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The effect of fertilization on the quantity and quality yield of some Romanian tomato cultivars grown in the greenhouse

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Abstract

The present paper studied the influence of mineral or organic fertilizers, applied together or separately, to soil or foliar administered in three applications between 51-89 BBCH, on the processes of flowering, growth, and fruiting of three cultivars of tomato grown in protected space at the National Institute of Research Development for Biotechnologies in Horticulture Stefanesti. The 2-year experiment was planned in a completely randomized block, with three replicates and four fertilization treatments (mineral soil fertilization, combined fertilization – soil and foliar Ca, combined soil fertilization and organic Biohumus applied foliar; v4- foliar fertilization). Significant, correlations were found in growth and fruiting processes, for all 4 fertilization methods (variants). In both years of the study, the combined fertilization of soil + foliar organic Biohumus induced an increase in SSC %, which attracted a higher MA %, while the combined fertilization of soil and Foliar Ca^{+} determined a higher percentage of fruit firmness, in both years of study. The highest productions were observed in the case of mineral fertilization combined with Biohumus organic foliar fertilization, with a production increase of 1.25 kg/plant compared to the application of foliar fertilization. Nitrates from fruits do not exceed the limits allowed for growing tomatoes in the greenhouse.

Keywords: *Solanum lycopersicum* L.; mineral elements, foliar fertilization, production, indicators of fruit quality

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops (Savić *et al.*, 2008) with an extensive distribution worldwide and a massive economic value (FAOSTAT, 2020). The yield and quality characteristics of tomato crops are, of course, affected by fertilization. Fertilization can be ensured by applying nutrients to both soil and foliage. Also, synthetic fertilizers can be administered, as well as organic or biofertilizer. As a rule, among the fertilizers with soil application, the synthetic ones ensure quickly the necessary mineral elements of the plants (they are easily accessible), but their use is correlated with the risk of leaching, being easily entrained by irrigation water or precipitation, therefore, nutrient removal by plant crops cannot be compensated if no fertilizer input is used (Chen, 2006). Bilalis *et al.* (2018) reported an increase in yield-related parameters with inorganic fertilization, while color, total soluble solids, and the ratio of total soluble solids to titratable acidity were significantly higher in tomatoes grown with organic or combined fertilization. Hernández *et al*. (2014) found that the combined application of organic and inorganic fertigations improved some soil biochemical parameters and resulted in tomato yield and fruit quality similar to the single inorganic fertigation control, suggesting that inorganic fertilizers can be reduced by about 40% For more sustainable agriculture, numerous researchers have studied the synergistic effects of applying organic fertilizers, combined with inorganic fertilizer (Bilalis *et al.*, 2018; Murmu *et al.*, 2013; Hallmann *et al.*, 2012; Polat *et. al*., 2010; Riahi *et. al,* 2009; Barrett *et al.*, 2007), on the main chemical-physical properties of the soil and the yield and quality parameters of a tomato cultivar. Considering that fertilizers—and, in particular, nitrogen (N)—represent the highest input cost for many crops since their production is energy intensive (Rothstein *et. al*., 2007) high-input farming systems are no longer sustainable, both from an environmental and energy cost perspective. This work aimed to study the synergistic effects of applying the combination of inorganic fertilization based on precision agriculture with organic or inorganic foliar fertilizers, on the main nutritional properties of tomato fruits and the yield and qualitative parameters of the crop, from a perspective of sustainable agriculture.

MATERIALS AND METHODS

In the experimental plot, the tomato culture in protected spaces (250 m^2 greenhouse) was established in the spring of 2020, respectively 2021, between March 27-30, the planting distance being 0.4 x 0.70 m, resulting in a density of 33,500 plants/ha. The irrigation system consists of 16 mm diameter tubes with drippers arranged at 40 cm and with a flow rate of 1.2 l/hour. Throughout the growing season, water was easily accessible to the plants through two daily waterings (a watering rate of 2.4 l/day of water). The experiment was arranged according to the block method, in three replicates according to the following scheme:

A Factor –Tomato cultivars: 'Stefanesti 22', 'Stefanesti 24', and 'Costate 21' and, B factor – Method of the fertilizers applying: b_1- soil fertigation, b_2- fertilizer combinate (soil and Ca^+ foliar fertilization, b_3- combined fertilization (soil and Biohumus foliar fertilization and b4- foliar fertilization). During the vegetation period, the following doses and forms of mineral fertilizers were applied to the soil, in the experimental plot, adapted to the requirements of the species for an estimated harvest of 100 t/ha, all doses being calculated according to Smartfertilizer Plus, expert program: N180P140K300. Calcium nitrate (11:0:0:26.5) in a concentration of 0.5% and Biohumus were applied foliar.

