Increase in the intensity of life and yield of green crops due to plant growth and the development of regulatory chemicals

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Abstract. Yearly agriculture longs to increase the yield of green crops with the help of different agrochemical methods such as application of organic and mineral fertilizers, creation of optimum moisture and temperature mode, dressing with growth-regulating chemicals and etc. In our work it is shown that under the influence of foliar treatment with zircon solution in the concentration of 0.001 mg/l and 1% of potassium sulfate solution the processes of photosynthesis and respiration are stimulated, plant water exchange is stabilized, which leads to growth and yield increase of cultures. The highest stimulating effect is due to simultaneous spraying by zircon and potassium sulfate, herewith the effect of these regulators is summarized, i.e. additive character of their interreacting is demonstrated. Foliar treatment with potassium sulfate compensate the lack of these elements in soil, which are necessary for many physiological processes of plants, in particular, for the synthesis of protein, vitamins, sugar, the regulation of water evaporation and etc. The study was carried out on the green crops of families Solanaceae (on the example of Solanum lycopersicum and Capsicum annuum) and Fabaceae (on the example of Pisum sativum) are indicative of these facts.

1. Introduction
Tomatoes, peppers, peas are an important part of food structure of the human. Theses cultures are grown either on an industrial scale by farmer and collective households or by market gardeners for personal consumption [1]. Tomatoes, peppers, peas are under cultivation in all the countries of the world, where climatic conditions correspond their biological peculiarities. These cultures have got such a wide spread thanks to their useful nutritional properties: tomatoes are rich in ferrum, lycopene and rare vitamin K, peppers are a leader among vegetables in matter of ascorbic acid in fruits and peas are distinguished by high protein content [2]. Agriscientists aim at increasing the yield of these cultural plants with the help of fertilizers, growth-regulating chemicals and other agricultural methods. One of such methods is foliar treatment with zircon and potassium sulfate. Zircon is a synthetical analogue of natural growth and development regulator of plants, which is completely safe and consists of plant components, one of the main is purple Echinacea, and an active ingredient is hydroxyl-cinnamic acids. It helps to increase growth and development, protects the plants from stress and diseases [3]. Potassium sulfate raises the contents of sugar and vitamins as it contains SO₄²⁻ and sulfur is a part of many organic substances, in the first place of proteins. The features of these preparations explain their ability to activate biological processes in the plant [2].

Aim of research: to study the influence of foliar treatment with the solutions of zircon and potassium sulfate on the intensity of life and yield processes of green crops of family Solanaceae (on the example
of *Solanum lycopersicum* variety Gina and *Capsicum annuum* variety California Miracle) and family *Fabaceae* (on the example of *Pisum sativum* variety Children’s Sweetness) on their separate and combined application.

### 2. Methods and materials

The research has been carried out for 3 years from 2016 to 2018 on the basis of a personal subsidiary plot (Kurgan, the Kurgan region, the Russian Federation) in the conditions of field experiment. The research objects have been *S. lycopersicum* variety Gina, *C. annuum* variety California Miracle, *P. sativum* variety Children’s Sweetness, growth and development regulators: zircon and potassium sulfate. The plants of Solanaceae family were grown in the conditions of outdoor growing through seedlings, and *P. sativum* was grown in the conditions of outdoor growing through seeds sowing. The plant treatment with the solution of zircon in the concentration and 1% of potassium sulfate solution was held singly: tomatoes and peppers were treated in 10 days after planting seedlings into the soil; peas - in 10 days after sprouting.

The test scheme included four variants: Variant 1 – water treatment (control or control variant), Variant 2 – treatment with zircon solution (zircon), Variant 3 – treatment with potassium sulfate solution (K₂SO₄), Variant 4 – combined treatment with potassium sulfate and zircon (K₂SO₄+ zircon).

