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Original article

EVALUATION OF THE CONTENT OF MACRO- AND MICROELEMENTS IN THE LEAVES OF GARDEN STRAWBERRY (*FRAGARIA ANANASSA* DUCH.) UNDER DIFFERENT MINERAL NUTRITION SYSTEMS

A.D. Kotelnikova, M.A. Shishkin, I.M. Bamatov

The use of mineral fertilizers is a necessary practice that contributes to realizing the yield potential of crops. However, the efficiency of nutrient utilization by plants remains low, which can lead to non-productive losses and negative environmental consequences. One of the possible solutions is the use of fertilizers of prolonged action, including modern Russian developments in the field of polymer-modified fertilizers (PMFs). In this work we evaluated the changes in the content of a number of elements (Ca, P, K, Mg, Cu, Zn, Mn, Fe) in the leaves of strawberry (Fragaria ananassa Duch.) cultivars Elizaveta-2, Profusion, Irma under the conditions of different nutrition systems – without fertilizers, with the application of traditional mineral fertilizers, the author's system with the use of PMF (with a polymer content of 5% and 10%) and with the use of a foreign analog of PMF. Strawberry plants were grown under greenhouse conditions, and leaf samples were taken at three vegetative stages – the stage of formation of white fruits, the stage of beginning of fruit ripening, and the stage of ripe fruits. Elemental analysis of the leaves was performed by inductively coupled plasma optical emission spectrometry (ICP-OES). Differences between strawberry cultivars and between nutrition systems for plants of the same cultivar were found. At the same time, according to the results of the evaluation of the changes in the content of a number of macro- and microelements in the leaves of strawberry plants at different stages of vegetation under different nutrition systems, no striking regularities were observed that would be characteristic of each variety used in the experiment. However, the increase in the content of Ca, Mg, Cu and Fe observed in a number of cases when using the author's nutrition system may indicate the improvement in the conditions for the uptake of these nutritional elements when using PMF.

Keywords: *elemental composition; slowly soluble fertilizers; polymer-modified fertilizers; optical-emission spectrometry*

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Научная статья

ОЦЕНКА СОДЕРЖАНИЯ МАКРО- И МИКРОЭЛЕМЕНТОВ В ЛИСТЬЯХ ЗЕМЛЯНИКИ САДОВОЙ (*FRAGARIA ANANASSA* DUCH.) ПРИ РАЗНЫХ СИСТЕМАХ МИНЕРАЛЬНОГО ПИТАНИЯ

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Применение минеральных удобрений – необходимая практика, способствующая реализации потенциальной урожайности сортов. Однако, эффективность использования элементов питания растениями остается низкой, что может приводить к непроизводственным потерям и негативным экологическим последствиям. Одним из возможных решений – использование удобрений пролонгированного действия, в том числе современных отечественных разработок в области полимер-модифицированных удобрений (ПМУ). В работе проведена оценка изменений содержания ряда элементов (Ca, P, K, Mg, Cu, Zn, Mn, Fe) в листьях земляники садовой (Fragaria ananassa Duch.) сортов Елизавета-2, Профьюжен, Ирма в условиях различных систем питания – без внесения удобрений, с внесением традиционных минеральных удобрений, авторской системы с применением ПМУ (с содержанием полимера 5% и 10%) и с применением зарубежного аналога ПМУ. В условиях закрытого грунта выращивали растения земляники, отбирали образцы листьев на трех стадиях вегетации – стадия сформировавшихся плодов белого цвета, стадия начала созревания плодов, стадия созревших плодов. Элементный анализ листьев проводился методом оптико-эмиссионной спектрометрии с индуктивно-связанной плазмой (ИСП-ОЭС). Выделены различия как между сортами земляники, так и между системами питания для растений одного сорта. При *этом по результатам оценки изменений содержания ряда макро- и микроэлементов в листьях растений земляники на разных стадиях вегетации при разных системах питания не отмечено ярких закономерностей, которые были бы характерны для каждого сорта, использованного в эксперименте. Однако, отмеченное в ряде случаев увеличение содержания Ca, Mg, Cu и Fe при использовании авторской системы питания может свидетельствовать об улучшении условий для поступления данных элементов питания при использовании ПМУ.*

Ключевые слова: *элементный состав; минеральные удобрения пролонгированного действия; полимер-модифицированные удобрения; оптико-эмиссионная спектрометрия*

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Introduction

Garden strawberry (*Fragaria ananassa* Duch.) is the most popular berry crop in the world, which is of great economic importance [7; 20]. During the ripening process, strawberry fruits accumulate various biologically valuable substances, the accumulation of which can be influenced by the mineral nutrition of the plants [19]. Balanced mineral nutrition of plants is one of the key factors in realizing the yield potential of varieties and obtaining products of appropriate quality [8].