Foliar fertilization (V4) was applied as follows: NPK: 20:20:20 in 3 applications throughout the vegetation period in the amount of 3 kg/ha, magnesium nitrogen applied during the flowering period 5 kg/ha, and during the period of formation and ripening the fruits were administered NPK in a ratio of 13:7:40 - 5 kg/ha and Calcinit 0.05%. All 3 repetitions of each graduation of A factor (a1, a2, a3), with the afferent graduations of B factor (b1, b2, b3), were arranged on a row of plants in the experimental plot. The 3 repetitions within the same row were separated from each other by leaving one untreated plant (isolation). The fruit samples were harvested in three replications, at the technical maturity of harvesting. The following fruit quality parameters: firmness (N), soluble solids content (SSC, % Brix), tartic (TA %), malic (MA %) and citric acids (CA %). Flesh firmness was measured on two

opposite sides of each fruit with a penetrometer HPE II Fff Qualitest (Qualitest Inc., Canada), with a plunger of diameter 0.25 cm^2, results were expressed in kg cm^2. The soluble solids content was determined with a digital refractometer (ATAGO PR-32, Japan). The malic, tartaric, and citric acids were determined by the method for determining total acidity in fresh juice using a minititrator by Hanna Instruments, model HI84532 (STAS 5957-71). Nitrates, potassium and calcium from the fruits were analyzed using Laquatwin NO3-, Laquatwin Ca2+ and Laquatwin K+, according to the working protocol and were expressed in mg/100 g.
The data were analyzed using two-way ANOVA with IBM SPSS 14 software and MS Office Excel 2010. Duncan's Multiple Range Test was used to determine the significant differences ($P<0.05$).

RESULTS AND DISCUSSIONS

Figure 1 describes the intensity of the existing correlation between fruit production per plant (y) and the volume of the aerial part of the plants (x) for each fertilization variant, in part (factor B). In other words, how are the assimilates distributed for the two important processes, growth and fruiting, according to fertilization methods and options, in the two years after application. It is observed that in all four fertilization methods (gradations), the correlations between growth and fruiting processes are very significant, but the slope of the regression lines differs. In the case of combined fertilization (soil and Biohumus - foliar application - 77.21%), the oscillation of fruit production was determined by the variation in the volume of the bushes (R2=0.7721***), 71.68% in the case of mineral fertilization on the soil (R2=0.7168***) and 50.30% in the case of foliar fertilization (R2=0.503***).
A significant correlation between fruit production and the annual growth of the plant volume is observed in the V1 variant (fertilization on the ground), (R2=0.7168*). For this fertilization variant, a tendency of decreasing vegetative growth could be observed as fruit production increased. Plants within the V3 variant produced a higher fruit yield (between 3.6 and 5.8 kg plant-1) and also had a lower vegetative growth (0.83-1.90 m^3).
Foliar fertilization (V4) stimulated the vegetative growth of plants to the detriment of fruit production, more concretely the effect of foliar fertilization was materialized only in the vegetative growth of plants, the fruit yield per plant being between 2.0 and 5.0 kg, while the increases vegetative were from 1.21 and reached 2.2 m3.
Greenhouse tomato production has attracted attention as a potential adjustment to climate change (Sumedrea *et. al.,* 2021, Truffault *et al.* 2019), and because controlled conditions increase fruit yield and quality (Peet and Welles 2005), and in terms of control of pests is easier with less need for chemical procedures (Jones Jr., 2007). To obtain good-quality tomatoes in greenhouses, good fertilization management is important (Sumedrea *et. al.*, 2021, Gruda *et al.* 2018).
Analyzing the tomato production obtained in the three studied cultivars (table 1), significant differences can be observed between the four fertilization methods, regardless of the study year. Both soil fertilization and combined fertilization (V3)- soil and foliar Biohumus, but also soil and foliar applied Ca (V2) determined increases in fruit production of 1.05 kg/plant, respectively 0.3 kg/plant, compared to the application of foliar fertilization (V4). In 2020, at 'Stefănești 22' cv., fruit production increased from 2.39 in the case of foliar fertilization, to 3.09 kg/plant in the case of soil and combined (soil and foliar) fertilization, the statistically significant difference ensuring an increased production of 0.70 kg/plant.
The same differences were also observed in the case of the 'Costate 21' cv., in both years of the study, which recorded the highest production in the case of soil fertilizer application and foliar Biohumus application (5.40 kg/plant in 2020, respectively 5.47 kg/plant in the year

2021), compared to only 4.10 (2020), respectively 4.34 kg/plant (2021) recorded in the case of foliar fertilization.
These differences led to a growth increase of 1.3 kg/plant in 2020, respectively 2.19 kg/plant in 2021. Sumedrea *et al.* (2021) also reported that both soil fertilization and combined fertilization caused increases in fruit production of 0.38 kg/plant and 0.3 kg/plant, respectively, compared to the application of foliar fertilization.

