Microelements application methods influence on physiological-biochemical processes and yellow pepper yields

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Abstract: According to the results of numerous researches carried out in the Russian Federation and abroad, it was found that microelements, at their skillful use, are an important factor in increasing crop yields and improving the quality of products. The aim of our research was to study the pepper plants pre-sowing seed treatment and foliar feeding with microelements influence on the growth, development and productivity of this crop. The experimental part of the work was carried out in the period of 2014 ... 2016 in the conditions of the Volgograd region. Experiments on the study of microelements were carried out according to a scheme consisting of 3 options: application into soil; presowing seed treatment; foliar top dressing of plants. Chemically pure compounds of manganese sulphate, zinc sulphate, copper sulphate, ammonium molybdate, and boric acid were used as microelements. The use of microelements in the conditions of the dry steppe zone of the Nizhneje Pvolzhje region is an important agrotechnical method, contributing to the acceleration of growth, development, increase in yield and improve the quality of the pepper fruits. It is recommended to carry out pre-sowing seed treatment by 0.05% solutions of copper sulphate, boric acid and manganese sulphate, as a way to increase seed viability, accelerate yield and improve seedling quality. In order to increase the yield and improve the quality during the period of pepper budding, foliar top dressing should be carried out by 0.05% solutions of boric acid, ammonium molybdate. Due to its high efficiency, simplicity and availability, presowing seed treatment and foliar top dressing of plants by microelements will find wide application in vegetable production.

1. Introduction
According to the researches carried out in the Russian Federation and abroad, it was found that microelements are an important factor in increasing crop yields and improving product quality [1,2,3,4,5].

Participating in the physiological and biochemical processes of plants, microelements significantly influence on growth, development, yield and product quality.
Based on the analysis of literature data, the authors put forward a hypothesis about controlling plant growth rates, increasing productivity and obtaining environmentally safe products when using micro-elements.

Issues of increasing the seeds viability have long attracted the attention of researchers. In this direction, many proposals were made and found their application in agronomy, but the various agricultural crops seeds germination remains at a rather low level [6,7,8].

Of the requirements for seeds, the main is the requirement of high viability. In the seed during the growing season nutrients are accumulated, but due to the fact that the plants growth conditions in different soil-climatic zones with different levels of nutrition, agrotechnics are different, they are not fully accumulated in the endosperm all that is necessary to ensure biological needs for their growth and more intensive use of soil fertility [9,10,11].

On this basis, in order to enhance the seeds viability, many researchers have proposed different ways of pre-sowing enrichment of seeds with different nutrients, growth activating substances.

One of the ways to increase the seeds viability and increase plant productivity is pre-sowing treatment by their microelements. The effectiveness of this technique was noted by many authors [3,12,13,14].

Increasing the seeds germination energy and germination is important, since with intensive germination of seeds less stored organic matter is consumed than with slow one. In the latter case, most of the spare substances are used for unproductive breathing. As the result, these seeds do not have enough energy to germinate in the field. At the same time, with intensive germination even seeds that contain few reserve substances in the endosperm have time to germinate. As the result, when seed is treated by microelements, their field germination increases, the emerged seedlings are previously included in the process of photosynthesis and form more powerful seedlings, which contributes to better subsequent development of plants, increasing their productivity and product quality [15,16].

The purpose of our research is to study the sweet pepper plants pre-sowing seed treatment and foliar treatment by microelements influence on the growth, development and productivity of this crop.

2. Materials and methods
The experimental part of the work was carried out in the period of 2014 ... 2016 in the conditions of the sole proprietor economy IZaitsev V.A. (Gorodishchensky district, Volgograd region).

Experiments on the study of microelements was carried out according to the scheme, consisting of 3 options:

1. soil application;
2. presowing seed treatment;
3. plant foliar top dressing.

Chemically pure compounds of manganese sulphate, zinc sulphate, copper sulphate, ammonium molybdate, and boric acid were used as microelements.

Microelements were applied into the soil in spring before sowing seeds in doses: manganese sulphate - 2.0 kg / ha, zinc sulphate - 3.0 kg / ha, copper sulfate - 3.0 kg / ha, ammonium molybdate - 0.5 kg / ha, boric acid - 1.5 kg / ha. For this, salt was thoroughly mixed with dry sand and evenly, manually scattered it on the experimental plots. Then there was a disking area.

When introducing microelements into the soil for three years (2014 ... 2016), we did not notice any changes in the course of biochemical and physiological processes and did not receive reliable yield gains. Therefore, the results are not described. The decrease in the effectiveness of microelements when they were applied into the soil was due to the fact that they were absorbed by soil colloids and became inaccessible to plants, and some of them, reacting with the soil solution, turned into indigestible forms for plants.

Pre-sowing seed treatment by microelements was performed by soaking them in 0.05% solutions of the above compounds. With this aim, the seeds were placed in gauze bags and immersed in the solution for 24 hours (the ratio of the weight to the hay to the solution was 1:2). Every 3.0 ... 4.0 hours the seeds were removed from the solution for 1.0 ... 1.5 hours. Control seeds were soaked in distilled water. Then the seeds were dried to flowability.
Plants foliar top dressing by microelements was carried out in the budding phase with 0.05% solutions in the evening time. Solution consumption was 1 liter per 10 m$^2$. Control plants were sprayed with tap water.