Deficiency of essential and nutrient elements can lead to significant disturbances in plant growth and development. Moreover, the predominant accumulation of elements in organs other than fruits does not mean that these elements do not play an important role in fruit formation. For example, Ca, which is mainly found in plant organs other than fruits, is thought to affect the firmness of strawberry fruits [18]. It has been shown that the leaves of strawberry plants with misshapen fruits have Ca, Mg, Zn and Cu contents below normal levels [10]. Deficiency of these elements was observed in malformed strawberry fruits, which also affected the reduction of fruit quality parameters – vitamin C content and total anthocyanin content [10]. At the same time, the elemental composition of leaves of strawberries is not only important for yield formation, but also has an independent significance, since leaves can be used as medical raw materials [5]. Essential trace elements also contribute to the formation of biologically active substances in plant organs, their deficiency can reduce the quality of the yield [4].

Mineral fertilizers, which are the main element of the technology of intensive cultivation of agricultural crops, are most often used to improve the availability of nutrient elements in soils [16]. However, despite significant advances in the development of various modern fertilizer application systems, the efficiency of nutrient use remains low [21]. This can be a limiting factor in increasing strawberry production, with negative economic and environmental consequences [20]. Extended-release fertilizers, such as polymer-modified fertilizers (PMFs), can be considered as a possible solution [9; 17]. Slow release of nutrients can help match the nutrient supply in the soil with the nutrient needs of plants at each stage of development and maintain nutrient availability in the soil [22]. In addition, the gradual dissolution of fertilizers can reduce the negative effects of salts on plants, which is particularly relevant for the cultivation of strawberries, this crop is sensitive to the salt content in the substrate [6; 20].

The aim of this work was to assess changes in the content of a number of macro and microelements in the leaves of garden strawberries of three remontant cultivars (Elizaveta-2, Profusion, Irma) under conditions of different nutrient systems – without fertilizers, with the application of traditional mineral fertilizers (Azofoska 16:16:16 and monoammonium phosphate), author’s system (polymer-modified Azofoska16:16:16 and polymer-modified monoammonium phosphate) and with application of foreign analog Osmocote Pro.

Materials and methods

The experiment was conducted in the greenhouse complex of “Scientific and Production Company “Sady Chechnya”” (limited liability company) in the city of Kurchaloy, Chechen Republic, Russia. Strawberries were planted on March 30, 2023 in wooden trays using a drip irrigation system. For growing strawberries in trays, beds were formed by filling soil that was sampled nearby and characterized as southern chernozem. The soil had the following agrochemical characteristics: pH of water extract – 8.3±0.1, content of organic carbon – 4.0±0.4 %, content of mobile forms of phosphorus – 202±14 mg/kg, content of mobile forms of potassium – 54±17 mg/kg (the characteristics were determined by standardized methods [1, 2, 3], the mean and standard deviation for three replicates are given).

Within the framework of the experiment, 5 different nutrition systems for strawberry were used: control group (without fertilizer, K), traditional system (T), foreign analog of prolonged fertilizer (Osmocote Pro, A), and two author’s nutrition systems with different degree of polymer modification – F5% and F10%. The author's feeding systems, designated as "F5%" and "F10%", were tablet forms of polymer-modified Azofoska and monoammonium phosphate (MAP). The traditional nutrition system used 2 tablets of Azofoska and 1 tablet of MAP per 4 plants. The author's nutrition system included the same fertilizers, but with polymer modification to reduce their solubility and prolong the release of mineral substances into the soil. The polymer content in them was 5% and 10% by weight, respectively, designed for 3 and 6 months of prolonged action of fertilizers. The technology of obtaining these PMFs in different concentrations was previously described [9].

The total amount of active ingredient in the three fertilizer tablets for each nutritional system was the same and amounted to 8.4 g per 4 plants, which was equivalent to 2.1 g per plant. Each Azofoska tablet contained NPK macronutrients in equal proportions, reaching 0.8 g of active ingredient, while the MAP tablet contained 0.6 g of nitrogen and 3 g of phosphorus (P_2O_5). The dosage of fertilizers per plant was calculated on the basis of practical experience in the region and recommendations of the Ministry of Agriculture of Russia, and was 80-85 kg of active ingredient per hectare when planting 35-40 thousand plants per hectare in field conditions. This corresponds to an average of 2.1 g of active ingredient per plant. The fertilizer tablets were applied to the soil on April 6, 2023. The fertilizer tablets were placed in the center of a square, with 4 strawberry plants at the top of the square.