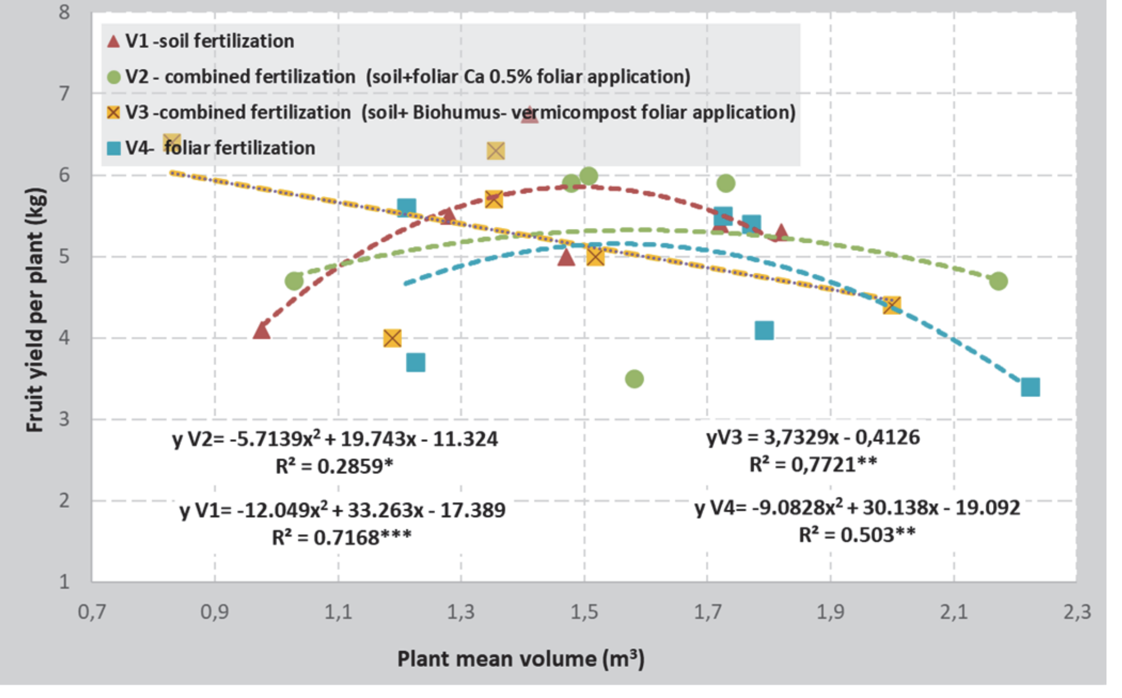

Figure 1. Correlation between plant volume (m3) and fruit production (kg plant-1), for each type and fertilization method applied, Stefanesti-Arges, (2020-2021)

The combined fertilization (V2- soil and Ca+0.5% foliar application) induced higher values regarding fruit firmness. Thus, in both years of the study in all three analyzed cultivars, the highest fruit firmness was recorded when applying the combined soil and foliar Ca 0.5% fertilization, with values between 58.65 N/cm2 and 65.33 N/cm2 in 2020, respectively 58.8 N/cm2 and 65.45 values recorded in 2021.
The lowest value was highlighted when applying combined soil fertilization and foliar applied Biohumus (V3), in both years of studies (between 50.48-53.45 N/m2 in 2020, respectively 47. In the 'Ștefănești 22' cultivars, the firmness increased from 59 N/cm2 in the case of soil fertilization, to 66.54 N in the case of foliar fertilization, the differences between them being statistically significant.
Analyzing the soluble dry substance content of the fruits, differences induced by the fertilization methods of the three cultivars studied were found. Thus, all 3 cultivars 'Ștefănești 22', 'Ștefănești 24' and 'Costate 21' recorded the highest content value in soluble dry mater when applying the combined soil and foliar fertilization Biohumus (V3), (between 4.71-4.9% in both years of the study), (table 2).
The highest content in SSC % was highlighted in 'Ștefănești 22' cv. (4.9% Brix) in both years of study. Gupta *et al.,* (2011) reported that quality attributes such as the total soluble solids content of fruits varied between 3.67 and 6.0 % Brix.

