Changes in the parameters of photosynthetic maize activity with applying micronutrient fertilizers

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Abstract. The most important factor that determines the yield of agricultural crops is mineral nutrition. It is important to supply the plants in the required amount and the optimal ratio of basic nutrients and microelements. Foliar treatment is the most rational way to apply micronutrient fertilizers. The current research aimed at examining the species (Azosol 36 Extra, 3.0 l/ha; Aquarin 5, 3.0 l/ha) and the terms of application (5 maize leaves; 8 maize leaves; 5 leaves + 8 maize leaves) of micronutrient fertilizers, depending on the early ripening of the hybrid, providing the formation of the best indicators of photosynthetic activity, was carried out on leached heavy loamy chernozem. When foliar treatment of an early ripe hybrid with Azosol 36 Extra solution, the increase in the total leaf surface of sowing in relation to options with water on a natural agro background was 3.0%, and from Aquarin 5-9.1%, and for the mid-early, the increase was 4.3 and 6.9%, respectively. Against the background of N110P70K40, the gains varied from 4.0 to 5.9%, but no significant advantage, both types of micronutrient fertilizers and in terms of foliar treatment, was not revealed. The use of Azosol 36 Extra on the natural agro background promoted an increase in the total photosynthetic potential by 2.7-4.1% compared to the treatment with water, the effect of Aquarin 5 was more effective, the increase was 6.9-8.9%. With the improvement of root nutrition conditions, the increase from Azosol 36 Extra was obtained a bit more - 4.1-5.8%, and from Aquarin 5, on the contrary, less (3.7-5.6%). Variants with foliar treatment with Azosol 36 Extra in the phase of eight leaves and double application, the increase varied from 7.5-7.9% on a natural agricultural background to 13.2% on an improved one. Aquarin 5 had a better effect on plants during foliar treatment in the phase of five leaves of maize, but the increase was 2.7-8.5%.

1. Introduction
Maize is the most important food, fodder and industrial crop. Due to its high yield, fodder advantages and adaptability to cultivation, this crop is grown in different regions of the country. The most important factor that determines the yield of agricultural crops is mineral nutrition [1-3]. When cultivating maize, it is important to apply the necessary treatment to the plants in the required amount and the optimal ratio of basic nutrients and microelements. The modern trend in agriculture is to find and apply the techniques for the efficient productivity of cultivated plants without increasing the rates of fertilization. It is required to find the ways of reducing the cost and improve the nutritional conditions of maize using micronutrient fertilizers [4-8]. In addition to the direct benefits of increasing crop yields, micronutrients increase the efficiency of macronutrient use [9]. Maize, in comparison with other crops, needs special treatment. The results of the current research show that foliar treatment is the most rational way to apply micronutrient fertilizers. Fertilizer doses for foliar treatment could be 5-
10 times lower than those applied to the soil. Microelement fertilization is carried out when the plants feel the maximum need for them [10-14]. In recent years, chelates and organic complexes with a high content of microelements have been used as a source of trace elements for crops. Their advantage is that the nutrients, getting on the leaves, are quickly included in the metabolic processes of crops, which is especially important when they are lacking in the soil, which is observed during critical periods of plant growing and development [15-18].

Since the intensity of leaf formation has a decisive influence on the productivity of plants, the total leaf area and its photosynthetic activity, study of the effect of various types of complex fertilizers with microelements and the terms of their use on the parameters of photosynthetic activity of maize hybrids of different early maturity in the forest-steppe conditions of the Middle Volga region relevant in scientific and applied terms, which determined the purpose of the current research.