In each group of the experiment there were grown three strawberry cultivars which are in demand in the southern regions of Russia – Elizaveta-2, Profusion, Irma. Selection of different strawberry cultivars was carried out taking into account practical considerations, such as reduction of risks of yield loss, selection of the most productive cultivar, as well as exclusion of possible specific influence of a particular cultivar on the results of using prolonged type of nutrition. There were 45 such beds, three (3 replications) for each of the three cultivars and five nutrition systems.

Leaf samples of strawberry plants were taken at three stages of vegetation: sampling 1 – stage of formed fruit of white color, sampling 2 – stage of the beginning of fruit ripening, fruit of pink color/half of fruit is colored, sampling 3 – stage of ripe fruit. Fully expanded leaves were taken from the center of the bush, without petioles, and washed with distilled water. Samples were dried in a ventilated desiccator at 60°C for 48 hours. Dried leaves were pulverized and digested with nitric acid (HNO_3) using the ETHOS EASY microwave sample digestion system (Milestone, Italy). Elemental analysis of the obtained solutions was performed by inductively coupled plasma optical emission spectrometry (ICP-OES) (5800 ICP-OES, Agilent Technologies, USA). The concentrations of a number of elements in the samples were measured: Ca, P, K, Mg, Cu, Zn, Mn, Fe, Co.

Statistical analysis. The results of the study were processed by nonparametric statistical methods using STATISTICA 10.0 and the R programming language in the R Studio environment. The calculated mean concentration values (M) for each group of samples and standard deviation (±SD) are presented in the text and on the graphs. Differences were considered statistically significant at $p<0.05$ for all tests. The Kraskell-Wallis criterion was used to determine whether there were differences between groups [15]. If the test showed statistically significant differences between groups, the Gao test was used for multiple comparisons between groups [11].

Results and discussion

The analysis of the samples made it possible to estimate the content of a number of macro- and microelements in the leaves of plants of three strawberry cultivars when mineral fertilizers were applied (except for Co, the concentration of which was below the detection limit in all the samples studied <0.1 mg/kg). The assessment was made for samples of fruit-bearing plants, since it is noted that at these stages of development the most active accumulation of elements by strawberry plant organs occurs [18]. The analysis of the elemental composition of leaves is preferable to the analysis of petioles [14].

When developing new feeding systems and evaluating the performance of existing ones, differences between cultivars should be considered, and the nutritional system should ideally be tailored to the needs of a particular cultivar or group of cultivars with similar needs [18]. Differences in assimilation and transport of mineral nutritional elements and their requirements for different strawberry cultivars can be genetically determined, which affects the content of nutritional elements in the tissues of strawberry plants [13]. Statistically significant differences between plant samples of different cultivars under the same nutritional system were observed in several cases: in group A, sampling 3, Mg content in leaves of plants of cultivar Profusion (4.6±0.3 mg/kg) was significantly higher than in leaves of plants of cultivar Elizaveta (3.3±0. 2 mg/kg); in experimental group F5%, sampling 2, Cu content in leaves of plants of cultivar Irma (5.2±1.2 mg/kg) was significantly higher than in leaves of plants of cultivar Profusion (4.8±0.2 mg/kg); in experimental group T, sampling 1, Fe content in leaves of plants of cultivar Profusion (0.15±0.01 mg/g) was significantly higher than in leaves of plants of cultivar Elizaveta (0.08±0.01 mg/g).

