Intensification of corn fertilizer system under irrigation conditions in the Chechen republic

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Abstract. The article presents the results of studying options for the use of mineral and organic fertilizers in order to improve the nutritional conditions of corn during irrigation in the Chechen Republic. The studies were conducted in 2015-2017 on corn hybrids PR38A24 and Beshtau. Against the background of N90P120K60, the effectiveness of plant nutrition with the following agrochemicals was studied: Bioplant Flora 1 l/ha; Nagro 0.5 l/ha; mixture (Crystalon 3 kg/ha + Brexil Zn 0.15 kg/ha + urea 7 kg/ha). Against the background of N90P120K60 + fertilizing plants with a mixture of agrochemicals, the effectiveness of presowing seed treatment with fertilizers Bioplant Flora 1 l/t and Nagro 1 l/t was studied. Mineral fertilizers N90P120K60 and agrochemicals used for plant nutrition and seed treatment caused changes in the concentration of trace elements in corn grain. The content of trace elements in the grain was significantly lower than the maximum permissible concentration (MPC). The studied options for fertilizer systems significantly increased the yield of corn. The maximum grain yield of PR38A24 and Beshtau hybrids was provided by the application of N90P120K60 mineral fertilizers in combination with fertilizing plants with a mixture of fertilizers (Kristallon + Brexil Zn + Urea) and pre-sowing seed treatment with organic fertilizer Bioplant Flora (14.4 and 12.1 t/ha), as well as organic fertilizer Nagro (15.4 and 12.0 t/ha). The starch content increased with the use of certain mineral fertilizers at a dose of N90P120K60 in the grain of the PR38A24 hybrid to 77.28 % (6.64 %), the Beshtau hybrid – up to 73.02 % (10.39 %). The availability of grain protein PR38A24 hybrid increased to a greater extent (up to 9.89 %) due to the use of mineral fertilizers. In the grain of the Beshtau hybrid, the maximum protein content (12.28 %) was provided by a combination of mineral fertilizers with Bioplant Flora plant nutrition.

1. Introduction

Worldwide corn is the highest-yielding grain crop and occupies a significant share in the structure of sown areas. Obtaining high yields of high-quality, environmentally friendly grain for food and feed purposes is an important task of agricultural science and production.

Under irrigation conditions, fertilizers are the most effective way to increase corn yields. For intensive growth and development of corn plants, it is not enough to use only mineral fertilizers containing trace elements.

The fertilizer system should also include various agrochemicals containing trace elements, humic acids, amino acids, growth regulators, and other substances useful for plants [1]. The decisive role is
played by trace elements that increase the activity of enzyme systems in plant and improve the use of nutrients from soil and fertilizers [2].

The adaptation of the cultivated culture can be increased by using plant growth regulators with high anti-stress activity [3]. The high agro-technical background created to optimize the nutritional conditions of plants and herbicidal treatment of crops increase the susceptibility of plants to diseases, which requires the use of antistress components [6].

Seed treatment and plant nutrition using fertilizers with trace elements provides a significant positive effect, enhances the growth of corn plants, increases the yield of corn and improves the quality of grain [4, 5].

Therefore, recently, leading producers of corn grain are increasingly focusing on the integrated use of traditional mineral fertilizers and various agrochemicals for the treatment of seeds and plants in order to maximize the biological potential of modern corn hybrids and obtain the largest grain yield.

The purpose of our research is to develop an intensive fertilizer system for corn grown under irrigation in the conditions of the Chechen Republic.

2. Methods and materials

The experiments were carried out on the fields of the Chechen Research Institute of Agriculture in 2015–2017. The soils of the experimental plot are meadow-chernozemic carbonate, with pebbles subsurface from a depth of 60–80 cm, slightly humus and slightly washed out. The humus content in the arable layer is 4.1–5.9 %, gross nitrogen is 0.38 %, gross phosphorus is 0.18 % and gross potassium is 1.86 %. By the content of mobile forms of nutrients, they have a low supply of mobile phosphorus and metabolic potassium. These soils are characterized by a neutral reaction of soil solution (6.9–7.1).

