Influence of fertilizers on the productivity of tea plants in the conditions of the north-west Caucasus

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Abstract. The research is aimed at finding effective ways to regulate the functional state of tea plants under stress, increase in yield and its stability, preserving and improving the quality. Foliar spraying of the tea stimulated the active formation of Proline (135.1-179.2 mg/g, in the control – 122.6 mg/g) and ascorbic acid (177.8-226.5 mg/g, in the control – 131.4 mg/g) in the leaves, which indicates the inclusion of processes associated with the mechanism of nonspecific protection against stress. The optimal state of tea plants treated with fertilizers explains the more developed specific surface density of the leaf (1.44 mg/cm², in the control – 1.24 mg/cm²). The developed specific surface density of the leaf was ensuring the active operation of the leaf apparatus on the experimental variants, which is expressed in a higher productivity of the leaves (1.27-1.31 g/dm²), compared to the control plants. The highest yield (about 23.05 centner per ha) was observed in the variant with foliar treatments with rokogumin, in the variant with sodium humate (31.47 centner per ha), the yield exceeded the control (26.88 centner per ha) only in 2020, which may be due to the accumulative effect.

1. Introduction
Since 2017, the program for the restoration of the tea growing industry in the Krasnodar Territory has been launched, including the expansion of the area of culture in the tea-friendly northern territories. The study of the functional state of tea plants growing in the Republic of Adygea and the search for mechanisms of regulation of adaptive and productive potential are of great importance in this issue. However, in the Republic of Adygea, the intensification of the tea growing industry is possible only if conditions are created that meet the requirements of the culture, in which the genetically inherent potential of plants would be revealed [1,2]. Agroecological assessment of the natural resources of the region was allowed us to identify the main factors limiting the productivity of tea plants – low air temperatures in the winter and early spring periods, insufficient moisture supply in combination with
high temperatures and atmospheric drought in the summer months [3]. This is what causes the low yield of tea plantations in this region of 20±5 c/ha (with 80±10 c/ha in the Krasnodar Territory) [4]. However, the analysis of the quality characteristics of raw materials (tannin on average 29.7±2.4%, extractive substances – 37.6±9.7%) shows the undoubted prospects of its production in Adygea in comparison with the biochemical indicators of the tea sprouts in coastal zones (tannin about 26.4±1.9%, extractive substances-29.2±4.2%) [5].

According to the research of domestic and foreign scientists, increasing the immunity of plants, frost and drought resistance of crops is possible by using innovative forms of fertilizers, which are physiologically active substances [6-8].

Since tea belongs to food products, in particular, to beverages widely consumed by different age groups of the population, it is important to use eco-friendly technologies for cultivating tea plantations on plantations, which include the use of innovative forms of fertilizers based on humates, amino acids, etc., used in organic farming [6,8,9].

Impact studies of humic acids on agricultural crops, conducted by researchers in Russia and abroad, have shown good results of their impact on plant resistance and quality indicators [9-11]. Thus, rokohumin tests on cereals, potatoes and peppers revealed an increase in yield and sugar content. The use of the bombardier growth stimulator on an apple tree showed an increase in the number of ovaries, the length of the total growth, the number of apples on the tree [12,13]. When it was used on vegetable crops, an increase in the number and weight of fruits on the plant was observed, and when tested on grapes, an increase in the content of sugars, ascorbic acid, and dry matter was observed [14].

However, no such studies have been conducted on tea plants. So, conducting this study is important for the development of agrotechnical recommendations for the use of innovative forms of fertilizers in the cultivation of tea in the foothill zone of the Republic of Adygea. The main objective is to study the effectiveness of innovative forms of fertilizers on the physiological and biochemical processes that determine the productivity and resistance of tea plants to abiotic stressors.

The research is aimed at finding effective ways to regulate the functional state of tea plants under stress, ensuring an increase in yield and its stability in varying climatic conditions, preserving and improving the quality of products (ready-made tea).

2. Materials and methods

The research has been conducted since 2019 on the basis of the Adyghe branch of the Subtropical Scientific Centre. The objects of the study are tea plants of the Kimyn variety population, planted in 1969, growing on brown forest soils. We used complex fertilize (NPK 16:16:16), which applied annually with the addition of ammonium nitrate before the beginning of the growing season in April (N250, P100, K100 kg/ha d.v); in June, only ammonium nitrate was applied under the plants, according Methodological guidelines on the technology of tea cultivation in the subtropical zone of the Krasnodar Territory [15].

The following agrochemicals were used as innovative forms of fertilizers (calculated per ha): rocogumin (5 L/150 L of water); sodium humate (150 g/1000 L of water); bombardier (5 L/1000 L of water); consumption of working solutions – 50 L/ha. All the selected agrochemicals are humic acids with a complex of amino acids and mineral elements. Sodium humate – is a solution of sodium salts of humic acid, acts as a stimulator of plant development; produced in Russia. Rokohumin is a liquid complex of amino acids with the addition of humic, fulvic acids and trace elements, the composition is chemically neutral (pH 6.7-7.3); produced in Slovakia, tested in Russia. Bombardier – is a liquid complex of biostimulator (amino acids, polysaccharides) and biofertilizer (humus extract with the addition of basic macro- and microelements) of plant origin; produced in Spain, passed registration tests in Russia. Control – treatment of plants with water.