2. Methods

The research was carried out in 2016-2018 on leached heavy loamy chernozem with an increased content of nitrogen, phosphorus and potassium, the reaction of the soil solution is weakly acidic. The field experiment was organized in accordance with generally accepted techniques [19-20], in a fourfold repetition according to the following scheme: factor A - hybrid: early maturing Ladoga 191 MB (FAO 190), mid-early Ronaldino (FAO 210); factor B - fertilization: 1. N\textsubscript{0}P\textsubscript{0}K\textsubscript{0} + treatment of plants with water; 2. N\textsubscript{0}P\textsubscript{0}K\textsubscript{0} + Azosol 36 Extra (3.0 l/ha); 3. N\textsubscript{0}P\textsubscript{0}K\textsubscript{0} + Aquarin 5 (3.0 l/ha); 4. N\textsubscript{110}P\textsubscript{70}K\textsubscript{40} + treatment of plants with water; 5. N\textsubscript{110}P\textsubscript{70}K\textsubscript{40} + Azosol 36 Extra; 6. N\textsubscript{110}P\textsubscript{70}K\textsubscript{40} + Aquarin 5; factor C - the period of foliar treatment: 1. in the phase of five maize leaves; 2. in the phase of eight maize leaves; 3.in the phase (5 leaves + 8 leaves). The arrangement of plots of the first and second parts is systematic, the third is randomized. The plot area of the third order is 28 m\textsuperscript{2}. Sowing was carried out with aisles 70 cm. The plant density is 80 thousand pieces/ha. The predecessor is winter wheat for pure fallow. Mineral fertilizers (ammonium nitrate, nitroammophos, potassium chloride) in accordance with the experimental scheme were applied under the first pre-sowing cultivation. Complex fertilizers with microelements were dissolved in water (at the rate of 200 l/ha). Foliar treatment of crops with complex fertilizers was realized with a knapsack sprayer.

Sufficiently favorable hydrothermal conditions during the growing season of the crop developed in 2016 year (hydrothermal coefficient (HC) 1.09), and the conditions of the growing season 2017 year were quite favorable (HC 0.98), and heavy rainfall in July contributed to the formation of a larger leaf area. The growing season in 2018 took place with insufficient moisture supply against the background of a moderately low air temperature, which negatively affected the formation of the leaf surface of plants and the realization of the potential of maize hybrids.

3. Results

For the sufficient yield, the leaf surface is of great importance. By changing the ratio of the rates of growth and development of plants by means of various methods, it is possible to regulate the leaf area, the number and size of leaves, thereby directly affecting the formation of the yield [21]. Therefore, it is very important with agritechnical techniques in the shortest period of time to achieve the optimal leaf area of plants.

As a result of the research, it was found that the growth of the leaf surface and its maximum size depend on the prevailing weather conditions during the growing season and the use of fertilizers. Measurement of the assimilating surface of one plant in the 5-leaf phase showed that over the years of research, the leaf area against the natural fertility conditions varied from 0.48 dm\textsuperscript{2} to 0.81 dm\textsuperscript{2}, and the differences in hybrids were insignificant. Improvement of the conditions for root mineral nutrition contributed to a significant increase in the leaf surface. But, if in the dry conditions of 2018, mineral fertilizers contributed to the growth of the leaf area of the early-ripening hybrid in the phase of five leaves of maize by an average of 30.2%, and in the mid-early - by 22.6%, then in more favorable weather conditions of 2016, the leaf surface against the conditions of the introduction of N\textsubscript{110}P\textsubscript{70}K\textsubscript{40} had doubled. On average, over the years of the study, due to the improvement of root nutrition, the
increase in the assimilating surface of one plant in the phase of five leaves of maize was 67.7-69.5% (Table 1). The formation of a larger leaf area at the initial stages of plant development and its maintenance in a functioning state for a long time, contributes to a greater accumulation of organic matter and had a positive effect on the maize productivity.