The field moisture capacity (MC) of the meter soil layer is 27.7 %, the bulk density is 1.24 %, the density is 1.24 g/cm$^3$, the total porosity is 51.8–54.8 %, and the maximum hygroscopicity is 8.5–11.5 %, wilting humidity is 10.6–15.4 %.

According to water regime, the zone where the experiments were carried out refers to insufficient moisture zone. Over the year, 506 mm of precipitation falls here with hydrothermal index of 0.89. During the period of corn vegetation (May-September), the average annual rainfall was 355 mm. During the years of research, meteorological conditions in the growing season of corn were different. In 2015, in May-September, 117 mm of precipitation fell, in 2016 – 434 mm, in 2017 – 229.9 mm.

The experience is two-factor. Hybrids of corn PR38A24 and Beshtau were taken as factor A. B Fertilizer Factor:

1. Without fertilizers (control);
2. N90P120K60 (Background);
3. Background + fertilizer Bioplant Flora 1 l/ha;
4. Background + fertilizer Nagro 0.5 l/ha;
5. Background + fertilizer (Crystalon 3 kg/ha + Brexil Zn 0.15 kg/ha + urea 7 kg/ha);
6. Background + fertilizer (Crystalon 3 kg/ha + Brexil Zn 0.15 kg/ha + urea 7 kg/ha) + seed treatment with Bioplant Flora 1 l/ha;
7. Background + fertilizer (Crystalon 3 kg/ha + Brexil Zn 0.15 kg/ha + urea 7 kg/ha) + seed treatment with Nagro 1 l/ha.

The used preparations of special Crystalon with the content of trace elements 18 + 18 + 18 + 3 and Brexil Zn are mineral fertilizers with trace elements. Bioplant Flora is an organic fertilizer based on humic acids with trace elements, has fungicidal properties, increases the immunity of plants to diseases, has a growth-promoting effect. Nagro is a bioorganic nano-fertilizer used both for seed treatment and corn sowing, which increases the immune resistance of plants to adverse environmental factors.

Corn sowing was carried out by a seeder according to the scheme of 70 cm x 21–22 cm, providing plant density of 65–75 thousand/ha. The seeding rate is 20–25 kg/ha.
The experiment was carried out under irrigation conditions while maintaining pre-irrigation moisture in a 0–60 cm soil layer of not less than 75–80 % of the lowest moisture capacity (MC). The timing of irrigation was regulated by the state of soil moisture and weather conditions of the growing season. Irrigation method of furrows was used.

3. Results
The role of trace elements in the life of corn is significant and diverse. They participate in complex biochemical and physiological processes, activate enzymes, vitamins, hormones, they are associated with the synthesis of organic substances and contribute to the increase of the productivity and quality of grain. The biological catalysts of all processes occurring in a living organism are enzymes that are activated by chemical elements, most of which are trace elements. These activators include copper, zinc, iron, manganese, cobalt, molybdenum, etc.

The applied mineral fertilizers and agrochemicals caused changes in the content of trace elements in grains. Moreover, their effect on the concentration of trace elements in the grain of different hybrids was ambiguous.

The chemical analysis showed that in all variants of the experiment, iron was more accumulated in the grain of the PR38A24 hybrid, with the exception of the option where mineral fertilizers were used in combination with plant nutrition and seed treatment with Nagro organic fertilizer. When processing crops with this fertilizer for both hybrids, the lowest iron content in the grain (28.39 and 37.44 mg/kg) was revealed, which turned out to be lower than the control by 22.44 and 27.83 mg/kg, respectively.

The amount of copper in the grain of the PR38A24 hybrid varied from 1.22 mg/kg in the control to 1.86 mg/kg in the variant with the use of mineral fertilizers (N90P120K60), fertilizing the plants with a mixture (Crystalon + Brexil Zn + urea) and pre-treating seeds with Bioplant Flora organo-mineral fertilizer. Less copper was accumulated in the grain of Beshtau hybrid (from 0.56 to 1.60 mg/kg).