The size of the experimental plots is 8 m², the repetition of the experiment was three-fold, the placement of options is randomized. Foliar spraying was carried out at the beginning of the growing season after pruning of tea plants (the second decade of May); after the second wave of growth (the first decade of July); in the second decade of November in preparation for the winter dormancy period.
Laboratory tests were conducted quarterly, starting from March to November. Repeatability of laboratory tests-three times. The following modern and routine methods were used: the dry matter content in the leaves was determined by the weight method by drying at a temperature of 105 °C to a constant weight; the Proline (Pro) content in physiologically mature leaves was determined by the ninhydrin method with a spectrophotometric ending [16]; the content of ascorbic acid (AA) in physiologically mature leaves – by the iodometric method [17]; the productivity of the leaves is calculated by the Nichiporovich’s formula, taking into account the mass and area of the leaves at the beginning and end of the determination period [18]; the specific surface density of the sheet (SSD) - calculated by the Mokronosov’s method [19].

The analysis of the hydrothermal conditions of the current year was carried out according to the data www.accuweather.com [20]. One of the main factors affecting the growth processes of tea plants is the temperature regime and precipitation during the growing season. Observation of the weather conditions of the winter period of 2018-2019 and 2019-2020 showed that there were no low temperatures in the winter period that could lead to freezing of branches. On average, the winters were warm (from 1.7-4.3 °C) and snowless (about 54 mm of mixed snow and rain). The spring period is prolonged, cool (on average 11.7 °C), with moderate precipitation (63.0 mm). This led to a certain delay (from a week in 2019 to two in 2020) in the start of the tea growing season.

Statistical processing of the research results was carried out according to Dospekhov [21] using the statistical software package STATGRAPHICS Centurion XV and the mathematical software package MS Excel.

3. Results and discussion
The summer period of 2019 was characterized as dry (an average of 22.3 mm of precipitation) and hot (an average temperature of about 27.5 °C, according to long – term data-21.5 °C). The year 2020 was even more stressful, with high temperatures of up to 30.1 – 31.3 °C in July-August, with a prolonged absence of precipitation (about 2-2.5 months). This led to a slowdown in the growth of flushes from the second decade of June, which affected the yield of the plantation and the quality of the raw materials collected (there was a greater number of coarse sprouts). The autumn months were cool (on average from 21.9 °C in September 2019 to 5.07 °C in November 2020) and wet (21-80 mm of precipitation per month, with 71 mm according to long-term data). Thus, the winter period during the research period can be considered favorable for the tea culture, while the summer was marked by hydrothermal stress.

The accumulation of dry substances in the leaves is an indicator of the intensity of the main metabolic processes of the plant, and characterizes the intensity of plant growth [22]. The accumulation of dry matter in the leaves allows us to judge the conditions of growth and development. A decrease in the amount of dry matter is a symptom of a violation of the functional state of plants. Determination of the dry matter content showed (table 1) that the greatest synthesis of assimilants is carried out in plants when treated with such humic fertilizers as sodium humate and rocohumin.

| Options          | Increase in dry matter (% of the initial value) | Ascorbic acid (mg/g of the raw mass) | Proline (mg/g of the raw mass) | Tannin (%) |
|------------------|-------------------------------------------------|-------------------------------------|-------------------------------|------------|
| Control          | 20.3±0.35                                       | 131.4±23.0                          | 122.6±15.6                    | 32.46±1.23 |
| Sodium humate    | 27.2±0.51*                                      | 226.5±30.1*                         | 179.2±11.4*                   | 36.62±2.11*|
| Rokogumin        | 26.1±0.50*                                      | 183.2±17.5*                         | 135.1±17.5*                   | 34.42±2.82*|
| Bombardier       | 23.1±0.26*                                      | 177.8±19.0*                         | 138.7±16.4*                   | 34.54±2.16*|
| LSD** (p ≤0.05)  | 2.3                                             | 10.2                                | 12.7                          | 2.15       |

*The differences are significant and reliable, **least significant difference.
It is known that the content of AA in the leaves is a manifestation of non-enzymatic components of the antioxidant system [23], moreover, under stress conditions, a decrease in AA occurs [24]. Also, we found that when processing innovative forms of fertilizers in tea leaves, an active significant (LSD (p \leq 0.05)=10) occurs. Ascorbic acid growth (table 1). An increase in the concentration of this metabolite indicates the activity of redox processes in the leaves of these variants under stress.

