The application of chelated forms of micronutrient fertilizers in sorghum cultivation

Konstantin Denisov¹, Oksana Kibalnik², Irina Efremova² and Julia Bochkareva²

¹ Saratov State Agrarian University named after N.I. Vavilov, Saratov, Russia
² Russian Research and Technological Institute of Sorghum and Maize “Rossorgo”, Saratov, Russia

E-mail: konpetrov@yandex.ru

Abstract. Experimental studies of the effect of chelated forms of fertilizers on sorghum yield in arid conditions have been carried out. It is found out that to increase productivity and improve the main economic characteristics of a crop, it is advisable to use liquid chelated micronutrient fertilizers Reasil Forte Carb-Ca / Mg / B-Amino and Reasil micro Amino Zn as foliar application in the phase of 5-7 leaves (first treatment) with subsequent treatments after 10 days. It is proved that this method provides an increase in the yield of grain and green mass of sorghum by 0.27-0.60 and 27.1-39.9 t/ha, respectively, and also increases the content of valuable amino acids in the green mass: arginine, threonine, isoleucine, valine, and phenylalanine, which in turn increases the nutritional value of sorghum green mass for feeding farm animals. It is concluded that foliar application with micronutrient fertilizers reduces plant stress from unfavorable climatic conditions, which leads to stabilization of yields over the years and partially removes dependence on weather conditions.

1. Introduction

Currently, in the world practice to improve the techniques of agricultural technologies, much attention is paid to the application of chelated forms of fertilizers. They have a number of valuable properties: they dissolve in water, are well adsorbed on the surface of leaves and in the soil, they are not destroyed by microorganisms for a long time, are highly stable in a wide range of acidity (pH), are combined with various pesticides, and are practically non-toxic. They are used to optimize mineral nutrition. An increase in the productivity of agricultural crops under the influence of foliar application is due to the activation of photosynthetic activity and protective antioxidant enzymes, stabilization of the membrane apparatus of cells and a decrease in the oxidation of photoassimilants during respiration [1-2]. With foliar application of chelates, the fertilizer molecules enter the leaf and do not accumulate with their accompanying ions on the surface [3].

Previously, many researchers have proven the positive effect of trace elements (zinc, calcium, magnesium, boron and many others) on the growth and development of plants. For the most complete realization of the bioclimatic potential of agricultural crops, a sufficient supply of magnesium is required during periods of the highest consumption of elements by plants [4]. With a lack of calcium in plants, the root system develops poorly. It enhances metabolism and enzyme activity (invertase, catalase) [5].
Calcium deficiency causes degradation of the cell membrane and leads to a loss of strength of plant tissue and chlorosis [6]. Boron is involved in the formation and maintenance of the structure of intermolecular and supramolecular complexes of biopolymers (proteins, nucleic acids, lipids, polysaccharides) that compose ribosomes [7-8]. Due to this ability, it affects the activity of enzymes (catalase, invertase, indoleacetic acid oxidase, peroxidase, etc.) [9-10]. Boron also enhances pollen germination, pollen tube growth and is necessary for the formation of viable pollen [11]. Its deficiency leads to a decrease in seed productivity [12].

Zinc is also an important element, which composes enzymes responsible for the biochemical reactions of synthesis, decay and metabolism of organic substances. Its low content in plants leads to disruption of carbohydrate conversion processes, causes growth retardation and a decrease in chlorophyll content in leaves [13].

The Saratov region is characterized by a sharply continental climate. During the growing season of agricultural crops, soil and air droughts are often observed. Currently, a large number of preparations are widely used in agricultural practice in order to increase the resistance of plants to changing environmental conditions. However, such difficult climatic conditions contribute to a decrease in the effectiveness of the use of granular fertilizers in comparison with liquid forms.

In addition, when using foliar fertilization of crops, the liquid form of fertilizers allows one to apply a more accurate amount of nutrients at different stages of growth and development. Improvement of agrotechnical methods of cultivation of grain sorghum to optimize mineral nutrition by foliar application with chelated micronutrient fertilizers is relevant [14].