Table 1. Content of trace elements in the grain of corn hybrids (mg/kg) for 2015–2017 in average.

| Trace elements | Experiment options | MCL, mg/kg |
|----------------|--------------------|------------|
|                | 1  | 2   | 3   | 4   | 5   | 6   | 7   |
| PR38A24 hybrid |    |     |     |     |     |     |     |
| Fe             | 59.88 | 64.81 | 66.48 | 37.44 | 51.84 | 55.16 | 37.70 | 110 |
| Cu             | 1.22  | 1.68  | 1.45  | 3.35  | 1.45  | 1.86  | 1.38  | 10 |
| Zn             | 5.15  | 6.10  | 4.94  | 6.87  | 6.18  | 5.97  | 5.09  | 50 |
| Mn             | 4.09  | 4.54  | 3.97  | 3.84  | 4.59  | 4.36  | 4.05  | 50 |
| Cd             | 0.02  | 0.01  | 0.03  | 0.01  | 0.01  | 0.01  | 0.01  | 10 |
| Ni             | 0.29  | 0.88  | 0.76  | 0.75  | 0.55  | 0.49  | 0.39  | 10 |
| Co             | 0.05  | 0.07  | 0.05  | 0.09  | 0.08  | 0.08  | 0.04  | 0.5 |
| Mg             | 1.29  | 0.37  | 0.86  | 0.68  | 1.17  | 0.49  | 1.37  | 10 |
| Ca             | 2.25  | 2.61  | 2.33  | 2.85  | 2.30  | 2.46  | 2.62  | 10 |
| Beshtau hybrid |    |     |     |     |     |     |     |    |
| Fe             | 56.22 | 53.08 | 53.33 | 28.39 | 41.06 | 44.99 | 47.1  | 110 |
| Cu             | 1.03  | 1.34  | 1.06  | 0.56  | 0.92  | 1.60  | 1.25  | 10 |
| Zn             | 9.28  | 7.51  | 6.26  | 6.14  | 6.57  | 9.45  | 5.21  | 50 |
| Mn             | 4.85  | 4.47  | 4.67  | 4.67  | 4.37  | 4.09  | 4.61  | 50 |
| Cd             | 0.01  | 0.01  | 0.06  | 0.04  | 0.01  | 0.01  | 0.01  | 10 |
| Ni             | 0.43  | 0.96  | 0.66  | 0.63  | 0.47  | 0.67  | 0.50  | 10 |
| Co             | 0.14  | 0.03  | 0.08  | 0.09  | 0.14  | 0.05  | 0.14  | 0.5 |
| Mg             | 0.58  | 0.39  | 1.19  | 0.69  | 0.74  | 0.57  | 0.91  | 10 |
| Ca             | 1.67  | 2.14  | 1.82  | 1.85  | 1.83  | 2.15  | 1.78  | 10 |

NOTE: 1 – without fertilizer (control); 2 – n90p120k60 – background; 3 – background + feeding bioplant flora; 4 – background + feeding; 5 – background + feeding (Crystalon + brexil + carbamide); 6 – background + feeding (Crystalon + brexil + carbamide) + treatment of seeds bioplant flora; 7 – background + feeding (Crystalon + brexil + carbamide) + seed processing.
The zinc content in most experimental variants was more contained in the grain of the Beshtau corn hybrid. At the same time, while in the grain of PR38A24 hybrid, feeding plants with Nagro organo-mineral fertilizer caused the increase in zinc content, then in the grain of the Beshtau hybrid this fertilizer caused the decrease in the accumulation of trace elements.

The manganese content in the grain of the PR38A24 hybrid varied from 3.84 to 4.59 mg/kg, Beshtau hybrid was higher (4.09–4.85 mg/kg). No regular changes in the manganese content were observed when applying the studied fertilizers. When cultivating Beshtau hybrid, the highest manganese content (4.85 mg) was determined in the control variant, the smallest (4.09 mg) was found using a combination of mineral fertilizers (N90P120K60) with fertilizing plants with a mixture (Crystalon + Brexil Zn + urea) and pre-treating seeds with Bioplant Flora organo-mineral fertilizer.