**Table 1. Dynamics of maize leaf area, average for 2016-2018.**

| Hybrid (factor A) | Fertilizer (factor B) | Term foliar treatment (factor C) | Leaf area, dm²/plant 9-10 leaves | Flowering cob | Ripeness |
|------------------|-----------------------|----------------------------------|-----------------------------------|--------------|----------|
| Ladozhsky 191 MV | N₀P₀K₀ + water treatment | 5 leaf | 17.61 | 31.27 | 28.50 |
|                  | 8 leaf | 17.58 | 30.66 | 27.93 |
|                  | 5 + 8 leaf | 17.76 | 31.42 | 28.74 |
|                  | N₀P₀K₀ + Azosol 36 Extra | 5 leaf | 19.47 | 32.20 | 29.23 |
|                  | 8 leaf | 19.13 | 30.27 | 27.29 |
|                  | 5 + 8 leaf | 19.93 | 31.38 | 29.49 |
|                  | N₀P₀K₀ + Aquarin 5 | 5 leaf | 19.01 | 34.06 | 31.78 |
|                  | 8 leaf | 19.27 | 32.77 | 31.02 |
|                  | 5 + 8 leaf | 19.88 | 33.46 | 31.45 |
| Ronaldino        | N₀P₀K₀ + water treatment | 5 leaf | 18.15 | 32.26 | 30.65 |
|                  | 8 leaf | 17.89 | 31.77 | 30.18 |
|                  | 5 + 8 leaf | 18.50 | 32.61 | 30.93 |
|                  | N₀P₀K₀ + Azosol 36 Extra | 5 leaf | 19.76 | 33.23 | 31.97 |
|                  | 8 leaf | 19.79 | 32.82 | 31.52 |
|                  | 5 + 8 leaf | 20.26 | 33.43 | 32.11 |
|                  | N₀P₀K₀ + Aquarin 5 | 5 leaf | 19.94 | 34.16 | 32.83 |
|                  | 8 leaf | 19.93 | 33.59 | 32.30 |
|                  | 5 + 8 leaf | 20.64 | 34.28 | 33.03 |

Analysis of the dynamics of leaf surface formation showed that by the phase of 9-10 maize leaves, plants with an improved agrophone also had the largest leaf area, but the differences in condition of root nutrition were somewhat smoothed out. On average, over three years of research due to macrofertilizers increase in the assimilating surface of one plant in the phase of five leaves of maize was 67.7-69.5% (Table 1). The formation of a larger leaf area at the initial stages of plant development and its maintenance in a functioning state for a long time, contributes to a greater accumulation of organic matter and had a positive effect on the maize productivity.
persisted against the improved conditions of root nutrition. The growth of the leaf surface was 2.56-2.67 dm² or 11.7-12.2% for an early-maturing hybrid and 2.19-2.36 dm² or 10.0-10.8% for a medium-early hybrid. However, a significant difference in terms of foliar treatment was not revealed, only a tendency to an increase in leaf surface was noted with double spraying of crops.

During the years of the experiment, the maximum leaf surface area on the plant was formed in the period from the beginning of the ejection of panicles to the full flowering of the cob, and then the assimilating leaf surface decreased due to the drying of the leaves of the lower layer. By this period, the largest assimilating surface was formed by mid-early hybrid plants with improved agricultural conditions in variants with the use of Azosol 36 Extra, the increase to the variants with water was 3.8-10.5% or 1.48-4.07 dm², and a large increase was obtained at processing in the phase of five maize leaves. The early maturing hybrid responded better to foliar treatment with Aquarin 5 when used in binary form.

