Influence of Mineral Nutrition Elements on Photosynthetic Processes Occurring in Plants and Productivity of Tomatoes in the Volga Delta Conditions

Lydia P. IONOVA

Ph.D. (in Agricultural Sciences)

Professor

Faculty of Agribusiness, Technologies, and Veterinary Medicine

Department of Agricultural Technologies, Engineering, and Agribusiness

Astrakhan State University

20a, Tatishchev Str., Astrakhan, 414000, Russia

Zhanna A. VILKOVA

Ph.D. (in Agricultural Sciences)

Assistant Professor

Faculty of Agribusiness, Technologies, and Veterinary Medicine

Department of Agricultural Technologies, Engineering, and Agribusiness

Astrakhan State University

20a, Tatishchev Str., Astrakhan, 414000, Russia

Rumia A. ARSLANOVA

Ph.D. (in Agricultural Sciences)

Assistant Professor

Faculty of Agribusiness, Technologies, and Veterinary Medicine

Department of Agricultural Technologies, Engineering, and Agribusiness

Astrakhan State University

20a, Tatishchev Str., Astrakhan, 414000, Russia

Anna S. BABAKOVA

Ph.D. (in Agricultural Sciences)

Assistant Professor

Faculty of Agribusiness, Technologies, and Veterinary Medicine

Department of Agricultural Technologies, Engineering, and Agribusiness

Astrakhan State University

20a, Tatishchev Str., Astrakhan, 414000, Russia

Michael Y. ANISHKO

Ph.D. (in Agricultural Sciences)

Faculty of Agribusiness, Technologies, and Veterinary Medicine

Department of Agricultural Technologies, Engineering, and Agribusiness

Astrakhan State University

20a, Tatishchev Str., Astrakhan, 414000, Russia

Abstract

Mineral fertilizers play an important role in increasing the productivity and yield of tomato plants in the conditions of irrigation. This article presents data on the study of various combinations of mineral elements ($N_{90}P_{80}K_{45}$ kg/ha), and their influence on photosynthetic processes occurring in plants, and tomato productivity in conditions of the Volga Delta on alluvial- meadow heavy loamy weakly saline alkali soils of the Astrakhan region.

Studies have shown that with the correct application of mineral fertilizers, it is possible to positively influence the flow of such an important physiological process in the plant as photosynthesis, contributing to an increase in organic matter and increasing the productivity of tomato plants in the conditions of irrigation.

For the formation of the assimilation apparatus of tomatoes, the most effective was the introduction of nitrogen fertilizers. The use of potash and phosphorous fertilizers in a paired combination restrained the growth of the leaf surface of plants.

Nitrogen and phosphorus fertilizers had approximately the same effect on the increase in daily increments of plant organic matter and the accumulation of fruit dry matter, which increased the biological yield of tomatoes by 35% compared to the control (without fertilizers). The exclusion of nitrogen or phosphorus from the composition of fertilizers led to a decrease in the yield increase. The use of potash fertilizers did not significantly affect the photosynthetic activity of plants.

Keywords: mineral fertilizers; tomato; photosynthetic processes; tomato yield; the Volga Delta.

Introduction

In the Astrakhan region, tomato is the leading vegetable crop and it covers 72.9% of the sown area. The main direction in increasing the productivity of vegetable crops, including tomatoes, is the improvement of agrotechnical methods contributing to the increase in photosynthetic activity of crops and yields. One of the main reserves for obtaining high yields of this crop is the development of a rational diet during the vegetation period.