The cadmium content in the grain of two hybrids was almost the same and ranged from 0.01 to 0.06 mg/kg. Nickel was accumulated in the grain of the PR38A24 hybrid in the range 0.29–0.88 mg/kg, and in Beshtau hybrid it was more (0.43–0.96 mg/kg). The smallest content of this trace element was found for both hybrids in unfertilized control, the highest content was observed when mineral fertilizers were used. The cobalt concentration was higher in the grain of Beshtau hybrid (0.03–0.14 mg/kg).

One of the most important trace elements is magnesium. It was consumed more by plants of PR38A24 hybrid, as evidenced by the higher grain content (0.37–1.37 mg/kg). Most of all it was revealed in the variant with the introduction of N90P120K60 mineral fertilizers + fertilizing the plants with a mixture (Crystalon + Brexil Zn + urea) + presowing treatment of seeds with Nagro organic fertilizer.

Calcium in all test variants accumulated more in the grain of PR38A24 hybrid (2.25–2.85 mg/kg). In the grains of this hybrid, the most significant increase in calcium was caused by Nagro fertilizer against the background of N90P120K60. The calcium content in the grain of Beshtau hybrid was positively affected by mineral fertilizers and seed treatment with Bioplant Flora fertilizer.

As it follows from the above mentioned data, the content of trace elements in the grain of various corn hybrids the fertilizers had an ambiguous effect.

The content of all trace elements in grains was significantly lower than the maximum permissible concentration (MPC), which indicates the absence of contamination of the grown products.

The studied variants of corn fertilizer systems during cultivation on irrigation have significantly increased grain yield (Table 2). In average, for three years of research without fertilizers, the grain yield of PR38A24 hybrid was 8.9 t/ha, Beshtau hybrid – 8.2 t/ha. Mineral fertilizers N90P120K60 increased the yield to 11.4 and 10.4 t/ha, respectively (by 28.9 and 24.1 %).

Against the background of mineral fertilizers, the nutrition of plants with Bioplant Flora fertilizer gave a grain yield increase of corn hybrids of 48.8 and 40.1 %, and Nagro fertilizer – 50.0 and 45.8 %. Against the background of N90P120K60, fertilization of plants with a mixture of preparations (Crystalon + Brexil Zn + urea) provided the increase of 69.0 and 28.0 % to the control and increased the grain yield of hybrids to 13.9 and 11.4 t/ha.

Pre-sowing seed treatment with Bioplant Flora fertilizer in combination with mineral fertilizer and a mixture of preparations (Crystalon + Brexil Zn + Carbamide) formed a grain yield of PR38A24 hybrid of 14.4 t/ha, Beshtau hybrid of 12.1 t/ha. Mineral fertilizers in combination with this mixture and seed treatment with Nagro fertilizer increased grain yield to 15.4 and 12.0 t/ha, respectively. The grain yield of PR38A24 hybrid obtained in this variant of the experiment was maximal.

The analysis of variance showed that over three years the average grain yield of two corn hybrids without fertilizers was 8.6 t/ha. Due to mineral fertilizers, the average grain yield for hybrids increased to 10.8 t/ha by 2.2 t/ha. The increase was significant, since there was more LSD by B factor (1.59 t/ha). Fertilizing plants with Bioplant Flora fertilizer of hybrids increased grain yield to 12.8 t/ha in average, with Nagro fertilizer – up to 12.2 t/ha and with a mixture (Crystalon + Brexil Zn + urea) – up to 12.6 t/ha.

The increase in yield due to fertilization in relation to the crop obtained only from mineral fertilizers was significant (more than LSD by B factor). The increase in grain yield due to fertilization with Nagro organic fertilizer amounted to 1.4 t/ha and was insignificant. Hybrid average grain yield
obtained from the combination N90P120K60 + fertilizing plants with a mixture (Crystalon + Brexil Zn + urea) + seed treatment with Bioplant Flora fertilizer was 13.3 t/ha, the difference with the yield obtained by applying mineral fertilizers was 2.5 t/ha and was significant.

Seed treatment with Nagro fertilizer also gave a significant increase of 2.9 t/ha. However, the differences between the yield obtained from seed treatment with Bioplant Flora and Nagro fertilizers were not significant. For PR38A24 hybrid in all years of observation, the use of organic Nagro fertilizer for seed treatment was more effective.