The analysis of the data showed that in the years of the experiment to the phase of grain ripeness on the variants treated with microelement fertilizers, the plants retained a large area of functioning leaves. It should be mentioned that, on average, over three years of research, by harvesting with water treatment and Azosol 36 Extra on an unfertilized agricultural conditions, the leaf surface area of an early-ripening hybrid plant decreased by 6.7-9.6% in relation to the period of "flowering cob" and better preservation of the photosynthesizing surface to the "ripeness" phase was facilitated by foliar treatment of Aquarin 5. For the mid-early hybrid on the natural agro conditions, the loss of the leaf surface of the plant was 1.29-1.62 dm² (3.9-5.0 %) and, also, a large leaf area was preserved by plants treated with Aquarin 5. Under improved conditions for root nutrition on crops of an early-ripening hybrid, Aquarin 5 showed better results, and for the mid-early, a slight advantage of Azosol 36 Extra was noted. The decrease in the assimilating surface in comparison with the previous measurement was 4.5-5.3% for the Ladoga 191 MV hybrid, and 3.0-3.9% for Ronaldinio. It was found that on a fertilized agricultural background, the best indicators were obtained when using Azosol 36 Extra in the phase of five leaves, and the effect of Aquarin 5 was stronger with binary processing. Against the conditions of natural soil fertility, the best results in the formation and preservation of the leaf surface were noted with double spraying with complex fertilizers with microelements. The decrease in the assimilating surface in comparison with the previous measurement was 4.5-5.3% for the Ladoga 191 MV hybrid, and 3.0-3.9% for Ronaldinio. It was found that on fertilized agricultural conditions, the best yield was obtained with the use of Azosol 36 Extra in the phase of five leaves, and the effect of Aquarin 5 was stronger with binary treatment. Against the conditions of natural soil fertility, the best yield results and preservation of the leaf surface were noted with double spraying with complex fertilizers with microelements. The decrease in the assimilating surface in comparison with the previous measurement was 4.5-5.3% for the Ladoga 191 MV hybrid, and 3.0-3.9% for Ronaldinio. It was found that on fertilized agricultural soil conditions, the best indicators were obtained when using Azosol 36 Extra in the phase of five leaves, and the effect of Aquarin 5 was stronger with binary processing. Against the condition of natural soil fertility, the best yield results and preservation of the leaf surface were noted with double spraying with complex fertilizers with microelements. The productivity of plant photosynthesis and, ultimately, the yield is directly determined by two main indicators - the total leaf area and the intensity of photosynthetic processes per unit of leaf area.

The average leaf area of the crop varied significantly over the years of the study. In the conditions of a cool, dry summer of 2018, the smallest average leaf surface was obtained - 8.58-10.90 thousand m²/ha under natural agro condition and 11.05-13.42 thousand m²/ha when applying macrofertilizers. A significantly larger leaf surface was formed with a greater amount of precipitation during the growing season in 2017 - from 18.64-21.14 thousand m²/ha under natural agro conditions to 21.11-24.23 thousand m²/ha with applying mineral fertilizers, and the maximum reached 34.73-40.89 thousand m²/ha. On average, due to macrofertilizers, the increase in the total leaf surface of the early maturing hybrid was 3.35 thousand m²/ha, or 23.3%, and the mid-early one - 3.40 thousand m²/ha, or 22.6% (Table 2). It was noted that all fertilizers used for foliar treatment of maize with microelements efficiently influenced on the size of the photosynthetic surface of the sown crops.
When foliar treatment of an early ripe hybrid with Azosol 36 Extra solution, the increase in leaf surface under the natural agro conditions was 3.0%, and from Aquarin 5 - 9.1%, and for the mid-early hybrid, 4.3 and 6.9%, respectively, were obtained. Under conditions with N₁₀P₀K₀, the increase varied from 4.0 to 5.9%, but without any significant advantage, both in the types of micronutrient fertilizers and in terms of foliar treatment, was not revealed. It should be noted that the largest assimilating sowing surface over the years of research was in variants with binary processing of a medium early hybrid with microelement fertilizers. A more significant characteristic of the assimilation activity of plants than the area of eaves is given by the photosynthetic potential of sowing (FP) [22]. Studies have shown that a significant size the total phytoplankton during the growing season was formed in sufficiently moisture-sufficient conditions in 2017 - 1938.10-2201.13 thousand m²/ha ∙ days, and the lowest it was in conditions of lack of moisture in 2018 - 1114.56-1430.06 thousand m²/ha ∙ days. A large FP was formed on crops of a medium early hybrid, regardless of the level of root

Table 2. Photosynthetic activity of maize depending on the conditions of mineral nutrition, average for 2016-2018.