Therefore, increasing their yields and product quality remains a pressing issue. It is known that photosynthesis plays a role in forming the harvest. As a result of photosynthesis, 90-95% of organic matter is formed in the plant, and the increase of photosynthetic process is an obligatory condition for high yields. The main factor that increases the photosynthetic activity of plants is the presence of nutrients in the soil, provided by the application of mineral fertilizers. Therefore, the development of a rational regime of mineral nutrition of plants with the selection of their combinations is of great importance in increasing the photosynthetic activity of crops and as a consequence, yield. Tomato requires at least twelve nutrients, also called "essential elements", for normal growth and reproduction. These are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and molybdenum (Mo). Without these nutrients, tomato cannot grow properly or bear fruits. Because soil cannot supply adequate amounts of N, P, and K for optimum growth and production of tomato, these nutrients are added as amendments in the form of manures and fertilizers to the soil. The method and timing of nutrient application from fertilization can also influence the growth and production of tomato and fertilizer-use efficiency (Bityutsky, 2015; Vasko, 2017; Vazhov, 2013; Ionova & Smashevskiy, 2019; Skillman et al., 2011; Laegreid et al., 1999; Sainju et al., 2000; Sainju et al., 2003; Viets, 1965; Winsor et al., 1967).

The purpose of the study is to study various combinations of mineral elements (NPK) and their influence on photosynthetic processes taking place in plants and productivity of tomatoes in the Volga Delta conditions on alluvial-meadow heavy loamy, weakly saline alkali soils of the Astrakhan region.

Methods

The object of the research was a variety of tomato Novichok pink, the most popular variety for growing in production conditions in the open field, which is characterized by friendly sprouts and ripening of fruits. From the moment the seedlings appear and until the formation of a full harvest usually takes 110-130 days. The bush is compact, low, which is due to the determinacy of the variety, the height of the plant reaches 80 cm, the first inflorescence is laid over 6-7 sheets, and all subsequent ones are formed after 1-2 sheets. On the average, 5-6 tomatoes appear on each brush, and there are practically no empty flowers. Fruits are oval-length, the average weight of the fruit is from 75 to 100 g, the fruit has both pink and saturated red coloring. The peel is strong and dense and does not allow the fruit to crack even after it has overripe. Soluble solids occupy about 4-6% of the fruit and are rich in lycopene. The variety is resistant to fungal and viral diseases and the tip of rot, as well as to overripe and mechanical damage, universal in purpose and has high taste and transportability.

Mineral elements (NPK) and their combinations are represented by the experience scheme: 1 - Control - without fertilizers; 2 - NP, 3 - NK, 4 - PK, 5 - NPK. Researches were carried out on a background of pair and triple combination between N90, P80, K45 kg/ha in various combinations (NP, NK, PK and NPK). Control, the plot was fertilizer-free. Ammonium nitrate, superphosphate and potassium salt were used as mineral fertilizers. The development of rational doses of fertilizers was based on the need of tomato plants for basic nutrients of this type of soil (Vasko, 2017; Zudilin et al., 2016).

Field experiments were carried out in the Volga region on alluvial meadow heavy loamy weakly saline soils, the humus horizon capacity of 35 cm contains 2-3% humus, hydrolyzable nitrogen in minimum quantity (in the layer 0-20 cm of absolutely dry soil - 41.7); 0-40 cm 37.0 mg/kg), mobile phosphorus (0-20-40 cm (72 56.1 mg/kg), exchange potassium (350 -282 mg/kg), ground water is 1.5-2 meters, PH is 6.9 – 7.4. The average long-term air temperature for the vegetation period is 22.50C, the sum of temperatures above +100C during the vegetation period is 3360 -33560C. Meteorological conditions during the research period were favorable.

Field studies were conducted using the generally accepted methodology of Dospekhov (Zudilin et al., 2016; Fundamentals of experimentation in crop husbandry, 2017). Agrotechnical methods of soil preparation, planting of seedlings and care of crops were conducted according to the generally accepted technology of tomato cultivation in the Astrakhan region. The background of mineral fertilization during the vegetation period corresponded to the scheme of experience. Top-dressing for the growing season was carried out three times: after disembarking seedlings in the soil and full establishment after two weeks spent the first fertilization in the phase 6-7 leaves, the second - in the phase of the beginning of mass flowering, the third - in the period of fruit formation, with simultaneous irrigation norm 450-500 m³/ha, after each dressing. In the experiments observations of plant growth and development, formation of the assimilation apparatus and its photosynthetic potential were made (Zudilin et al., 2016; Nikitin, 2017; Fundamentals of experimentation in crop husbandry, 2017; Smashevskiy, 2011).