The productivity of PR38A24 hybrid was significantly higher compared to Beshtau hybrid. In average, over three years, the grain yield of PR38A24 hybrid for all experimental options was 13.0 t/ha, and Beshtau hybrid was 11.0 t/ha. The difference in yield exceeded LSD in A factor (0.85 t/ha), which confirmed the significance of the differences.

Mineral fertilizers and seed treatment with agrochemicals changed grain quality indicators (Table 3).

The starch content increased with the use of certain mineral fertilizers in the grains of PR38A24 hybrid by 6.64 %, and Beshtau hybrid by 10.39 %. The highest increase in starch content was provided by foliar fertilizers with Bioplant Flora and Nagro agrochemicals. Fertilizing plants with a mixture (Crystalon + Brexil + urea) increased the starch content in the grains to a lesser extent.

| Options, B factor | Hybrids, A factor | 2015 | 2016 | 2017 | Average | Increase t/ha | % |
|-------------------|------------------|------|------|------|---------|--------------|---|
| Without fertilizers (control) | PR38A24 | 8.9 | 9.5 | 8.4 | 8.9 | – | – |
| N90P120K60 (Background) | Beshtau | 8.5 | 8.5 | 7.6 | 8.2 | – | – |
| Beshtau | 11.3 | 12.3 | 10.8 | 11.4 | 2.5 | 28.9 |
| Background + Bioplant flora | PR38A24 | 12.9 | 15.2 | 13.4 | 13.8 | 4.2 | 48.8 |
| Beshtau | 10.8 | 12.6 | 11.7 | 11.7 | 3.3 | 40.1 |
| Background + Nagro | PR38A24 | 14.3 | 13.7 | 10.6 | 12.9 | 4.3 | 50.0 |
| Beshtau | 11.1 | 13.7 | 9.9 | 11.6 | 3.7 | 45.8 |
| Background + (Crystalon +Brexil Zn + urea) | PR38A24 | 14.7 | 14.8 | 12.1 | 13.9 | 5.7 | 69.0 |
| Beshtau | 11.2 | 11.2 | 11.7 | 11.4 | 2.5 | 28.0 |
| Background + (Crystalon +Brexil Zn + urea) + seed treatment with Bioplant Flora | PR38A24 | 14.9 | 15.5 | 12.9 | 14.4 | 5.4 | 61.8 |
| Beshtau | 11.7 | 12.3 | 12.4 | 12.1 | 3.9 | 47.4 |
| Background + (Crystalon +Brexil Zn + urea) + seed treatment with Nagro | PR38A24 | 15.2 | 16.5 | 14.6 | 15.4 | 5.9 | 66.4 |
| Beshtau | 12.7 | 12.3 | 11.1 | 12.0 | 4.1 | 51.9 |
| LSD0.05 for A factor (t/ha) | 0.13 | 0.18 | 0.18 | 0.21 | 0.85 | 2.7 |
| LSD0.05 for B factor (t/ha) | 0.25 | 0.34 | 0.34 | 0.34 | 1.59 | 2.7 |
| Experiment accuracy, % | 1.04 | 1.30 | 1.64 | 1.47 | 4.17 | 1.7 |

The availability of protein grain PR38A24 hybrid increased to a greater extent due to the use of mineral fertilizers (by 0.47 %). Fertilization led to the decrease in protein content. In the grains of Beshtau hybrid, the maximum protein content (12.28 %) was provided by the combination of mineral fertilizers with Bioplant Flora.

The fat content slightly changed; in the grain of PR38A24 hybrid, its amount varied from 5.02 to 5.74 %, and the largest one was in the control variant. In the grain of Beshtau hybrid, the fat content was higher (5.45–5.80 %).