Table 1. The effect of applied fertilization on production, firmness, and S.S.C (% Brix), in the three cultivars, studied at Stefanesti-Arges, in the 2020- 2021 period

Indicators/ fertilization methods	Production (kg/plant^{-1})			Firmness (N/cm2)			S.S.C (Brix %)		
Cultivars	Stefanesti 22	Ştefăneşti 24	Costate 21	Ştefăneşti 22	Ştefăneşti 24	Costate 21	Stefanesti 22	Ştefăneşti 24	Costate 21
Methods of the fertilizer	**2020**								
V1- soil fertilization	3.09a	4.73a	5.15a	64.88a	60.18	55.81a	4.31a	3.87a	4.37a
Sig.	*0.442*	*0.247*	*0.266*	*0.218*	*0.234*	*0.329*	*0.149*	*0.111*	*0.194*
V2- combined fertilization (soil+Ca 0.5% foliar application	3.06a	4.78a	4.80a	65.33a	63.80a	58.65a	3.56b	3.8a	4.55a
Sig.	*0.442*	*0.247*	*0.266*	*0.218*	*0.234*	*0.329*	*0.064*	*0.111*	*0.147*
V3 - combined fertilization (soil+Biohumus foliar application	3.21a	4.47a	5.40a	55.14b	53.45b	50.48b	4.9a	4.78a	4.71a
Sig.	*0.442*	*0.247*	*0.266*	*0.017*	*0.104*	*0.163*	*0.149*	*0.111*	*0.194*
V4- foliar application	2.39b	4.70a	4.10b	61.13a	61.00	55.00a	4.49a	3.77b	4.14b
Sig.	*1.000*	*0.427*	*1.000*	*0.218*	*0.234*	*0.329*	*0.149*	*0.111*	*0.147*
Methods of the fertilizer	**2021**								
V1- soil fertilization	3.11a	3.62a	4.83a	65.20a	60.0ab	55.8a	4.51 ab	3.93 ab	4.53a
Sig.	*0.442*	*0.529*	*0.247*	*0.357*	*0.333*	*0.343*	*0.516*	*0.322*	*0.218*
V2- combined fertilization (soil+Ca 0.5% foliar application	3.06	3.15 ab	4.78a	65.45a	65.06a	58.8a	4.51 ab	3.83a b	4.32
Sig.	*0.442*	*0.583*	*0.247*	*0.357*	*0.205*	*0.343*	*0.516*	*0.322*	*0.218*
V3 combined fertilization (soil+Biohumus foliar application	3.16a	3.92a	5.47a	57.95b	54.10b	47.3b	4.9a	4.13a	4.7a
Sig.	*0.442*	*0.529*	*0.247*	*0.162*	*0.128*	*1.000*	*0.293*	*0.146*	*0.218*
V4- foliar application	2.70a	2.95b	4.34b	62.43 ab	62.35	56.9a	4.04b	3.65b	4.38a
Sig.	*0.442*	*1.000*	*1.000*	*0.519*	*0.205*	*0.343*	*0.223*	*0.176*	*0.218*

**Mean numbers and 5% least sig. difference of a Completely Random Designed experiment with four treatments and three replications, compared using Duncans' multiple comparisons test (SPSS 14.0, ANOVA, P≤0,05). *Values with different letters are statistically different at 5% probability, the Duncan test*

Tartric acid values varied according to the fertilization method. Thus, in the 'Ştefăneşti 22' cultivar, the highest concentration of CA % was evident when foliar fertilization was applied, in both years of study (1.56-1.62%), although the differences are not significant statistically ensured. (Table 1). The highest values of tartric acid were highlighted when fertilization was applied to the soil, for all three cultivars, in both years of the study, although the differences are not statistically significant. The same thing was highlighted in the case of the malic acid content of the fruits. It decreased in the 'Ştefăneşti 22' cultivar from 1.72 MA % in the case of the application of soil fertilization and of the combined fertilization (V2) (soil and Ca 0.5% foliar application) to 1.23% in the case of foliar fertilization (V4), in 2021, the differences between them being ensured from a statistical. In the 'Costate 21' cv., the increase in content was 0.2% MA, the highest content being recorded in the case of the application of combined fertilization (V3) with 1.45 MA%) and the lowest with foliar fertilization (V4) (1.23 MA), in the year 2020, the differences being ensured from a statistical point of view (Table 2).