2. Materials and methods
The scheme of experiments to study the effect of chelated forms of micronutrient fertilizers on sorghum productivity included the application of micronutrient fertilizers Reasil Forte Carb Ca / Mg / B Amino and Reasil micro Amino Zn (one - three treatments with a dose of 1.0 l / ha for vegetative plants of grain sorghum Garant). First treatment was in a phase of 3-5 leaves, the others were carried out with an interval of 10 days. The soils of the experimental site are dark chestnut, heavy loamy, coarse silty clay with a humus content of 2.8%.

Variants of experience with the application of microfertilizers are launched in accordance with the developed scheme:

- Variant 1 – control (without application of fertilizers);
- Variant 2 – single application of Reasil Forte Carb Ca/Mg/B Amino on vegetative plants in the phase of 3-5 leaves (1.0 l/ha);
- Variant 3 – double application of Reasil Forte Carb Ca/Mg/B Amino on vegetative plants: in the phase of 3-5 leaves and after 10 days of the first treatment (1.0+1.0 l/ha);
- Variant 4 – triple application of Reasil Forte Carb Ca/Mg/B Amino on vegetative plants: in the phase of 3-5 leaves, subsequent treatments after 10 days (1.0+1.0 l/ha +1.0 l/ha);
- Variant 5 – single application of Reasil micro Amino Zn on vegetative plants in the phase of 3-5 leaves (1.0 l/ha);
- Variant 6 – double application of Reasil micro Amino Zn on vegetative plants: in the phase of 3-5 leaves and after 10 days of the first treatment (1.0+1.0 l/ha);
- Variant 7 – triple application of Reasil micro Amino Zn on vegetative plants: in the phase of 3-5 leaves, subsequent treatments after 10 days (1.0+1.0 l/ha +1.0 l/ha);

The technology of sorghum cultivation in the experiment is zonal. The predecessor is fallow land. Sowing of sorghum samples was carried out on May 5 with a selection seeder SKS-6-10 with seed placement to a depth of 6-8 cm on the experimental plot of the Federal State Budgetary Scientific Institution RosNIISK “Rossorgo”. Shoots were recorded on May 30. The plot area was 15.4 m². The trial was carried out with three replications. The placement of the plots is randomized. The planting density was set manually - 100 thousand plants/ha.
Grain and biomass yield, bioenergetic assessment of sorghum crops were assessed according to generally accepted methods.

The varieties bred by the Federal State Budgetary Scientific Institution RosNIISK “Rossorgo” have complex resistance to diseases and pests: bacterial spot, grass aphids, dust, hard and covered brand, stem and root rot; viral, bacterial and especially common and harmful fungal diseases.

The Garant variety belongs to the early maturing group. The length of the period from germination to ear formation is 39-46 days, from germination to milky-wax ripeness of grain - 75-80 days, from germination to full ripeness of grain - 88-93 days. Plant height is 108-114 cm. Productivity of grains is 2.40-3.15 t/ha, of green mass - 11.80-17.40 t/ha, weight of 1000 grains is 22.8 g. Content of protein is 12.8-13.3%, of starch - 72.0-72.5%, of fat - 1.46%, of ash - 1.18%, of fiber - 1.78%, of nitrogen-free extractive substances - 84.63%. The variety is recommended to be used for grain feed and food purposes.

Reasil Forte Carb-Ca / Mg / B-Amino is a liquid fertilizer. A balanced composition with a high percentage of boroethanolamine, calcium and magnesium in combination with hydroxycarboxylic and amino acids, provides a high level of bioavailability of nutrients, their immediate intake and mobility in the plant. Calcium is the transporter of all minerals, regulates their absorption by the plant, plays an important role in the development of the cell walls of plants and fruits, and is responsible for cell division and strength.

Boron, a proven calcium synergist, improves carbohydrate and protein metabolism. Magnesium is the main component of chlorophyll and is essential for the synthesis of amino acids, vitamins, oils and sugars. It is used for a wide range of crops and is compatible with most pesticides and mineral fertilizers. Hydroxycarboxylic acids and amino acids provide the intake of nutrients at a higher level [15].

Reasil micro Amino Zn has a high zinc content in a form readily available to plants. Zinc is contained in a complex with humic, hydroxycarboxylic amino acids, which significantly increases its absorption by plants through the leaf surface, as well as their mobility within the plant. It does not contain chemical elements and compounds (synthetic chelating agents) that have a harmful effect on the growth and development of plants. This is a multicomponent fertilizer, in which each active substance enhances the effectiveness of the rest, allowing the plant to be influenced in all available directions at once. This contributes to a significant increase in yield and quality. It is suitable for intensive farming systems as well as organic farming applications.