*S. lycopersicum* was set out into the soil in a double-row way on the working plot with an area of 5 sqm according to the scheme 60 x 40, i.e. 4 plants per sqm. *C. annuum* was set out on the field in a double-row way on the working plots with an area of 4 sqm according to the scheme 60 x 30, i.e. 6 plants per sqm. The seeds of *P. sativum* were sown into the soil according to the scheme 30 x 15, i.e. 18 plants per sqm (drilling depth was 4-6 sm). The experiment was established in a four-time repetition for all the studied plants. The location of working plots was done in a randomization way [4]. Before the establishment of the experiment soil sample was taken for an analysis [5]. In the course of the experiment, together with agro-technical activities, observations and measurements of physiological processes of plants were held with the use of standard methods of plant physiology. Water retaining ability was defined by the method of «wilting», based on the weight method of water loss record in certain periods of time (according to Arland). The dynamics of water uptake by plant leaves was defined by the weight method of water loss record in certain periods of time. The method of Boysen-Jensen was used to define the intensity of plant photosynthesis and respiration; it is based on the account of absorbed carbon dioxide [6, 7]. Quantitative content of ascorbic acid in the fruits was carried out with the help of potassium hexacyanoferrite by means of photoelectric colorimeter [8]. The intensity of physiological processes was measured in 10 days after foliar treatment with the studied regulators. The received results of the research underwent statistical data processing. The significance of result differences was estimated with the help of Student’s coefficient with the confidence level 0.95 [9].

### 3. Research results and discussion

Water ratio is one of the most important values of plant water regime. Water test in the leaves enables to find out eco-physiological peculiarities of plants, define the mechanism of their adaptation to the [10]. The conducted researches have shown that the treatment with solutions of zircon and potassium sulfate increased water ratio in the plant leaves. The increase of their water retaining ability under the influence of the studied growth regulators encouraged the increase of water content of tissues (Table 1-3).

Against the increase of water-retaining ability and water content in plant leaves of the test variants under the influence of treatment with the solutions of zircon and potassium sulfate the increase of relative turgescence and the decrease of water deficiency were recorded (Table 1-3). It is necessary to note that as a result of the treatment, between the studied regulators additive effect of interreacting appeared as the influence of zircon and potassium sulfate on the values of water exchange summarized. According to the data from table 1, it is seen that while comparing the influence of zircon and potassium sulfate on the values of water exchange the specificity of the kind manifested in the fact that green crops of family *Solanaceae* – peppers appeared to be more sensitive to the treatment with studied regulators in comparison to tomatoes.
Table 1. Effect of foliar treatment with zircon and potassium sulfate on the water regime indicators of *Solanum lycopersicum* Gina.

| Values of water regime                     | Control          | Zircon          | K$_2$SO$_4$     | K$_2$SO$_4$+zircon |
|--------------------------------------------|------------------|-----------------|-----------------|---------------------|
| Water ratio, %                             | 86.1 ± 1.9       | 87.4 ± 2.1      | 88.2 ± 2.7      | 89.9 ± 1.6          |
|                                            | 100 %            | 101.5 %         | 102.4 %         | 104.4 %             |
| Water-retaining ability, %                 | 94.2 ± 3.8       | 95.1 ± 2.3      | 95.4 ± 1.5      | 95.7 ± 1.9          |
|                                            | 100 %            | 100.9 %         | 101.3 %         | 101.6 %             |
| Relative turgescence, %                    | 43.5 ± 1.1       | 52.3 ± 2.2      | 58.7 ± 2.5      | 69.9 ± 2.7          |
|                                            | 100 %            | 120.4 %         | 134.8 %         | 160.7 %             |
| Water deficiency, %                        | 56.6 ± 2.7       | 47.7 ± 2.4      | 41.4 ± 1.7      | 30.1 ± 0.9          |
|                                            | 100 %            | 84.3 %          | 73.1 %          | 53.3 %              |

Table 2. Effect of foliar treatment with zircon and potassium sulfate on the water regime indicators of *Capsicum annuum* variety California Miracle.

| Values of water regime                     | Control          | Zircon          | K$_2$SO$_4$     | K$_2$SO$_4$+zircon |
|--------------------------------------------|------------------|-----------------|-----------------|---------------------|
| Degree of water content, %                 | 49.2±0.2         | 65.4±0.4        | 74.6±1.2        | 83.4±2.0            |
|                                            | 100%             | 133.0%          | 151.6%          | 169.5%              |
| Water-retaining ability, %                 | 64.5±0.8         | 87.0±1.5        | 93.9±2.1        | 95.6±2.5            |
|                                            | 100%             | 134.9%          | 145.6%          | 148.3%              |
| Relative turgescence, %                    | 45.6±0.3         | 51.4±1.7        | 66.1±2.2        | 79.9±3.3            |
|                                            | 100%             | 112.6%          | 145.0%          | 175.2%              |
| Water deficiency, %                        | 54.4±2.4         | 48.7±2.0        | 33.9±1.6        | 20.1±1.0            |
|                                            | 100%             | 89.4%           | 62.3%           | 37.0%               |