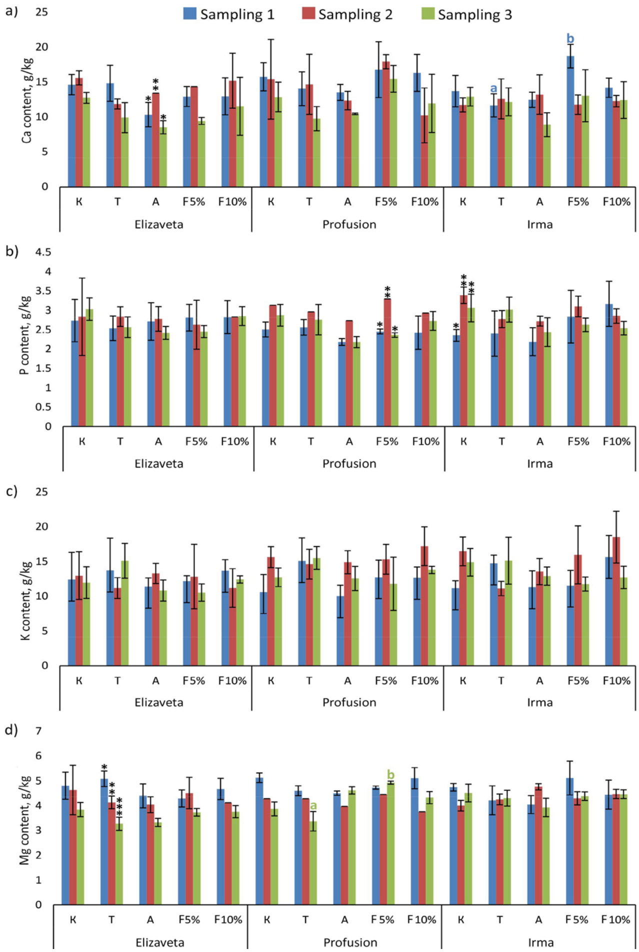

Fig. 1. Content of macronutrients – Ca (a), P (b), K (c), Mg (d) – in leaves of garden strawberry (*Fragaria ananassa* Duch.) plants under cultivation with different fertilizer systems: K – control without fertilizer application, T – traditional system, A – Osmocote Pro, F5% and F10% – author's nutrition systems with different degree of polymer modification (n=3, M±SD). Statistically significant differences for samples of the same cultivar according to the Gao test (p<0.05): different letters indicate statistically significantly different groups of the same sampling time and different nutrition systems, different numbers * indicate statistically significantly different groups of the same nutrition system and different sampling times (for groups of samples of the same cultivar).

There are a number of differences in the content of macronutrients between samples of the same plant cultivar and sampling time under different nutrition systems. Thus, for samples of plants of Irma cultivar, sampling 1, Ca content is significantly higher in the F5% experimental group (18.7±1.7 mg/g) compared to the T group (11.7±1.7 mg/g). For plants of Profusion cultivar, sampling 3, leave Mg content was significantly higher in the F5% group (4.9±0.4 mg/g) than in the T group (3.4±0.3 mg/g). No statistically significant differences in P and K content in leaves of plants under different nutrition systems were observed.

Micronutrients (Cu, Mn, Zn, Fe) are necessary for the normal course of many biochemical processes in plants, especially for the functioning of enzymes, which makes the assessment of their content an important task [12]. Differences in Cu content in leaves were observed in samples taken at the beginning of fruit ripening: in cultivar Elizaveta the content was significantly higher in group T (6.4±0.4 mg/kg) compared to F10% (5.5±0.8 mg/kg), in cultivar Irma the content was significantly higher in group F5% (6.1±0.3 mg/kg) compared to group A (4.4±0.4 mg/kg). At the stage of fruit formation the content of Fe in leaves differed: for samples of Elizaveta cultivar the content was significantly higher in the F10% (0.23±0.11 mg/g) compared to the T group (0.08±0.01 mg/g), in samples of Profusion cultivar the content was significantly higher in groups K (0.13±0.01 mg/g) and T (0.15±0.01 mg/g) than in group A (0.08±0.01 mg/g). Mn and Zn contents in leaves of plants of the same cultivar and time of sampling did not differ significantly when comparing different groups of the experiment.

Changes in elemental content of strawberry leaves during the growing season can also be observed. It is difficult to find consistent trends for different cultivars and fertilization systems, but there are a number of significant differences. Thus, at the stage of fruit ripening of Elizaveta cultivar in group A (13.4±0.1 mg/g) Ca content in leaves was statistically significantly higher than at the stage of white fruit formation (10.3±1.7 mg/g) and at the stage of ripe fruit (8.5±0.9 mg/g). This pattern is characteristic for the cultivar Elizaveta and under other nutrition systems, and in general, a decrease in Ca content in leaves of strawberry plants of all cultivars studied can be observed up to the ripe fruit stage. In plants of the Profusion cultivar, an increase in the leaves P content was observed at the stage of the beginning of fruit ripening (sampling 2), when all the nutritional systems studied were used. This change is statistically significant in the F5% group (P content at sampling 2 – 3.3±0.1 mg/g, at sampling 1 – 2.5±0.1 mg/g, at sampling 3 – 2.4±0.1 mg/g).