Reasil micro Amino Zn is a biological plant growth stimulator. Amino acids (L-glycine, L-lysine, L-threonine, etc.) are a powerful stimulant of plant growth, they act as complexing agents for essential trace elements, transporting them to the plant in an accessible form. Hydroxycarboxylic acids (gluconic, lactic, succinic, citric, etc.) promote the maximum absorption of nutrients by the plant. They stimulate metabolic processes in the plant, increase the permeability of the cell membrane.

3. Results and Discussion

Application of chelated micronutrient fertilizers had a positive effect on the formation of all the main economically valuable traits. The greatest effect was noted in variants 2, 3 after single and double application of Reasil micro Amino Zn (1.0 l/ha) and in variant 5 after a single application of Reasil Forte Carb-Ca / Mg / B-Amino (1.0 l/ha). A significant effect of the preparations was marked in grain yield, grain weight from one head and biomass yield.

For other productivity elements, such as plant height at ripening, inflorescence length, and the area of the largest leaf, an increase in the value of indicators was found compared to the control option, especially after a single application of Reasil micro Amino Zn and Reasil Forte Carb-Ca / Mg / B-Amino.

However, the analysis of variance did not confirm these differences between the variants of the experiment (Ffact ≤ Ftheor). Analysis of the majority of economically valuable traits revealed a tendency that with an increase in the number of foliar application, a decrease in the value of traits is observed (table 1).
Table 1. Variability of economically valuable traits of sorghum (Garant variety) in the experiment after application of chelated fertilizers, 2020.

| Trait                        | Variant | 1   | 2   | 3   | 4   | 5   | 6   | 7   | \( F_{\text{act}} \) | LSD05 |
|------------------------------|---------|-----|-----|-----|-----|-----|-----|-----|---------------------|-------|
| Plant height, cm             |         | 117.7 | 120.2 | 123.7 | 118.7 | 125.0 | 124.2 | 124.5 | 0.34                | –     |
| Inflorescence length, cm     |         | 26.1 | 29.0 | 28.5 | 28.7 | 28.5 | 29.1 | 27.1 | 0.59                | –     |
| Leaf area, cm\(^2\)         |         | 223.0 | 250.7 | 224.6 | 201.0 | 275.2 | 246.6 | 230.2 | 0.61                | –     |
| Tilling capacity, pcs        |         | 1.17 | 1.13 | 1.00 | 1.00 | 1.05 | 1.05 | 1.03 | 1.15                | –     |
| Biomass yield, t/ha          |         | 13.87a | 17.93b | 18.53b | 17.63b | 19.30b | 19.40b | 17.00ab | 3.14\(*\) | 3.28 |
| Grain yield, t/ha            |         | 4.03a | 4.63d | 4.57d | 4.30bc | 4.63d | 4.40cd | 3.87a | 13.76\(*\) | 0.25 |
| Weight of 1000 grains, g     |         | 28.2 | 27.0 | 32.3 | 27.3 | 27.8 | 30.6 | 27.4 | 1.65                | –     |
| Grain weight from one head, t|         | 29.6a | 31.6ab | 38.0c | 35.8bc | 34.1abc | 35.3bc | 30.7ab | 3.78\(*\) | 4.84 |
| Grain number from one head, pcs |     | 1049 | 1072 | 1087 | 1319 | 1224 | 1169 | 1121 | 1.15                | –     |

Depending on the variant of the experiment, the increase in grain yield was 0.27-0.60 t/ha, which corresponds to 6.7-14.9%. The highest grain yield was in variants with a single application of Carb-Ca / Mg / B-Amino and Amino Zn – 4.63 t/ha (table 2).