Table 3. Effect of foliar treatment with zircon and potassium sulfate on the water regime indicators of *Pisum sativum* variety Children's Sweetness.

| Values of water regime                     | Control          | Zircon          | K$_2$SO$_4$     | K$_2$SO$_4$+zircon |
|--------------------------------------------|------------------|-----------------|-----------------|---------------------|
| Degree of water content, %                 | 73.2±0.6         | 75.1±1.8        | 78.7±2.2        | 84.6±3.5            |
|                                            | 100%             | 102.6%          | 107.5%          | 115.6%              |
| Water-retaining ability, %                 | 65.0±2.1         | 67.7±3.2        | 70.4±4.1        | 79.3±2.8            |
|                                            | 100%             | 104.2%          | 108.3%          | 122%                |
| Relative turgescence, %                    | 66.9±1.0         | 68.2±1.5        | 76.4±1.8        | 86.5±3.9            |
|                                            | 100%             | 102.4%          | 114.2%          | 129.3%              |
| Water deficiency, %                        | 33.1±2.4         | 31.8±1.8        | 23.6±1.5        | 13.5±0.8            |
|                                            | 100%             | 96.1%           | 71.3%           | 40.8%               |

So, the treatment with zircon and potassium sulfate encouraged the increase of water content, water-retaining ability, and relative turgescence and at the same time the decrease of water deficiency of plants of families *Solanaceae* and *Fabaceae*. It means that the treatment with the studied regulators optimized plant water regime.

The growth and the productivity of plants depend on the values of photosynthesis and respiration greatly. Respiration is necessary for all living organisms as well as for plants. In the course of this process the combustion of organic substances and energy release necessary for the processes of growth.
and development [11]. The conducted researches have shown (Figure 1-3) that the highest intensity of respiration belongs to plants *P. sativum*, in the variant of combined treatment with zircon and potassium sulfate, but it does not allow considering peas to be less sensitive to treatment as in the control variant the intensity of their respiration is higher than in control variants of the plants of family *Solanaceae*.

**Figure 1.** Effect of foliar treatment with zircon and potassium sulfate on the intensity of photosynthesis and respiration of *Solanum lycopersicum* variety Gina.

Photosynthesis is a process of creation organic substances of non-organic with the help of light energy that is why the higher the intensity of photosynthesis is, the more intensive this process is [10]. The treatment with zircon and especially with potassium sulfate activated this process in studied plants. At the same time the highest stimulating influence is that of the combined treatment with zircon and potassium sulfate: photosynthesis of tomatoes increases by 3.6 times and of peppers by 3 times and of peas by 2.2 times in comparison with control variants.

**Figure 2.** Effect of foliar treatment with zircon and potassium sulfate on the intensity of photosynthesis and respiration of *Capsicum annuum* variety California miracle.

**Figure 3.** Effect of foliar treatment with zircon and potassium sulfate on the intensity of photosynthesis and respiration of *Pisum sativum* variety Children's Sweetness.

To estimate growth value, the measurement of the height of plant scions was held. The conducted measurements of this value during vegetation periods demonstrated that the dynamics of growth of studied plants corresponded to Sachs’ arc, being independent of the test variant (Figure 4-6). The treatment of peppers, tomatoes and peas with zircon and especially with potassium sulfate encouraged the increase of growth of plant scions. The most intensive growth belonged to the scions, treated with zircon and potassium sulfate simultaneously, as the effect on the height summarized.
Figure 4. Effect of foliar treatment with zircon and potassium sulfate on the height of *Solanum lycopersicum* variety Gina.

The treatment with zircon and especially with potassium sulfate encouraged the intensity of growth of leaf length and width of tomatoes and peppers. In peas apart from the growth of leaf, the growth of scale leaf bracts was noticed. But the plants, treated with zircon and potassium sulfate together, had the highest growth. The more detailed description of growth processes is presented in literature [12].

Figure 5. Effect of foliar treatment with zircon and potassium sulfate on the height of the shoots of *Capsicum annuum* variety California miracle.

It is necessary to state that foliar treatment with studied regulators was going on in the conditions of lack of content of potassium and sulfur in the soil (Table 4). According to Machigin, the ratio of potassium in the soil is low – 12.7 mg K₂O per 100 gr of soil, and the average norm of potassium for green crops is 20-30 mg K₂O per 100 gr of soil [5]. So, foliar treatment with potassium sulfate compensated the lack of this element for plants.