Table 2. The effect of applied fertilization on tartaric (TA %), malic (MA %), and citric acid (CA %) in the three cultivars, studied at Stefanesti-Arges, in the 2020- 2021 period

Indicators/ fertilization methode	TA (%)			MA (%)			CA (%)		
Cultivars	Ştefăneşti 22	Ştefăneşti 24	Costate 21	Ştefăneşti 22	Ştefăneşti 24	Costate 21	Ştefăneşti 22	Ştefăneşti 24	Costate 21
Methods of the fertilizer	**2020**								
V1- soil fertilization	1.44a	1.54a	1.36a	1.72	1.44	1.42a	1.51a	1.33b	1.25a
Sig.	*0.149*	*0.689*	*0.149*	*0.937*	*0.170*	*0.073*	*0.205*	*0.656*	*0.267*
V2- combined fertilization (soil+Ca 0.5% foliar application	1.35a	1.57a	1.46a	1.73a	1.38a b	1.40a	1.59a	1.51a	1.31a
Sig.	*0.149*	*0.689*	*0.149*	*0.937*	*0.170*	*0.073*	*0.205*	*0.066*	*0.267*
V3 - combined fertilization (soil+Biohumus foliar application	1.32a	1.53a	1.31a	1.72a	1.46	1.45a	1.50a	1.32b	1.23a
Sig.	*0.149*	*0.689*	*0.149*	*0.937*	*0.170*	*0.073*	*0.205*	*0.656*	*0.267*
V4- foliar application	1.30a	1.13b	1.30a	1.70a	1.34b	1.25b	1.62a	1.36 ab	1.32a
Sig.	*0.149*	*1.000*	*0.149*	*0.937*	*1.000*	*1.000*	*0.205*	*0.722*	*0.267*
Methods of the fertilizer	**2021**								
V1- soil fertilization	1.44a	1.83a	1.31a	1.72a	1.46a	1.43a	1.50a	1.37a b	1.21b
Sig.	*0.175*	*0.222*	*0.141*	*0.363*	*0.328*	*0.141*	*0.342*	*0.365*	*0.425*
V2- combined fertilization (soil+Ca 0.5% foliar application	1.27a	1.54a	1.31a	1.72a	1.45a	1.27b	1.57a	1.51a	1.31a
Sig.	*0.175*	*0.222*	*0.141*	*0.363*	*0.328*	*0.125*	*0.342*	*0.092*	*0.239*
V3 combined fertilization (soil+Biohumus foliar application	1.24a	1.15b	1.30a	1.65a	1.47a	1.21b	1.51a	1.32b	1.20b
Sig.	*0.175*	*1.000*	*0.141*	*0.363*	*0.328*	*0.141*	*0.342*	*0.273*	*0.425*
V4- foliar application	1.29a	1.47a	1.46a	1.23b	1.40a	1.25b	1.56a	1.41a b	1.25a
Sig.	*0.175*	*0.222*	*0.141*	*1.000*	*0.328*	*0.125*	*0.342*	*0.365*	*0.239*

The NO_3^- content of tomato fruits at the time of harvest, depending on the fertilization method

Method of fertilizer	Subset for alpha = .05	
soil	132. 25 b	
Combined fertilization (soil and foliar Ca0.5%)		137.98 a
Combined fertilization (soil and Biohumus foliar 3%)		145.69 a
Foliar		*147.95 a*
Sig.	*1.000*	*0.066*

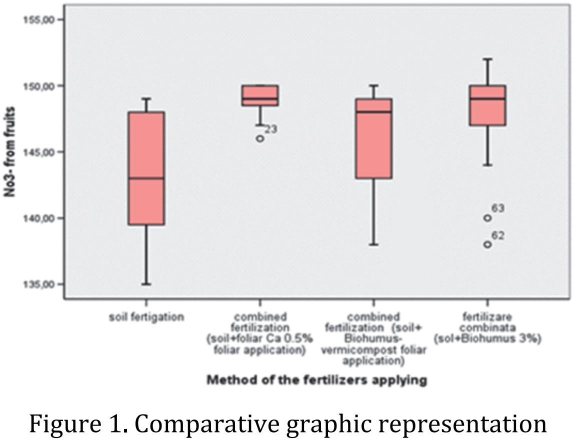

Figure 1. Comparative graphic representation of the NO3- concentration distributions in the fruits, depending on the fertilization variant

The lowest values of the K^+ content in fruits were obtained in the case of soil fertilization (148.7 mg/100 g fresh matter), and the highest in the case of combined fertilization (soil and foliar organic Biohumus) 187.4 mg/100 g fresh matter and statistically significantly different, for a 5% assurance level.

