plants is weakened, flowering is delayed, the leaves take on a light yellow color. They subsequently grow brown and die off [2, 4].

The participation of cobalt in the life of higher plants that are not capable of fixing nitrogen is either specific or indirect. The metal stimulates the cellular reproduction of leaves by increasing the thickness and volume of mesophyll in them, the size and number of cells of the columnar and spongy parenchyma of a leaf. The effect of cobalt on the formation and functioning of the photosynthetic apparatus of plants by the concentration of chloroplasts and pigments in leaves has been established. This is connected to an increase in plastid apparatus volume due to organelle growth [4, 6].

Studies of the effect of micro fertilizers on grain-crops were conducted throughout Russia. For instance, in studies of the influence of micronutrient fertilizers on the yield and quality of winter wheat, conducted by A Yu Oleinikov with the use of highly effective complex microelement fertilizers, seeds and agricultural crops, designed for pre-sowing treatment and non-root treatment showed an increase in productivity [7]. Studies on the effect of micronutrient fertilizers during pre-sowing treatment of seeds and in the cultivation of oats were conducted in Izhevskaya State Agrarian Academy (city of Izhevsk). Presowing seed treatment showed an increase in grain yield by 11 - 28% [8].

Omsk State Agrarian University named after P A Stolypin conducted research to optimize the use of micronutrient fertilizers in the cultivation of winter wheat. The study used micronutrient zinc sulfate (Zn - 22%), copper sulfate (Cu - 25.5%) and manganese sulfate (Mn - 22.8%). It has shown that while seeds were dusted, the use of zinc and manganese at a dose of 100 g per 100 kg was the most effective: an increase in grain yield of 0.44 tons per hectar or 14.6% against the base value is obtained from zinc, and 0.54 tons per hectar or 18.1% from manganese; at a dose of 50 g per 100 kg respectively 0.39 tons per hectar and 13.1% from copper [9].

Besides the effect of micronutrient fertilizers on grain crops many researches were carried out on other agricultural plants. Thus, in the Republic of Belarus they studied the effectiveness of micronutrients in the cultivation of beetroot [10], their influence on the yield and quality of medicinal valerian [11], the effect of various forms and doses of micronutrient fertilizers on the yield and quality of oilseed flax [12], their effect on productivity and quality of sunflower seed oil [13].

In 2015, in Serbia, an experiment to use zinc in the cultivation of corn for grain was conducted. It has shown an increase in grain yield up to 24% and a mass of 1000 seeds [14]. In 2016, in Sweden, seven major trace elements for plants were studied. They showed a significant impact on the growth and development of crops [15]. The effect of zinc on corn has been studied in Virginia, USA. Melvin Gerhardt researched the use of zinc sulfate and zinc chelates to find out that the introduction of these elements revealed a positive effect on the growth and yield of corn [16].

Studies on the use of micronutrient fertilizers for soy and corn were carried out in Amur region in the 1970s. The largest increase in the yield of green mass in mixed crops of soybean and corn against the background of N_{90}P_{60}K_{30} was obtained from cobalt, copper, molybdenum - 17.8 - 20.0%. Cobalt was studied in paired and triple combinations with Mo and B for soybean, zinc - for corn when cultivated for green mass and silage, the yield increase mounted to 10 - 15% [17, 18].

During research, conducted in 2015-2017 on the experimental field of Far Eastern State Agrarian University, the effect of various methods of using zinc sulfate, cobalt sulfate and ammonium molybdate upon corn for grain was studied. As a result of the research, the maximum yield of corn was obtained with a combination of cobalt sulfate application methods. The application of zinc sulfate in seed treatment and plant spraying during vegetation contributed to an increase of protein content of corn [19].

The area under corn in Amur region is expanding. Under current production situation, due to
imperfect agricultural practices, the genetic potential of hybrids is not fully realized. The yield of corn for green mass in Amur region in 2019 amounted to 93,000 t from an area of 5,100 ha.

The aim of the research is to study various types of micronutrient fertilizers and methods of their application, their effect on the growth, development and productivity of corn when cultivated for green mass.

2. Objects and methods of research

The research was conducted in 2017-2019 on medium chernozem-like soil in the southern agricultural zone of Amur region on the experimental field of Far Eastern State Agrarian University in the village of Gribskoie in Blagoveshchensk district.