Table 4. Content of some chemical elements in the soil sample.

| % humus | % mould | Potassium content (K₂O) | Sulfates |
|---------|---------|-------------------------|----------|
| 1.88%   | 1.09%   | 12.7 mg/100 gr soil     | 0.003 %  |

While analyzing the yield the number and the mass of fruits were considered from each plant. As can be seen from tables 5, 6, the lowest yield of tomatoes and peppers was in the control variant and the highest - in the variant with combined treatment of zircon and potassium sulfate. The increase of yield in the test samples was going on against the increase of the number and mass of fruits.
Table 5. Influence of foliar treatment with zircon and potassium sulfate on the yield structure of Solanum lycopersicum variety Gina.

| Yield elements                  | Control          | Zircon           | K2SO4            | K2SO4+zircon     |
|---------------------------------|------------------|------------------|------------------|------------------|
| Number of fruits from 10 plants, pieces |                  |                  |                  |                  |
| Big                             | 23.0 ± 3.2       | 18.0 ± 1.1       | 10.0 ± 0.3       | 8.0 ± 2.3        |
| 100 %                           | 78 %             | 44 %             | 35 %             |                  |
| Middle-sized                    | 31.0 ± 2.1       | 58.0 ± 3.8       | 36.0 ± 0.9       | 49.0 ± 4.1       |
| 100 %                           | 187 %            | 116 %            | 158 %            |                  |
| Small                           | 120.0 ± 0.9      | 132.0 ± 2.3      | 228 ± 1.1        | 369.0 ± 0.8      |
| 100 %                           | 110 %            | 190 %            | 308 %            |                  |
| Total                           | 174.0 ± 1.8      | 198.0 ± 0.9      | 274.0 ± 2.6      | 426.0 ± 1.6      |
| 100 %                           | 120 %            | 158 %            | 245 %            |                  |
| Mass of fruits from 10 plants, kg |                  |                  |                  |                  |
| Big                             | 5.2 ± 4.3        | 2.2 ± 0.8        | 3.9 ± 0.8        | 1.7 ± 3.4        |
| 100 %                           | 42 %             | 75 %             | 32 %             |                  |
| Middle-sized                    | 4.5 ± 0.9        | 5.0 ± 1.0        | 6.5 ± 1.1        | 6.4±1.5          |
| 100 %                           | 111 %            | 144 %            | 143 %            |                  |
| Small                           | 6.5 ± 0.4        | 11.4 ± 2.4       | 12.4 ± 2.5       | 19.5 ± 0.1       |
| 100 %                           | 175 %            | 191 %            | 298 %            |                  |
| Total                           | 16.2 ± 1.3       | 18.6 ± 2.1       | 22.8 ± 3.4       | 27.6 ± 4.3       |
| 100 %                           | 115 %            | 141 %            | 170 %            |                  |
| Productivity, kg/sqm            | 6.48 ±0.10       | 7.44 ±0.30       | 9.12 ±0.40       | 11.04 ±0.50      |
| 100%                            | 115 %            | 141 %            | 170 %            |                  |

The peas of variety Children’s Sweetness also underwent yield recording on the following parameters: the number of legumes and grains (grains of pea). The analysis of the received data (table 7) has shown that the peas of variety Children’s Sweetness of the control variant the lowest yield productivity. The treatment of the plants with the solutions of zircon and potassium sulfate encouraged the increase of productivity. The increase of productivity was due to the increase of the number of legumes on the pea plant as well as the increase of the number and grain size in the fruits. This indicates implicitly that under the influence of the treatment of the studied regulators the nutrient outflow to the forming legumes and grains intensifies. The highest effect on the yield productivity of the peas occurred while treating the peas with the combined treatment of zircon and potassium sulfate solutions. It is important that while analyzing separate and combined influence of the studied regulators on all the yield elements their effect summarized, i.e. the additive character of interreacting between the studied regulators manifested itself.
Table 6. Influence of foliar treatment with zircon and potassium sulfate on crop structure of *Capsicum annuum* variety California miracle.