An increase in the proline content in plants is a common physiological response to any adverse effects. The result of the stress effect is the formation of reactive oxygen species (ROS), for the neutralization of which plants use low-molecular compounds (including proline) [25-27]. In our experience, the treatment of tea plants with innovative forms of fertilizers led to a more active formation of Pro in the leaves (table 1). This characterizes the active processes associated with the activation of non-specific defense mechanisms, and modifies not only the proline content in the cell, but also the functioning of antioxidant enzymes. Moreover, treatment with sodium humate caused a significant (LSD (p \leq 0.05)=12.7) increase in Pro synthesis in the leaves.

Many studies point to the relationship between the adaptive potential of plants and the content of tannins in the leaves [28-30].

We have shown that non-root treatment with innovative forms of fertilizers (especially with sodium humate and bombardier (LSD (p \leq 0.05)=2.15) leads to the activation of tannin synthesis (table 1), which is a manifestation of the mechanism of stability under the action of hydrothermal stress. Morphophysiological indicators of photosynthetic activity are important for assessing the adaptive and productive capacity of plants, including in non-root treatments with agrochemicals. For example, the specific surface density of the leaf is directly related to ensuring the active work of the leaves and is an integral indicator of the content of structural and functional elements of the mesostructure of the leaf. In its turn, the size of the assimilation apparatus and the time of its operation make it possible to calculate the productivity of the assimilation organs, the so-called productivity of the leaves [31,32]. The developed specific surface density (SSD) (1.39-1.44 mg/cm² at 1.24 mg/cm² in the control) ensures the active work of the leaves and causes greater productivity of their work on the variants with sodium humate and bombardier treatment (1.27-1.31 g/dm²) compared to the control plants (1.23 g/dm²); the differences with the control are significant (table 2). The formation of SSD and the productivity of the leaves are directly related to the anatomical parameters of the leaf, such as its thickness and area. We have shown that the treatment of plants with sodium humate and rokogumin led to the stimulation of these biometric indicators (table 2). In these variants, there was an increase in the area of the sheet and an increase in its thickness (LSD (p \leq 0.05)=0.10-0.94, respectively).

Table 2. Anatomical and morphophysiological parameters of leaves when treated with innovative forms of fertilizers, (M±m).

| Options       | Leaf thickness, mg/m² | Leaf area, cm² | Specific surface density, mg/cm² | Leaf’s productivity, g/dm² |
|---------------|------------------------|----------------|----------------------------------|---------------------------|
| Control       | 0.67±0.085             | 27.35±8.903    | 1.24±0.150                      | 1.23±0.081                |
| Sodium humate | 0.84±0.051*            | 29.76±6.289*   | 1.44±0.200*                     | 1.30±0.042*               |
| Rokogumin     | 0.77±0.022             | 28.32±8.915    | 1.39±0.125*                     | 1.27±0.050                |
| Bombardier    | 0.78±0.066             | 27.04±5.121    | 1.40±0.109*                     | 1.31±0.130*               |
| LSD (p≤0.05)  | 0.10                   | 0.94           | 0.06                            | 0.05                      |

*The differences are significant and reliable.

The integral indicator of the state of plants is its productivity. We have noted that non-root treatments with innovative forms of fertilizers, improving the functional state of plants, activate production processes (figure 1).
Moreover, in the first year of using agrochemicals (2019), there was a slight increase in the crop productivity of the experimental plantation on the variants with rocogumin and bombardier treatment (25.32-24.78 centner per ha, on the control-22.64 centner per ha). In the second year of research (2020), a cumulative effect was observed, which led to a significant increase in crop productivity on all variants using innovative forms of fertilizers (LSD (p=0.05)=2.20).

4. Conclusion

Thus, the use of innovative forms of fertilizers can be an effective way to increase the yield of tea, especially in stressful conditions, providing an increase in crop yields.

There was an increase in the synthesis of non-enzymatic components of the antioxidant system in the leaves: ascorbic acid to 177.8-226.5 mg/g of the raw mass (on the control – 131.4±23.0 mg/g of the raw mass); proline, in frequency when treated with sodium humate (179.2 mg/g of the raw mass, on control-122.6 mg/g of the raw mass) and tannins, especially-sodium humate and bombardier, LSD (p ≤0.05)=2.15.

It is shown that the treatment of plants with sodium humate and rocogumin led to the stimulation of the leaf thickness and area (LSD (p ≤0.05)=0.10-0.94, respectively), as well as morphophysiological indicators of photosynthetic activity: the specific surface density of the leaf (1.39-1.44 mg/cm² at 1.24 mg/cm² in the control) and the productivity of their work (when treated with sodium humate and bombardier – 1.27-1.31 g/dm² compared to the control plants – 1.23 g/dm²).

Non-root treatments with innovative forms of fertilizers, improving the functional state of plants, activate production processes.

Acknowledgments

The publication was prepared as part of the implementation of the state task of the Federal Research Centre the Subtropical Scientific Centre of the Russian Academy of Sciences No 0492-2021-0007

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