The object of research was a hybrid Mashuk 175MV (FAO 170) - an early ripe three-linear corn hybrid of universal use. This hybrid is an intensive type that meets the recent requirements of cultivation technology. It's drought-resistant and in arid conditions consumes moisture effectively. Hybrid's grain quickly loses moisture when it's ripening. It is included in the Federal Register of breeding achievements and approved for use in the Russian Federation. It has been introduced in Amur region since 2003.

Agrotechnics in the experiments is generally applicable in the agricultural conditions of Amur region. The sowing was executed by SN-1.6 seeder with the sowing rate of 80 000 seeds per 1 ha. Processing of corn seeds and plants with micronutrient fertilizers was made with 0.1% concentration solutions.

The experiment was designed according to the following chart (table 1):

| Experiment variant                                                                 |
|-----------------------------------------------------------------------------------|
| control without fertilizers                                                      |
| N60P30 (background)                                                              |
| background + zinc sulfate (seed treatment)                                       |
| background + zinc sulfate (seed treatment + spraying in the 3d-5th leaf phase)    |
| background + cobalt sulfate (seed treatment)                                    |
| background + cobalt sulfate (seed treatment + spraying in the 3d-5th leaf phase)  |
| background + ammonium molybdate (seed treatment)                                |
| background + ammonium molybdate (seed treatment + spraying in the 3d-5th leaf phase) |
| background + zinc sulfate, cobalt sulfate, ammonium molybdate (seed treatment)   |
| background + zinc sulfate, cobalt sulfate, ammonium molybdate (spraying in the 3-5 leaves phase) |
| background + zinc sulfate, cobalt sulfate, ammonium molybdate (spraying in the 3d-5th leaf phase) |
| background + zinc sulfate, cobalt sulfate, ammonium molybdate (spraying in the 3d-5th leaf phase) |

The repetition in the experiments is 4-fold, the accounting field area is 20 m².

Statistical data processing was carried out according to the method of B A Dospekhov. The variance analysis of digital material was conducted and LSD (least significant difference) was determined. LSD is a value indicating the limit of possible chance fluctuations in the experiment, which is considered essential at a 5% significance level (LSD₀₅) [20]. Statistical analysis makes it possible to systematize extensive digital material and prove the reliability of experimental data.

3. Research results and their discussion

Elements of micronutrient nutrition are one of the most important factors in crop formation. Doses, periods and methods of micronutrient fertilizer application are based on the knowledge of
The formation of dry overground mass of plants is decisive in crop productivity. All variants of microfertilizer application have positive effects on the formation of dry overground mass (Table 2).

**Table 2. The effect of micronutrient fertilizers on the accumulation of dry overground mass of corn in the phase of 3d-5th leaf (mean value for 2017-2019).**

| Experiment variant                      | The phase of growth and development of corn |
|-----------------------------------------|---------------------------------------------|
|                                         | 3d-5th leaf | 5th-7th leaf | 9th-11th leaf | paniculation | cobbing |
| control without fertilizers             | 0.06        | 0.10        | 0.42         | 1.30        | 1.83    |
| \(N_{60}P_{30}\) (background)          | 0.08        | 0.18        | 0.50         | 1.72        | 2.15    |
| background + zinc (seed treatment)      | 0.08        | 0.19        | 0.68         | 2.45        | 2.78    |
| background + cobalt (seed treatment)    | 0.09        | 0.18        | 0.61         | 2.61        | 2.96    |
| background + molybdenum (seed treatment)| 0.07        | 0.13        | 0.77         | 2.56        | 2.83    |
| background + zinc (plant spraying)      | 0.09        | 0.21        | 0.68         | 2.48        | 3.05    |
| background + cobalt (plant spraying)    | 0.08        | 0.23        | 0.66         | 3.03        | 3.65    |
| background + molybdenum (plant spraying)| 0.08        | 0.16        | 0.75         | 2.86        | 3.21    |
| background + zinc (seed treatment + plant spraying) | 0.08 | 0.22 | 0.70 | 2.53 | 2.80 |
| background + cobalt (seed treatment + plant spraying) | 0.07 | 0.26 | 0.87 | 3.12 | 3.52 |
| background + molybdenum (seed treatment + plant spraying) | 0.09 | 0.14 | 0.83 | 3.03 | 3.23 |
| background + Zn, Co, Mo (seed treatment) | 0.09 | 0.16 | 0.86 | 2.68 | 3.03 |
| background + Zn, Co, Mo (seed treatment + plant spraying) | 0.08 | 0.22 | 0.72 | 2.31 | 2.86 |
| background + Zn, Co, Mo (plant spraying) | 0.08 | 0.21 | 0.86 | 2.55 | 2.98 |
| LSD0.05                               | 0.02        | 0.05        | 0.24         | 0.57        | 0.41    |