To study the seeds presowing treatment by microelements influence on germination energy and germination, seeds of Pompeo F1 hybrid sweet pepper, soaked in solutions of these elements for 24 hours, were germinated in Petrie dishes at the temperature of 25°C. Control seeds were soaked in distilled water.

3. Influence of methods of application of microelements on the physiological-biochemical processes and yellow pepper yield

As you know, pepper seeds germinate slowly. Usually in greenhouses, under optimal conditions, shoots appear on 15 ... 17 days, and sometimes later.

We found that pre-sowing soaking of sweet pepper seeds increased their germination energy (table 1).

Analysis of the data showed that already on the 7th day of germination the positive effect of microelements clearly manifested and in the future (with the exception of zinc) was maintained. The most effective influence on the germination energy was done by copper, manganese, molybdenum and boron, which increased this indicator by 40.0, 23.3 and 18.4%, in comparison with the control.

The increase in the sweet pepper seeds germinating energy was caused by the enzymes action activation and an increase in the intensity of respiration by the microelements entering the seeds.

We have found that these microelements, enhancing the vital processes of seeds, increased their germination. Sowing pepper seeds soaked in solutions of microelements, we received shoots 4 ... 5 days earlier than when sown with dry seeds. It should be noted that sowing dry seeds, seedlings appear and grow unevenly. Some plants, developing faster, create unfavorable conditions for stunted ones.

Table 1. The influence of microelements on the germination of sweet pepper seeds, %, (average for 2014 ... 2016)

| Experiment variant | Number of germination days | in % to control by the 12th day |
|--------------------|---------------------------|-------------------------------|
|                    | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 |
| Control            | 13 | 19 | 24 | 32 | 40 | 48 | 53 | 60 | 100,0 |
| Manganese          | 12 | 15 | 24 | 36 | 47 | 58 | 64 | 74 | 123,3 |
| Zink               | 7  | 11 | 16 | 20 | 33 | 34 | 37 | 43 | 71,1 |
| Copper             | 10 | 20 | 37 | 56 | 63 | 75 | 81 | 84 | 140,0 |
| Molybdenum         | 12 | 17 | 32 | 45 | 65 | 69 | 71 | 74 | 123,3 |
| Boron              | 11 | 18 | 30 | 39 | 55 | 62 | 64 | 71 | 118,4 |

All this had negative influence on the standard plants production and a decrease in their yield per unit area (Table 2).

According to the data obtained, manganese, copper and boron had the best effect on the primary growth processes, which were determined on average in 30-day-old plants of 20 specimens.

A significant impact on the pepper plants growth processes was exerted by soaking the seeds in water before sowing. Thus, the plants were higher than the control when sowing with dry seeds by 20 mm, the weight of one plant increased by 0.81 g, and the leaf area by 5 cm$^2$. At the same time, germination has also increased, the quality of seedlings improved, compared with dry control.
Table 2. The microelements influence on the sweet pepper plants growth processes, %, (average for 2014...2016)

| Experiment    | Plants height, mm | Weight of one plant, g | Leaf area, cm² |
|---------------|-------------------|------------------------|----------------|
| Control (dry) | 60                | 3,26                   | 12             |
| Control (wet) | 80                | 4,07                   | 17             |
| Manganese     | 120               | 5,90                   | 25             |
| Zink          | 60                | 3,75                   | 15             |
| Copper        | 110               | 5,42                   | 23             |
| Molybdenum    | 80                | 4,13                   | 18             |
| Boron         | 110               | 5,58                   | 20             |

Zinc had a negative effect on germination energy and other growth processes. This effect is due to its high concentration of zinc sulphate used for seeds soaking. We took this concentration of zinc sulphate on the basis of the scientific recommendations available in the literature for pre-sowing soaking of vegetable seeds, so it should be reduced.

The microelements influence on the growth and development of peppers seedlings was caused by the positive influence of microelements on the internal biochemical processes and the increase in seed germination energy.

Increased seed viability had a positive effect on the primary growth processes and manifested itself during the whole ontogenesis of the peppers.

As can be seen from the data presented in Table 2, the effect of seeds presowing treatment by microelements was clearly manifested a month after receiving shoots under production conditions and persisted until the end of the growing season.

Studying the effect of microelements on the pepper fruits yield and quality, we found that their effectiveness largely depended on the method of application. So, according to the results of our research, the most productive ways of using microelements in the sub-zone of light chestnut soils of the Nizhneje Povolzhje region are seed treatment and plants top dressing. As noted earlier, the microelements application into the soil did not give significant increases (Table 3).

The decrease in the efficiency of microelements when they are introduced into the soil, as compared to other methods of application, was associated with the absorption of introduced elements by soil colloids, as well as their transformation into unassimilated forms when these elements enter into reaction with the soil solution.