Table 2. Deviation of economically valuable traits of sorghum (Garant variety) after application of chelated fertilizers from the control variant (without application of fertilizers), 2020.

| Trait                        | Deviation from the control | 2   | 3   | 4   | 5   | 6   | 7   | \( F_{\text{act}} \) | LSD05 |
|------------------------------|----------------------------|-----|-----|-----|-----|-----|-----|---------------------|-------|
| Plant height, cm             | cm                         | 2.5 | 6.0 | 1.0 | 7.3 | 6.5 | 6.8 | 2.1                | 5.1   |
| Inflorescence length, cm     | %                          | 2.9 | 2.4 | 2.6 | 2.4 | 3.0 | 1.0 | 11.1               | 9.2   |
| Area of the largest leaf, cm\(^2\) | %                     | 27.7 | 1.6 | -22.0 | 52.2 | 23.6 | 7.2 | 12.4               | 0.7   |
| Biomass yield, t/ha          | t/ha                       | 4.06 | 4.66 | 3.76 | 5.43 | 5.53 | 3.13 | 29.3               | 33.6  |
| Grain yield, t/ha            | %                          | 0.60 | 0.54 | 0.27 | 0.60 | 0.37 | -0.16 | 14.9               | 13.4  |
| Grain weight from one head, g| %                          | 2.0 | 8.4 | 6.2 | 4.5 | 5.7 | 1.1 | 6.8                | 28.4  |

The increase in productivity of the biomass of the Garant variety ranged within 3.13-5.53 t/ha, which is 22.6-39.9%. The biomass yield was most influenced by the double foliar application with both preparations. Reasil Forte Carb-Ca / Mg / B-Amino proved to be more effective.

Grain sorghum plays a leading role among agricultural crops used in animal husbandry as forage, as it is characterized by high productivity and nutritional value. Sorghum grain is a good concentrated feed for pigs, poultry, cattle, sheep, horses, rabbits and pond fish. It has a positive effect on their growth and development, ensures a high level of productivity and good quality of livestock products. The digestibility of sorghum grain reaches 86%.
An important component in assessing feed merits is the determination of gross energy per 1 kg of feed and per unit area, which is based on the biochemical parameters of the grain. Researches revealed a tendency to improve the values of biochemical components and gross energy in 1 kg of forage in variant 3 (double foliar application of Reasil micro Amino Zn at a dose of 1.0 l/ha). So, the content of crude protein in variant 3 was 10.70%, and crude fat 4.26%, which is higher than the control by 1.09 and 0.07%, respectively (table 3).

**Table 3.** Bioenergetic assessment of the cultivation of sorghum (Garant variety) for after application of chelated fertilizers, 2020.

| Indicator                                | Variant 1 | Variant 2 | Variant 3 | Variant 4 | Variant 5 | Variant 6 | Variant 7 |
|-------------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Content in grain, %:                      | 9.61      | 9.52      | 10.70     | 9.74      | 8.99      | 9.64      | 9.27      |
| crude protein                             | 4.19      | 3.79      | 4.26      | 3.94      | 4.28      | 3.89      | 3.88      |
| crude fat                                 | 2.49      | 3.33      | 2.25      | 3.01      | 2.68      | 2.66      | 2.92      |
| crude fiber                               | 82.33     | 81.87     | 81.26     | 81.75     | 82.71     | 82.40     | 82.52     |
| nitrogen-free extractive substances       |           |           |           |           |           |           |           |
| Gross energy in 1 kg of forage, MJ        | 18.84     | 18.75     | 18.89     | 18.77     | 18.83     | 18.78     | 18.75     |

However, the bioenergetic assessment per unit area is higher in variants 2, 3, 5, due to the higher productivity of the variety. The gross energy output varied from 86.33 to 87.18 GJ/ha (figure 1).

![Figure 1](https://via.placeholder.com/150)

**Figure 1.** The gross energy output per unit area depending on the number of foliar application of micronutrient fertilizers.

For feeding farm animals, the balance of the amino acid composition of proteins is of great importance. Therefore, the study of the effect of micronutrient fertilizers on the amino acid content in the grain of varieties of fodder use is also of great importance. In our studies, there was a tendency to an increase in the amount of the following amino acids in variant 3 (double foliar application of Reasil micro Amino Zn in a dose of 1.0 l/ha): arginine, threonine, isoleucine, valine, phenylalanine (table 4).
Table 4. The amino acid composition of the grain (%) after application of chelated fertilizers, 2020.