*The least significant difference, the average for 2017-2019.*

The results of the accumulation of dry above-ground mass of corn in the phase of 3d-5th leaf were obtained almost the same, since in the initial period, before the formation of the 1st above-ground stalk node, corn grows very slowly. In phase 5th-7th leaf, the maximum value of the dry above-ground mass is determined in the variant with the use of cobalt sulfate in seeds treatment and spraying during plants vegetation – 0.26 t/ha, that above control without fertilizers on 0.16 t/ha and background on 0.08 t/ha. In subsequent phases of growth and development of corn: 9th-11th leaf and paniculation the highest indices were also obtained in the variant with the double use of cobalt sulfate – 0.87 and 3.12 t/ha, respectively. The maximum value in the cobbing phase was noted in the variant with plants spraying by cobalt – 3.65 t/ha, which relatively above control variant on 1.82 t/ha and background on 1.5 t/ha.

Thus, the maximum values of the accumulation of dry above-ground mass of corn were obtained...
when using cobalt sulfate in various ways, in comparison with other microfertilizers used. The combined use of macro- and micronutrient fertilizers has a positive effect on the formation of leaf surface area of corn (table 3).

**Table 3.** The influence of micronutrient fertilizers on the area of leaf surface, in thousand square meters per hectare (1000 m²/ha), mean value for 2017 – 2019.

| Experiment variant | The phase of growth and development of corn | 3d-5th leaf | 5th-7th leaf | 9th-11th leaf | panicleation | cobbing |
|--------------------|--------------------------------------------|--------------|--------------|---------------|--------------|---------|
| control without fertilizers | 1.7 | 4.1 | 15.1 | 39.4 | 52.3 |
| N₀₆P₃₀ (background) | 2.2 | 4.8 | 17.9 | 40.5 | 67.0 |
| background + zinc (seed treatment) | **3.4** | 4.9 | 16.5 | 47.8 | 73.8 |
| background + cobalt (seed treatment) | 2.8 | 4.8 | 17.8 | 55.6 | 77.9 |
| background + molybdenum (seed treatment) | 2.5 | 4.5 | 15.4 | 42.4 | 68.8 |
| background + zinc (plant spraying) | 2.7 | 4.5 | 17.6 | 50.0 | 76.7 |
| background + cobalt (plant spraying) | 2.5 | 4.7 | **19.0** | **58.7** | 80.3 |
| background + molybdenum (plant spraying) | 2.6 | 4.8 | 17.8 | 46.8 | 71.3 |
| background + zinc (seed treatment + plant spraying) | 3.0 | 4.9 | 17.3 | 50.2 | 72.0 |
| background + cobalt (seed treatment + plant spraying) | 3.1 | **5.0** | 18.4 | 57.4 | **81.9** |
| background + molybdenum (seed treatment + plant spraying) | 2.9 | 4.8 | 16.1 | 49.8 | 71.2 |
| background + Zn, Co, Mo (seed treatment) | 2.4 | 4.3 | 15.8 | 40.1 | 63.4 |
| background + Zn, Co, Mo (seed treatment + plant spraying) | 2.5 | 4.4 | 17.3 | 47.3 | 70.2 |
| background + Zn, Co, Mo (plant spraying) | 2.1 | 4.2 | 17.0 | 46.9 | 71.0 |
| SSD₀₅a | 1.2 | 0.8 | 0.6 | 3.6 | 2.9 |

a The least significant difference, the average for 2017-2019.

The use of microfertilizers showed a significant increase in leaf surface area for all variants and phases of the growth and development of corn relative to the control and background variants. The maximum value of the leaf surface area of corn plants in the phase of 3d-5th leaf noted in the variant with seed treatment by zinc sulfate before sowing – 3.4 thousand m²/ha, which exceeded control by 1.7 thousand m²/ha and background by 1.2 thousand m²/ha. In phases 5th-7th leaf and cobbing the largest value of the leaf surface area was obtained in the variant with cobalt sulphate when seeds
treating and spraying the plants during vegetation – 5.0 and 81.9 thousand m²/ha. The maximum value of the leaf surface area in phases 9th-11th leaf and paniculation were in the variant with spraying plants by cobalt – 19.0 and 58.7 thousand m²/ha.

Thus, among all the results, it is worth noting the variants with using cobalt, where leaf surface area increased due to the stimulation of cell reproduction of leaves due to increase thickness and volume mesophyll in leaves, size and number of cells of columnar and spongy leaf parenchyma.