Results

In the intensive assimilation of the main mineral elements of nutrition of tomato plants, regardless of the combination and background of nutrition observed the following pattern: increased growth of vegetative mass and assimilation surface in the first half of the growing period and before fruit formation. In the second half of the growing period from fruiting to growing and ripening of fruits there was a decrease in the growth of assimilation surface and, as a result, a decrease in photosynthetic activity. The data on studying the effect of different combinations of mineral

fertilizers on morphological features of tomatoes during the growing season are presented in the Table 1.

Table 1. Influence of different combinations of mineral fertilizers on morphological features of tomatoes during vegetation period (on average for 2018 -2019)

Variants of experiment	Plant height, cm	Amount of footstalk growth, %	Number of leaves, pcs.	Increase of leaf coverage, %	Number of trusses, pcs.
Control	62	-	30.2	-	4.8
N ₉₀ P ₈₀	65	4.8	36.2	19.9	7.2
N ₉₀ K ₄₅	72	16.1	34.3	13.6	6.0
P ₈₀ K ₄₅	79	27.4	32.4	7.3	5.7
N ₉₀ P ₈₀ K ₄₅	85	37.1	39.7	31.5	11.0

The analysis of the Table 1 shows that the growth of the assimilation surface and the percentage of foliage are the most effective for the triple combination of NPK and double NP. At a combination of NPK, where there was a lack of nitrogen as a growth element, the percentage of foliage was the lowest - 7.3%.

The leaf-area duration in sowing gives an objective idea of the nature of plant growth during vegetation. The data in Table 2 shows the growth and overall size of tomato plant leaf surface when applying NPK in various combinations.

Table 2. Leaf surface and photosynthetic potential of a tomato when NPK is applied in various combinations (on average for 2018 -2019)

Variants of experiment	Ultimate leaf-area duration, thous./m ²	Variation, %	Photosynthetic potential, mln .m ² / days	Variation, %
Control	16.7	-	0.853	-
N ₉₀ P ₈₀	19.4	16.2	1.053	23.4
N ₉₀ K ₄₅	18.9	13.2	0.989	15.9
P ₈₀ K ₄₅	15.6	-6.6	0.889	4.2
N ₉₀ P ₈₀ K ₄₅	20.2	20.9	1.101	29.1

Discussion

As studies have shown, under irrigation conditions for the formation of the assimilation apparatus of tomatoes, the most effective was the application of nitrogen fertilizers, which allowed increasing

the maximum area of leaves by 20.9% to control. The positive effect of phosphate and potassium fertilizers was shown only against the background of nitrogenous fertilizers. The use of these elements in paired combination (PK) inhibited the growth of tomato leaf area.

However, the leaf area indicator does not fully reflect the photosynthetic activity of crops. It is very important to know how long the leaf surface has been functioning for biomass accumulation, i.e. photosynthetic potential (Table 2). Application of mineral fertilizers for tomatoes in paired and triple combination and in doses of N90, P80, K45 kg/ha increased photosynthetic capacity of crops by 29.1% to control.

Application of fertilizers in various combinations has had a positive impact not only on the increase in leaf area and photosynthetic potential, but also in some periods of vegetation and in general during the season has slightly increased the productivity of photosynthesis (Figure 1, Table 3).

I – the first decade; II – the second decade; III – the third decade; Error bars show $\pm$ SD

Figure 1. Effect of mineral fertilizer elements on the productivity of photosynthesis of tomatoes (on average for 2018 -2019)

Table 3. Influence of mineral fertilizer elements on photosynthesis productivity and daily gain of tomato DMC (on average for 2018 -2019)

Variants of experiment	Net productive capacity of photosynthesis, g/m ² per day		Increase of DM, kg/ha	
	Mean season difference	Variation, %	Mean season difference	Variation, %
Control	7.8	-	87.9	-
N ₉₀ P ₈₀	8.8	13	116.8	33
N ₉₀ K ₄₅	8.4	8	104.3	19
P ₈₀ K ₄₅	8.0	3	97.1	11
N ₉₀ P ₈₀ K ₄₅	8.3	6	112.1	28