Table 4. The potassium (K+) content of tomato fruits at the time of harvest, depending on the fertilization method

Method of fertilizer	Subset for alpha = .05	
soil	148.75 b	
Combined fertilization (soil and foliar Ca0.5%)		178.50 a
Foliar		183.61 a
Combined fertilization (soil and Biohumus foliar 3%)		187.40 a
Sig.	*1.000*	*0.353*

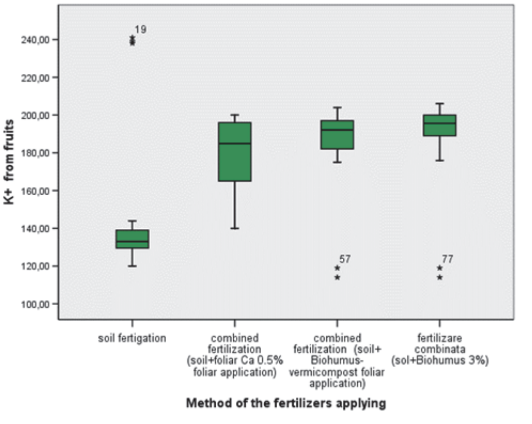

Figure 2. Comparative graphic representation of the K^+ concentration distributions in the fruits, depending on the fertilization variant

The content of potassium (k+) in the fresh substance of the fruits is in a series of contents generally quoted in the literature (Voican and Lăcătuș, 1998, Sumedrea *et. al*., 2021). Voican and Lăcătuș present values of 244 mg/100 g fresh matter for potassium in the edible part of tomatoes, and Sumedrea *et al.* reported values between 240-243 mg/100 g.

Table 5. The potassium (Ca^+) content of tomato fruits at the time of harvest, depending on the fertilization method

Method of fertilizer	Subset for alpha = .05	
soil	10.00b	
Combined fertilization (soil and foliar Ca0.5%)		11.27a
Combined fertilization (soil and Biohumus foliar 3%)		11.90a
Foliar		12.04a
Sig.	*1.000*	*0.086*

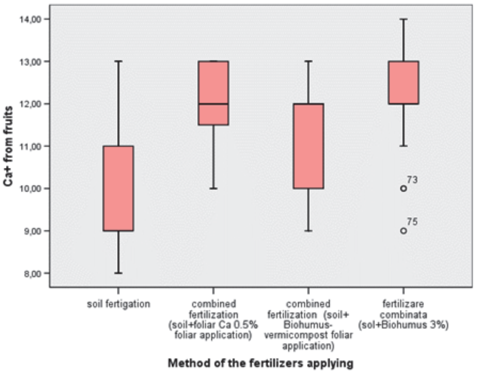

Figure 3. Comparative graphic representation of the K^+ concentration distributions in the fruits, depending on the fertilization variant

Analyzing the average values of the content of tomato fruits in calcium (mg/100g fresh matter) they varied between 10 mg/100g fresh fruit in the case of the soil fertilization option and 12.04 mg/100 g fresh matter, in the case of combined fertilization (V3- soil and foliar Biohumus organic), the differences between them being statistically significant. The content of calcium (Ca^+) in the fresh substance of the fruits is in a series of contents generally quoted in the literature (Voican and Lăcătuș, 1998; Sumedrea *et. al.,* 2021).

CONCLUSIONS

This study required the application of organic Biohumus organic foliar with mineral fertilizer had better effects on tomato growth and yield than soil or foliar application. Combined fertilization (soil and foliar organic Biohumus) determined increases in fruit production of 1.05 kg/plant compared to the application of foliar fertilization. Also, the fruit content in SSC increased from 4.07% in the case of foliar fertilization to 4.25% when applying mineral fertilization to the soil, recording the highest values when applying the combined fertilization 4.7% (soil and organic Biohumus applied foliar). The same differences were also evident in the fruit content in MA %, the highest values being obtained when applying foliar fertilization with organic Biohumus on a soil mineral fertilization. Therefore, we recommend mineral fertilization applied in optimal doses for the greenhouse culture of tomatoes supplemented with the organic fertilizer Biohumus applied foliar, increasing the yield and improving the quality indicators of the tomato fruits.

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