Corn is capable of producing high yields of green mass by its biological characteristics. T gives the highest yields of green mass with a density of 120-150 to 250-300 thousand per hectare, depending on the zone. The productivity of corn for green fodder and its quality vary markedly depending on the time of use. Relatively early cutting of corn for green fodder allows to get green mass of higher quality, but its yield is lower.

One of the most important determinants of corn productivity is the formation of green mass (table 4).

**Table 4.** The effect of micronutrient fertilizers on the yield of green mass, in t/ha, mean value for 2017-2019.

| Experiment variant | The phase of growth and development of corn | 3d-5th leaf | 5th-7th leaf | 9th-11th leaf | paniculation | cobbing |
|--------------------|-------------------------------------------|-------------|-------------|--------------|--------------|---------|
| control without fertilizers | 0.45 | 1.10 | 4.03 | 12.24 | 34.09 |
| N₆₀P₉₀ (background) | 0.48 | 1.37 | 6.43 | 16.09 | 38.69 |
| background + zinc (seed treatment) | 0.50 | 1.63 | 7.67 | 23.01 | 40.22 |
| background + cobalt (seed treatment) | 0.41 | 1.19 | 6.76 | 20.28 | 38.50 |
| background + molybdenum (seed treatment) | 0.45 | 1.19 | 7.03 | 21.09 | 39.62 |
| background + zinc (plant spraying) | 0.40 | 1.08 | 5.98 | 17.94 | 38.06 |
| background + cobalt (plant spraying) | 0.49 | 1.87 | 7.41 | 21.45 | 39.88 |
| background + molybdenum (plant spraying) | 0.58 | 1.87 | 6.98 | 20.94 | 38.66 |
| background + zinc (seed treatment + plant spraying) | 0.55 | 1.51 | 7.08 | 21.24 | 40.18 |
| background + cobalt (seed treatment + plant spraying) | 0.47 | **2.04** | **8.03** | **25.83** | **43.65** |
| background + molybdenum (seed treatment + plant spraying) | 0.49 | 1.45 | 7.54 | 22.62 | 42.14 |
| background + Zn, Co, Mo (seed treatment) | **0.62** | 1.84 | 7.66 | 22.98 | 43.15 |
| background + Zn, Co, Mo (seed treatment + plant spraying) | 0.59 | 1.73 | 7.38 | 21.54 | 39.78 |
| background + Zn, Co, Mo (plant spraying) | 0.58 | 1.81 | 6.71 | 20.13 | 38.31 |
| SSD₀₅⁺ | 0.04 | 0.83 | 1.22 | 2.13 | 4.42 |

*The least significant difference, the average for 2017-2019.*

The influence of microfertilizers has a positive effect on the yield of green mass of corn, in almost all variants of the experiment. The maximum yield of green mass was noted in the phase of 3d-5th leaf in the variant with seeds treatment by zinc sulfate, cobalt and ammonium molybdate – 0.62 t/ha, which relatively above control variant on 0.17 t/ha and background on 0.14 t/ha. The combined use of cobalt sulfate in seed treatment and spraying during vegetation has shown a good increase in the yield of
green mass of corn in subsequent phases of corn growth. The increase in relation to the control without fertilizers ranged from 0.94 t/ha in phase of 5th-7th leaf to 9.56 t/ha in cobbing phase.

Consequently, the use of cobalt sulfate together with seed treatment and when applied during vegetation of plants helps to increase the maximum yield of green mass of corn in almost all studied phases of growth and development compared to other experimental variants.

4. Conclusion

Thus, it is worth noting that the use of each micronutrients in various ways, and the combined use of all micronutrients positively affects the growth and development of corn.

The use of cobalt evinced to be the most effective. With the accumulation of dry above-ground mass of corn the largest increase was obtained from the use cobalt when seeds treatment and applied during vegetation of plants from 0.16 to 1.82 t/ha, respectively, to the growth phase. The most effective variant for seed treatment is the combined use of micronutrients.

In the treatment of seeds and plant spraying the use of cobalt showed a significant increase in leaf square area by 29.6 thousand m²/ha in cobbing phase. When plant treatment during vegetation the most effective result was shown by the use of zinc.

The best microfertilizer effect on the corn’s green mass yield was obtained when seeds treatment and spraying plants by cobalt in all phases of growth. The most effective variant for seeds treatment is the combined use of microfertilizers. The use of micronutrient fertilizers during vegetation showed insignificant effectiveness.

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