| Hybrid (factor A) | Fertilizer (factor B) | Term of the foliar treatment (factor C) | Average leaf surface size, thousand m²/ha | Photosynthetic potential, thousand m²/ha ∙ days | PPP, g/m² ∙ day |
|------------------|----------------------|----------------------------------------|------------------------------------------|-----------------------------------------------|-----------------|
| Ladozhsky 191 MV | N₀P₀K₀ + water treatment | 5 leaf | 13.77 | 1428.62 | 7.75 |
| | N₀P₀K₀ + water treatment | 8 leaf | 13.73 | 1425.28 | 7.85 |
| | N₀P₀K₀ + water treatment | 5 + 8 leaf | 14.03 | 1455.50 | 7.62 |
| | N₀P₀K₀ + Azosol36 Extra | 5 leaf | 14.42 | 1495.79 | 7.97 |
| | N₀P₀K₀ + Azosol 36 Extra | 8 leaf | 13.80 | 1425.16 | 8.47 |
| | N₀P₀K₀ + Azosol 36 Extra | 5 + 8 leaf | 14.55 | 1506.18 | 8.13 |
| | N₀P₀K₀ + Aquarin 5 | 5 leaf | 15.11 | 1566.90 | 7.91 |
| | N₀P₀K₀ + Aquarin 5 | 8 leaf | 14.91 | 1544.30 | 7.53 |
| | N₀P₀K₀ + Aquarin 5 | 5 + 8 leaf | 15.27 | 1581.43 | 7.98 |
| Ladozhsky 191 MV | N₀P₀K₀ + water treatment | 5 leaf | 14.61 | 1511.85 | 8.19 |
| | N₀P₀K₀ + water treatment | 8 leaf | 14.34 | 1484.88 | 8.14 |
| | N₀P₀K₀ + water treatment | 5 + 8 leaf | 14.54 | 1505.45 | 8.15 |
| | N₀P₀K₀ + Azosol36 Extra | 5 leaf | 15.32 | 1583.43 | 8.44 |
| | N₀P₀K₀ + Azosol 36 Extra | 8 leaf | 14.93 | 1542.19 | 8.58 |
| | N₀P₀K₀ + Azosol 36 Extra | 5 + 8 leaf | 15.12 | 1562.35 | 8.76 |
| | N₀P₀K₀ + Aquarin 5 | 5 leaf | 15.69 | 1622.40 | 8.41 |
| | N₀P₀K₀ + Aquarin 5 | 8 leaf | 15.26 | 1578.40 | 8.15 |
| | N₀P₀K₀ + Aquarin 5 | 5 + 8 leaf | 15.59 | 1613.00 | 8.36 |
| Ronaldino | N₀P₀K₀ + water treatment | 5 leaf | 17.36 | 1793.65 | 7.97 |
| | N₀P₀K₀ + water treatment | 8 leaf | 16.87 | 1745.48 | 7.84 |
| | N₀P₀K₀ + water treatment | 5 + 8 leaf | 17.32 | 1790.02 | 7.70 |
| | N₀P₀K₀ + Azosol36 Extra | 5 leaf | 18.19 | 1882.27 | 8.36 |
| | N₀P₀K₀ + Azosol 36 Extra | 8 leaf | 17.82 | 1846.42 | 8.21 |
| | N₀P₀K₀ + Azosol 36 Extra | 5 + 8 leaf | 17.68 | 1821.80 | 8.72 |
| | N₀P₀K₀ + Aquarin 5 | 5 leaf | 18.20 | 1877.28 | 8.65 |
| | N₀P₀K₀ + Aquarin 5 | 8 leaf | 17.55 | 1812.87 | 7.69 |
| | N₀P₀K₀ + Aquarin 5 | 5 + 8 leaf | 18.73 | 1937.28 | 7.96 |
| Ronaldino | N₀P₀K₀ + water treatment | 5 leaf | 17.79 | 1835.98 | 8.80 |
| | N₀P₀K₀ + water treatment | 8 leaf | 17.67 | 1826.35 | 8.89 |
| | N₀P₀K₀ + water treatment | 5 + 8 leaf | 18.10 | 1867.26 | 8.65 |
| | N₀P₀K₀ + Azosol36 Extra | 5 leaf | 19.46 | 2009.37 | 9.07 |
| | N₀P₀K₀ + Azosol 36 Extra | 8 leaf | 18.28 | 1886.77 | 9.19 |
| | N₀P₀K₀ + Azosol 36 Extra | 5 + 8 leaf | 18.97 | 1957.37 | 9.04 |
| | N₀P₀K₀ + Aquarin 5 | 5 leaf | 18.59 | 1912.20 | 9.05 |
| | N₀P₀K₀ + Aquarin 5 | 8 leaf | 18.24 | 1875.81 | 8.44 |
| | N₀P₀K₀ + Aquarin 5 | 5 + 8 leaf | 18.85 | 1944.50 | 8.67 |
nutrition. On average, for three years of research, the application of mineral fertilization made it possible to increase the seed production rate by 22.2-22.9% in comparison with the level of natural soil fertility (Table 2). The use of Azosol 36 Extra under unfertilized agricultural conditions promoted an increase in the value of the total FP by 2.7-4.1% in comparison with the treatment with water, the effect of Aquarin 5 was stronger, the increase was 6.9-8.9%. With the improvement of the conditions of root nutrition, the increase from Azosol 36 Extra was obtained slightly more —4.1-5.8%, and from Aquarin 5, on the contrary, slightly less (3.7-5.6%). It should be noted that both micronutrient fertilizers had significant results under natural agricultural conditions in the variants with binary treatment, and the mid-early hybrid formed a greater FP when applied in the five-leaf phase. Under the conditions of improved root nutrition, a slightly different pattern was noted: both for the early ripening hybrid and for the medium early large sizes, FP was obtained by processing Azosol 36 Extra in the phase of five leaves of maize and double applying of Aquarin 5.