Mineral fertilizers and agrochemicals increased the content of macronutrients. The highest nitrogen content in the grains of two hybrids was observed when using only mineral fertilizers and in the combination with Bioplant Flora. The phosphorus content changed insignificantly, varying in the grains of PR38A24 hybrid from 0.32 to 0.41 %, Beshtau hybrid – from 0.30 to 0.36 %. The potassium content in the grains of both hybrids increased most significantly with the use of mineral fertilizers and with Nagro organic fertilizer.
### Table 3. Chemical composition of grain hybrides (in average for 2015–2016).

| Indicators, % | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 | Option 6 | Option 7 |
|---------------|----------|----------|----------|----------|----------|----------|----------|
| PR38A24       |          |          |          |          |          |          |          |
| Starch        | 62.72    | 69.36    | 77.28    | 77.17    | 73.04    | 73.94    | 73.24    |
| Protein       | 9.42     | 9.89     | 8.47     | 8.57     | 8.62     | 8.93     | 8.21     |
| Fat           | 5.74     | 4.73     | 5.54     | 5.47     | 5.50     | 5.02     | 4.95     |
| Ash           | 1.34     | 1.33     | 1.39     | 1.57     | 1.33     | 1.42     | 1.32     |
| N             | 1.50     | 1.58     | 1.66     | 1.37     | 1.38     | 1.43     | 1.31     |
| P₂O₅          | 0.41     | 0.37     | 0.37     | 0.32     | 0.40     | 0.39     | 0.41     |
| K₂O           | 2.42     | 1.61     | 2.32     | 3.70     | 1.21     | 1.76     | 1.56     |
| Beshtau       |          |          |          |          |          |          |          |
| Starch        | 62.63    | 73.02    | 72.08    | 74.97    | 65.91    | 67.6     | 64.69    |
| Protein       | 10.65    | 8.30     | 12.28    | 9.02     | 5.06     | 8.95     | 9.03     |
| Fat           | 5.59     | 5.45     | 5.46     | 5.46     | 5.80     | 5.67     | 5.59     |
| Ash           | 1.27     | 1.23     | 1.32     | 1.22     | 1.3      | 1.31     | 1.25     |
| N             | 1.70     | 1.33     | 1.96     | 1.44     | 1.63     | 1.43     | 1.44     |
| P₂O₅          | 0.31     | 0.31     | 0.32     | 0.30     | 0.33     | 0.36     | 0.32     |
| K₂O           | 1.96     | 1.45     | 1.41     | 2.05     | 1.99     | 3.34     | 1.99     |

Note: 1 – without fertilizer (control); 2 – n90p120k60 – background; 3 – background + top dressing bioplant flora; 4 – background + top dressing; 5 – background + top dressing (crystal + brexil + urea); 6 – background + top dressing (crystal + brexil + urea) + seed treatment bioplant flora; 7 – background + top dressing (crystal + brexil + urea) + seed treatment nagro.

### 4. Conclusion

1. Mineral fertilizers of N90P120K60 type and agrochemicals used for plant nutrition and seed treatment caused changes in the concentration of trace elements in corn grain, having an ambiguous effect on their content in the grains of PR38A24 and Beshtau hybrids. Despite the increase in the content of trace elements in grain, the changes were significantly lower than the maximum permissible concentrations (MPC).

2. The studied options for corn fertilizer systems significantly increased grain yield. Under irrigation conditions, the maximum grain yield of PR38A24 and Beshtau hybrids was provided by the introduction of N90P120K60 mineral fertilizers in combination with fertilizing the plants with a mixture of fertilizers (Crystallon + Brexil Zn + Carbamide) and pre-sowing seed treatment with Bioplant Flora organo-mineral fertilizer (14.4 and 12.1 t/ha), as well as Nagro organic fertilizer (15.4 and 12.0 t/ha).

3. Mineral fertilizers, plant nutrition, and seed treatment with agrochemicals changed the grain quality indicators. The content of starch increased with the use of certain mineral fertilizers at a dose of N90P120K60 in the grains of PR38A24 hybrid by 6.64%, and Beshtau hybrid – by 10.39%. The availability of grain protein of PR38A24 hybrid increased to a greater extent (up to 9.89%) due to the use of mineral fertilizers. In the grain of Beshtau hybrid, the maximum protein content (12.28%) was provided by the combination of mineral fertilizers with Bioplant Flora.

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