| Indicator      | 1   | 2   | 3   | 4   | 5   | 6   | 7   |
|----------------|-----|-----|-----|-----|-----|-----|-----|
| Arginine       | 0.37| 0.37| 0.40| 0.37| 0.35| 0.37| 0.36|
| Methionine     | 0.17| 0.17| 0.18| 0.17| 0.16| 0.17| 0.17|
| Threonine      | 0.31| 0.31| 0.34| 0.32| 0.29| 0.31| 0.30|
| Triptophane    | 0.10| 0.11| 0.12| 0.11| 0.10| 0.11| 0.11|
| Cystine        | 0.17| 0.17| 0.19| 0.18| 0.16| 0.18| 0.17|
| Isoleucine     | 0.37| 0.37| 0.42| 0.38| 0.35| 0.37| 0.36|
| Valine         | 0.47| 0.46| 0.52| 0.48| 0.44| 0.47| 0.45|
| Histidine      | 0.22| 0.22| 0.24| 0.22| 0.21| 0.22| 0.21|
| Phenylalanine  | 0.49| 0.49| 0.56| 0.50| 0.46| 0.50| 0.48|

4. Conclusion
The experimental data confirm the results of the authors’ earlier studies on improving the elements of the technology of cultivation of sorghum crops: methods of pre-sowing seed treatment, as well as foliar application of growth-stimulating preparations, nitrogen and humic fertilizers. Their stimulating effect on the yield of varieties was revealed. The possibility of using chelated micronutrient fertilizers in the varietal technology of cultivation of grain sorghum is being studied for the first time and is a topical area.

Thus, to increase productivity and improve the main economic characteristics of grain sorghum, it is economically expedient to apply liquid chelated micronutrient fertilizers Reasil Forte Carb-Ca / Mg / B-Amino and Reasil micro Amino Zn as foliar application in the phase of 5-7 leaves (the first treatment) and the next one - after 10 days. This technique allows not only to increase the yield of both grain and sorghum green mass by 0.27-0.6 and by 27.1-39.9 t / ha, respectively, but also to increase the content of valuable amino acids in the green mass: arginine, threonine, isoleucine, valine, phenylalanine that increases the nutritional value of sorghum green mass.

Moreover, foliar application with micronutrient fertilizers reduces the stress of plants from unfavorable climatic conditions, which leads to stabilization of yields over the years and partially removes dependence on weather conditions.

References
[1] Karpova L V and Stroganova A V Niva Povolzhya 4 (2019) 32
[2] Gaisin I A and Khisameeva F A 2007 Multifunctional chelated micronutrient fertilizers (Kazan) 432
[3] Bineev R G and Kazakov H Sh 1983 Chelates of microbiogenic metals in the soil - plant - animal system (Kazan) 234
[4] Voevodina L A and Voevodin O V 2015 Scientific Journal of the Russian Research Institute of Melioration Problems 2(18) 3211
[5] Mut H, Gulumser E, Dogruso M C and Basaran U 2017 Animal Nutrition and Feed Technology 17(2) 34-39
[6] Dovlatbekyan KG and Volkov V A 2017 Actual Research and Development 32 453
[7] Shersnev E A and Schneer V S 1970 Physiological role of trace elements in plants (Leningrad) 328
[8] Dvorakovsky M S 1983 Plant Ecology (Moscow) 298
[9] Katalymov M V 1965 Microelements and Microfertilizers (Moscow) 382
[10] Kibalenko A P 1976 Trace elements in plant metabolism (Kiev) 182
[11] Shkolnik M Ya Trace elements in plant life (Leningrad) 281
[12] Dautov RK, Minibaev VG and Kalimulina S N 1979 Trace elements in the soils of the Chuvash Autonomous Soviet Socialist Republic and the rational use of micronutrient fertilizers (Cheboksary) 281
[13] Pukhovskaya T Yu 2009 *Agrochemical Bulletin* **2** 55-63

[14] Niu J H, Liu C, Huang M L, Liu K Z and Yan D Y *Journal of Soil Science and Plant Nutrition* Retrieved from: http://appswebofknowledge.com/OutboundServicedo?SID=D3LayKv1hTyK9oZtkIl&mode=rrcAuthorRecordService&action=go&product=WOS&lang=ru_RU&daisIds=2991600

[15] Zia M H, Ahmed I, Bailey E H, Lark R M, Young S D, Lowe N M, Joy E J M, Wilson L, Zaman M and Broadley M R 2020 *Frontiers in Sustainable Food Systems* **4** 135