| Yield elements | Variant                  |
|----------------|--------------------------|
|                | Control | Zircon  | K$_2$SO$_4$ | K$_2$SO$_4$+zircon |
| Number of fruits from 10 plants, pieces |         |         |             |                   |
| Big            | 2.0 ± 0.1 | 3.0 ± 0.1 | 5.0 ± 0.1 | 10.0 ± 0.3 |
| Middle-sized   | 27.0 ± 0.8 | 33.0 ± 1.0 | 39.0 ± 1.1 | 45.0 ± 1.8 |
| Small          | 20.0 ± 0.4 | 17.0 ± 0.3 | 19.0 ± 0.8 | 17.0 ± 0.7 |
| Total          | 49.0 ± 1.2 | 53.0 ± 1.4 | 63.0 ± 1.4 | 72.0 ± 2.0 |
| Mass of fruits from 10 plants, kg |         |         |             |                   |
| Big            | 0.490 ± 0.014 | 0.623 ± 0.018 | 1.026 ± 0.030 | 1.920 ± 0.057 |
| Middle-sized   | 3.019 ± 0.084 | 3.442 ± 0.125 | 4.536 ± 0.130 | 4.909 ± 0.165 |
| Small          | 0.943 ± 0.025 | 0.877 ± 0.039 | 0.989 ± 0.048 | 1.162 ± 0.062 |
| Total          | 4.452 ± 0.123 | 4.942 ± 0.135 | 6.551 ± 0.208 | 7.991 ± 0.254 |
| Productivity, kg/sqm | 2.671 ± 0.070 | 2.965 ± 0.047 | 3.931 ± 0.098 | 4.795 ± 0.109 |

Table 7. Influence of foliar treatment with zircon and potassium sulfate on the crop structure of *Pisum sativum* variety Children’s sweetness.

| Yield elements | Variant                  |
|----------------|--------------------------|
|                | Control | Zircon  | K$_2$SO$_4$ | K$_2$SO$_4$+zircon |
| Number of legumes from 10 plants, pieces | 100 ± 3 | 116 ± 4 | 141 ± 6 | 152 ± 5 |
| Number of pea grain in legume, pieces | 5.0 ± 0.2 | 6.0 ± 0.2 | 6.0 ± 0.2 | 7.0 ± 0.2 |
| Mass of 100 pea grains in air-dried state, gr | 14.0 ± 0.5 | 16.0 ± 0.4 | 17.0 ± 0.5 | 18.0 ± 0.6 |
| Productivity, gr/sqm | 74 ± 2 | 111 ± 2 | 148 ± 4 | 191 ± 7 |

The treatment of zircon and potassium sulfate solutions influenced the quality of the fruits too. In fruits, treated with zircon and potassium sulfate, the content of ascorbic acid rose (figure 7). It is interesting that in tomato fruits, treated with zircon and potassium sulfate solutions, the content of vitamin C rose higher than in pepper fruits. For example, while treating with the combined solutions of zircon and potassium sulfate, the content of ascorbic acid in tomato fruits increased by 58.0% and in pepper fruits by 20.3%.
The plants of variety Fabaceae are able to fix air nitrogen with the help of legume bacteria of genus Rhizobium, living in roots [13]. In the course of research the influence of treatment with the studied regulators on the formation of knobs and the number of bacteria of genus Rhizobium was learnt. Thus the treatment with zircon and especially potassium sulfate activated the growth of knobs and increased the number of bacteria in them. The highest number of knobs on the roots and bacteria in them was found out in the peas of the variant, treated with the combination of zircon and potassium sulfate. It is important to emphasize that the plants treated with zircon form knobs on the main root intensively, the variant treated with potassium sulfate – on the lateral roots and the variant with a combined treatment – on either main or lateral roots.

4. Conclusions
1. Foliar treatment with zircon and potassium sulfate solutions encourage the stability of water regime of the green crops of families Solanaceae and Fabaceae.
2. Foliar treatment with zircon and potassium sulfate solutions increases the intensity of photosynthesis and respiration of the green crops of families Solanaceae and Fabaceae.
3. Treatment with zircon and potassium sulfate activate growth processes, encourages the increase of yield productivity of the green crops and the content of ascorbic acid in their fruits.
4. Treatment with studied regulators encourages the formation of knobs on the roots of the pea plants of variety Children’s Sweetness.
5. The most stimulating effect on the growth and yield productivity is due to the simultaneous treatment with zircon and potassium sulfate solutions.
6. While treating with the combination of zircon and potassium sulfate solutions, the influence of these regulators on the physiological values of the green crops summarized, which says of the additive character of interreacting between the studied regulators.

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