To obtain high and stable yields, it is very important to have not only a powerful, but also a highly productive photosynthetic apparatus, an indicator of which is the pure productivity of photosynthesis (PPP). It was found that smaller values of the assimilated dry matter were recorded under conditions of uneven precipitation during the growing season of 2018 and with a lack of active temperatures in 2017 (5.05-7.47 g/m² · day) and the best results were obtained in conditions of sufficient heat and moisture supply in 2016 (11.96-14.15 g/m² · day). It is necessary to mention that in the conditions of 2018, the leaves "worked" more productively under unfertilized agricultural conditions, and in 2016-2017 the best indicators of PPP were recorded when the conditions of root nutrition were improved.

The applied complex microelement fertilizers contributed to the improvement of the "work" of the leaf apparatus. On average, over the years of research at both levels of root nutrition, large PPP results were obtained in variants with foliar treatment of crops with Azosol 36 Extra in the phase of eight leaves and double application, the increases varied from 7.5-7.9% under the natural agro conditions to 13.2% - on the improved one. Aquarin 5 had a better effect on plants during foliar treatment in the phase of five leaves of maize, but the increase was 2.7-8.5%.

4. Conclusions

By the phase of grain ripeness during foliar treatment of an early-ripening hybrid with Azosol 36 solution, the extra increase in the total leaf surface of sowing in relation to options with water under natural agro conditions was 3.0%, and from Aquarin 5 - 9.1%, and for a mid-early increase received 4.3 and 6.9%, respectively. Under conditions with N110P70K40, the gains varied from 4.0 to 5.9%.

The use of Azosol 36 Extra under the natural agricultural conditions promoted an increase in the total photosynthetic potential by 2.7-4.1% compared to treatment with water; in the variants with Aquarin 5, the increase was 6.9-8.9%. With the improvement of root nutrition conditions, the increase from Azosol 36 Extra was obtained a little better - 4.1-5.8%, and from Aquarin 5, on the contrary, slightly less (3.7-5.6%).

Large values of the pure productivity of photosynthesis were obtained in variants with foliar treatment of crops with Azosol 36 Extra in the phase of eight leaves and two-fold application, the increments varied from 7.5-7.9% under the natural agro conditions to 13.2% on the improved one. The efficiency of Aquarin 5 was more effective when foliar treatment in the phase of five leaves of maize.

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