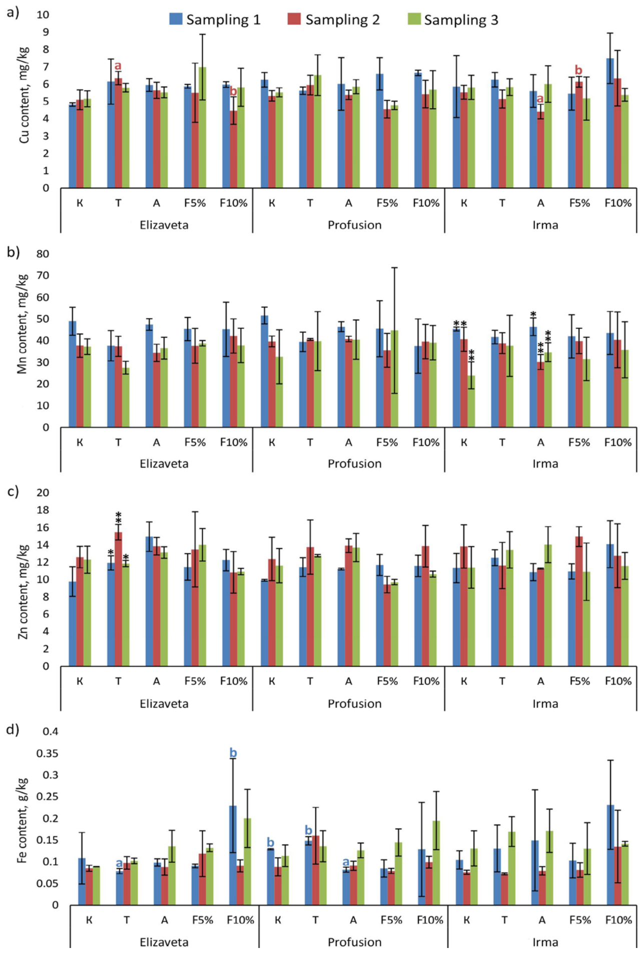

Fig. 2. Content of micronutrients – Cu (a), Mn (b), Zn (c), Fe (d) – in leaves of garden strawberry (*Fragaria ananassa* Duch.) plants under cultivation with different fertilizer systems: K – control without fertilizer application, T – traditional system, A – Osmocote Pro, F5% and F10% – author's nutrition systems with different degree of polymer modification (n=3, M±SD). Statistically significant differences for samples of the same cultivar according to the Gao test ($p<0.05$): different letters indicate statistically significantly different groups of the same sampling time and different nutrition systems, different numbers * indicate statistically significantly different groups of the same nutrition system and different sampling times (for groups of samples of the same cultivar).

A similar pattern was observed for Zn in some groups of experiments, with statistically significant differences in group T of cultivar Elizaveta (Zn content in sampling 2 – 15.5±0.9 mg/g, in sampling 1 –11.9±0.8 mg/g, in sampling 3 – 11.9±0.4 mg/g). For Mg in a number of cases there was a decrease in content in later stages of vegetation, the most pronounced in plants of Elizaveta cultivar. Thus, for this cultivar, the differences in group T were statistically significant for all three sampling periods (5.1±0.7, 4.1±0.3, 3.3±0.3 mg/g for samples 1, 2 and 3, respectively). The content of Mn in strawberry leaves also decreased in many experimental groups during the vegetation period, and the differences were statistically significant in groups K and A of Irma cultivar. The results obtained may indicate different needs of strawberry plants in macro- and microelements at different stages of development. Namely, an increase in the consumption of Ca, P and Zn at the stage of fruit ripening and a decrease in the consumption of Mg and Mn. Such data can be taken into account in the development of new systems of mineral nutrition of strawberry plants, which can be created according to the needs of plants at different stages of development.

Conclusion

Thus, according to the results of the evaluation of the changes in the content of a number of macro- and microelements in the leaves of strawberry plants at different stages of vegetation under different nutrition systems, no striking regularities were observed that would be characteristic of each cultivar used in the experiment. However, the increase in the content of Ca, Mg, Cu and Fe observed in a number of cases when the author's nutritional system was used may indicate improved conditions for the uptake of these nutritional elements when PMFs is used. Changes in the content of elements in leaves not directly added to the soil with fertilizers could be due to antagonistic or synergistic interactions of elements with each other. The more gradual release of nutrient elements from PMF could result in a more favorable ratio of elements in the soil at certain stages of vegetation than the application of other fertilizer systems. The observed regularities require additional research to confirm or refute them during further vegetation of the plants.

Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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