Table 3. The microelements use influence on the sweet pepper productivity, (average for 2014 ... 2016)

| Experiment variant | Application in soil | Presowing treatment | Foliar top dressing |
|--------------------|---------------------|---------------------|---------------------|
|                    | Crop yield, t/ha    | increase %          | Crop yield, t/ha    | increase %          | Crop yield, t/ha    | increase %          |
| Control            | 30,1                | 33,6                | 31,2                |                     |                     |                     |
| Manganese          | 31,4                | 36,7                | 43,3                | 12,1                | 38,78               |
| Zink               | 29,3                | 31,3                | 42,1                | 10,9                | 34,94               |
| Copper             | 30,9                | 38,7                | 43,0                | 11,8                | 37,82               |
| Molybdenum         | 30,5                | 35,7                | 46,6                | 15,4                | 49,36               |
| Boron              | 30,2                | 38,8                | 46,2                | 15,0                | 48,08               |
| HCP 0.05           | 0,83                | 1,86                | 5,6                 |                     |                     |

The sweet pepper seeds pre-sowing treatment by microelements contributed to the increase in the peppers yield. Boron, copper and manganese had the most effective influence on the sweet pepper yield.
These elements gave a significant increase in yield for an average of three years at 15.48; 15.18 and 9.23%, compared with the control group.

When foliar top dressing the most effective effect on the sweet pepper productivity had molybdenum and boron, which gave an average increase over three years by 49.03 and 48.08%, compared with the control, respectively.

A negative effect on the pepper yield during the pre-sowing treatment was provided by zinc, and during foliar processing this element contributed to the lowest yield increase - by 34.94%, relative to the control. The influence of this element was associated with the toxicity of the solution concentration used by us and the studied culture plants biological characteristics.

Microelements also had a positive effect on the quality of sweet pepper fruit. As can be seen from the data presented in Table 4, copper, boron and manganese exerted the most effective effect on the content of dry matter and sugars during presowing treatment. The highest content of vitamin C in all years of research was observed in the variants with boron, copper, manganese and molybdenum treatment.

With foliar top dressing, all microelements also increased the quality indicators of sweet pepper fruits.

Table 4. The microelements use influence on the sweet pepper fruits quality, (average for 2014 ... 2016 years), on the raw substance

| Experiment variant | Dry matter | Sugars sum | Vitamin C | Nitrates |
|--------------------|------------|------------|-----------|----------|
|                    | % in % to control | % in % to control | % in % to control | mg/kg in % to control |
| Seeds presowing treatment |
| Control            | 7.91       | 4.86       | 151.70    | 64.1     |
| Manganese          | 8.40       | 6.19       | 7.41      | 189.60   | 58.3 |
| Zink               | 7.92       | 0.13       | -5.76     | 174.40   | 59.9 |
| Copper             | 8.81       | 11.38      | 5.77      | 198.80   | 58.7 |
| Molybdenum         | 8.11       | 2.53       | 4.97      | 188.30   | 57.5 |
| Boron              | 8.69       | 9.86       | 5.60      | 15.23    | 57.2 |
| Foliar top dressing |
| Control            | 6.91       | 4.61       | 151.40    | 72.8     |
| Manganese          | 7.55       | 9.26       | 6.29      | 168.60   | 66.8 |
| Zink               | 7.70       | 11.43      | 4.93      | 155.70   | 71.2 |
| Copper             | 7.41       | 7.24       | 5.14      | 153.30   | 69.6 |
| Molybdenum         | 7.35       | 6.37       | 5.07      | 176.40   | 65.5 |
| Boron              | 7.33       | 6.08       | 5.31      | 169.30   | 66.2 |

The most effective options for seed treatment were boron, copper and manganese; when foliar top dressing - molybdenum and boron.

Taking into account the direct and side negative effects of nitrates on the human body, in many countries of the world, including our own, maximum permissible concentrations of nitrates in food products and raw materials have been developed. For sweet pepper in the open field, this indicator should not exceed 200 mg / kg. In our studies, this figure decreased with the presowing treatment of seeds from 64.1 to 57.2 mg / kg, with foliar top dressing from 72.8 to 65.5 mg / kg, thereby not reaching the maximum MAC level. Presowing soaking of sweet pepper seeds in solutions of microelements (boron, molybdenum, copper, zinc, iron) contributed to a better digestibility of nitrates and thus inhibited their accumulation in plants. Foliar top dressing with microelements also reduced nitrogen accumulation in sweet pepper. The use of microelements is an environmentally friendly method of increasing yields and product quality.
4. Conclusions
The use of microelements in the conditions of the dry steppe zone of the Nizhneje Povolzhje region is an important agrotechnical method, contributing to the acceleration of pepper fruits growth, development, increase in yield and improve the quality. It is recommended to carry out the pre-sowing seed treatment by 0.05% solutions of boric acid, copper sulphate and manganese sulphate, as a way to improve seed viability, speed up the yield and improve the quality of seedlings. In order to increase the yield and improve the quality during the period of pepper budding, foliar top dressing should be carried out by 0.05% solutions of boric acid, ammonium molybdate.

Due to the high efficiency, simplicity and accessibility, pre-seeding seed treatment and plants foliar top dressing by microelements will find wide application in vegetable production of the Nizhneje Povolzhje region to produce environmentally safe products.

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