The highest rates of net photosynthesis productivity were observed during the period of intensive biomass formation of tomato plants, namely, in the first and second decades of July. Of all combinations, the most effective was nitrogen-phosphorus fertilization (N₉₀ P₈₀ kg/ha). Against this nutrition background, the net productivity of photosynthesis increased by 13% on average per vegetation compared to control (Table 3).

Along with the total size of the leaf surface, an important role in the formation of yield is played by the productivity of the leaves, i.e., the total amount of organic matter accumulated by plants per day per unit of leaf surface (Figure 2).

I – the first decade; II – the second decade; III – the third decade; Error bars show $\pm$ SD

Figure 2. Influence of mineral fertilizer elements on daily gain of tomato DMC (on average for 2018 -2019)

Studies have shown that better growth of leaf area in the variants with fertilizer and higher productivity of photosynthesis of plants provided an increase in daily growth of biomass dry matter in tomatoes. The largest daily increases in plant dry matter were observed when fertilizers were applied in paired combination of nitrogen and phosphorus (N₉₀ P₈₀ kg/ha), and the average for the season was 116.8 kg/ha, which was 33% higher than control. Triple application (N₉₀P₈₀K₄₅ kg/ha) was also found to be very effective. The difference in biomass dry matter growth was 28% in this option compared to the control. Potassium fertilizers did not have a significant positive impact on daily organic matter growth (Table 3, Figure 2).

There were the same data for productivity of tomatoes in making mineral fertilizers in different combinations (Table 4).

Table 4. Productivity of tomatoes in making mineral fertilizers in different combinations (on average for 2018 -2019)

Variants of experiment	Biological yield, t/ha			
	Wet weight	Increase of control, %	DM	Increase of control, %
Control	55.9	-	3.42	-
N ₉₀ P ₈₀	75.5	35	4.73	38
N ₉₀ K ₄₅	64.7	16	3.93	17
P ₈₀ K ₄₅	62.4	12	3.95	15
N ₉₀ P ₈₀ K ₄₅	73.7	32	4.70	37

Thus, the daily gain of tomato DMC and the accumulation of fruit DM, determined the value of the biological yield (Table 4).

Studies have shown that nitrogenous and phosphate fertilizers (in the case of common combination) increased the biological yield of tomatoes by 35% compared to control. Excluding nitrogen or phosphorus from the mineral diet reduced the yield increase.

Conclusion

Thus, the application of mineral fertilizers for tomatoes in paired and triple combination, and doses of N₉₀P₈₀K₄₅ kg/ha on alluvial-meadow heavy loamy soils of the Volga Delta helps to improve the food regime of plants, thereby contributing to the strengthening of photosynthetic activity of crops and increase tomato productivity. For the formation of the assimilating apparatus of tomato plants the most effective was the application of nitrogen fertilizers. Nitrogen is the most limiting nutrient for tomato growth and is required in large amount for optimum production because tomato removes large amount of N from the soil. Nitrogen is a constituent of protein and amino acids, without which vital functions in the growth and reproduction of plants would not be possible (Sainju et al., 2000; Sainju et al., 2003; Viets, 1965). In combination with phosphate fertilizers there

was an increase in daily growth of plant organic matter and accumulation of fruit dry matter, which increased the biological yield of tomatoes by 35% compared to control (without fertilizers). Phosphorus helps in the production of large number of blossoms in the early growth of tomatoes and early setting of fruits and seeds. As a result, it increases the number and production of tomato fruits, with increased total soluble solids and acidity contents (Laegreid et al., 1999; Sainju et al., 2003; Winsor et al., 1967). The exclusion of nitrogen or phosphorus from fertilizers led to a reduction in yield increase. The application of potash fertilizers did not have a significant impact on photosynthetic activity of plants.

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