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Effects of Potassium Fertilization, Cultivar Specifics and Seedling Temperature Regime on Growth Parameters and Yield of Tomato (*Solanum lycopersicum* L.)

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ABSTRACT

Background: Potassium fertilization shows beneficial effect on formation of tomato vegetative biomass and productivity. The purpose of this study was to determine the extent to which split potassium application and seedling temperature regime affects the growth parameters (leaf number, leaf area, fresh leaf weight and LAI) and yield of various tomato cultivars.

Methods: A pot experiment was conducted to investigate the impact of single dose and split potassium fertilization treatments, cultivar specifics and seedling temperature regime on growth parameters and yield of tomato. Ten high yielding classic round shape tomato cultivars with determinate growth habitat were planted on Fluvisol. Single and split potassium fertilization treatments were tested.

Result: The seedlings growth temperature regime and splitting the potassium fertilization treatment did not have a significant effect on the development of leaf biomass in tomato plants. Results revealed that leaf number, leaf area, fresh leaf weight and LAI of tomato plants was significantly affected by the cultivar genetic factor. Tomato yield were significantly affected by cultivars and split potassium fertilization treatments. Cultivars that measured the highest leaf area, fresh leaf weight and LAI and were also the highest yielding ones. A positive correlation between LAI and tomato fruit yield was observed.

Key words: Fresh leaf mass, LAI, Potassium fertilization, Seedling temperature regime, Tomato yield.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is among the most widely grown and economically important vegetable crops worldwide. Production of high-quality seedlings is essential for plant growth (Vasileva and Dinev, 2021). Stronger root system, increased biomass and photosynthetic capacity of the seedlings are factors known to improve access to environmental resources, which results in higher yield (Lazcano *et al*.; 2009; Narolia and Reddy, 2010; Zaller, 2007).

The rate of growth and development of the seedlings is dependent upon the temperature of the micro-environment, fertilization, illumination, soil and air humidity (Carvalho and Nakagawa, 2000; Gupta *et al*., 2012; Stoykov and Mitova, 2006; Stoykov and Mitova, 2007; Singh *et al*. 2006). According to Papadopoulos (1991), air temperature 18±4°C is optimal for tomato seedling production, while temperatures higher than 25°C adversely affect plant growth and its developmental and reproductive processes.

Lechov *et al*. (2013) described leaf area as one of the most important morphological characteristics of plants, directly affecting water and nutrient uptake and an indicator for plant health. Leaf area determines the solar radiation regime and temperature regulation, controlling the energy balance, canopy photosynthesis and the amount of transpiration of the crops. In addition, photosynthesis is related to various vegetative growth parameters such as leaf area, number and age (Jo and Shin, 2020). According to Luo *et al*. (2006) Leaf area index (LAI) represents the area of photosynthesising and transpiring organs. Therefore, it is important to predict LAI accurately for estimations of crop canopy photosynthesis and transpiration.

Lower LAI values would reduce light interception and increase yield losses due to sunburn, while higher values may delay the fruit production and reduce the effectiveness of foliar pesticides. At LAI of 3, an indeterminate crop theoretically intercepts about 90% of the available light. Estimated light interception for an LAI of 4-5 is about 50-60% during the period of maximum seasonal fruit development (Scholberg *et al*., 2000; Heuvelink *et al*., 2004). According to Heuvelink *et al*. (2005) most light interception occurs at LAI>3 and further LAI increase has an insignificant effect. Heuvelink *et al*. (2004) also determined that tomato yield could be optimized by managing the leaf area during the plant vegetation period.

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Boteva and Kostova (2009) reported that potassium fertilization shows beneficial effect on formation of vegetative biomass and plant productivity. Adequate potassium supply improves nutrient uptake, enhances photosynthetic assimilation and maintains proper leaf inclination. Potassium is known to play a fundamental role in stomata-opening control, responsible for water, nutrient and metabolite transport (Armstrong, 1998).

MATERIALS AND METHODS

A pot experiment under controlled conditions was carried out at the experimental greenhouse of Institute of Soil Science, Agrotechnologies and Plant Protection "Nikola Poushkarov" in 2017 on Fluvisol (FAO, ISRIC World Soils). Ten high yielding, early and mid-early Classic Round shape tomato cultivars with determinate growth habitat were tested at single and split potassium fertilization treatments.

The soil had the following characteristics: neutral to low alkaline pH (pH_{H_2O}-7.1, pH_{KCl}-6.20, low hummus content (2.3%) and high content of mobile nitrogen (NH_4-N-70.2 mg kg^{-1}, NO_3-N-7.5 mg kg^{-1}) and P_2O_5 and K_2O values of 76.2 mg P 100 g^{-1} and 40.4 mg K 100 g^{-1}.

The seedlings were initially grown in an artificial climate control chamber KHER-03 in plastic 0.650 kg nursery pots, under 17°C and 27°C temperatures. The duration of the phytoperiod was 16 hours with illumination intensity of 22 000 lx and soil humidity was maintained 75% of field capacity (FC).

After 4 weeks, when the seedlings reached vegetative stage (2-4 fully formed leaves), they were transplanted in 2.5 kg pots and moved to the greenhouse conditions.

Potassium in the form of K_2SO_4 was applied, at constant nitrogen (NH_4NO_3) and phosphorus [$Ca(H_2PO_4)_2.H_2O$] fertilization rates. Single and split potassium fertilization treatments were tested (1. $N_{200+200}P_{300}K_{450}$ 2. $N_{200+200}P_{300}K_{225+225}$).

Experimental sites were divided according to a split plot design with two treatments and three repetitions of four plants each:

1. 100% $Ca(H_2PO_4)_2.H_2O$, 50% NH_4NO_3 and 100% K_2SO_4 at seedling transplanting and 50% NH_4NO_3 at flower initiation;
2. 100% $Ca(H_2PO_4)_2.H_2O$, 50% NH_4NO_3 and 50% K_2SO_4 at seedling transplanting and 50% K_2SO_4 and 50% NH_4NO_3 at flower initiation.

Leaf area was measured *via* O'Neal *et al.* (2002) method at the beginning of flowering and fruit formation stages. Leaf area index (LAI) was calculated by dividing the total leaf area per plant by the ground area.

Multi-factor ANOVA (Analysis of variance at 95% confidence level) and Duncan multiple range test (DMRT) test at 5% level of significance data analyses were performed using STATGRAPHICS Centurion software package.

RESULTS AND DISCUSSION

Biomass production is primarily driven by photosynthesis, while photosynthesis to a great extent depends on light interception, which furthermore varies with leaf area. Moreover, a high biomass production does not necessarily result in a high yield, since only the tomato fruit is of economic interest (Heuvelink, 2005).

Each of the factors in scope of the experiment - temperature regime, potassium fertilization and the genetic factors were evaluated separately to assess their effect on plant growth parameters (Table 1 and 2).

Crop growth may be increased by higher temperature in the long term, because increased temperature may increase leaf area development, resulting in higher future light interception (Heuvelink, 2005). Although leaf number per plant, leaf area, fresh leaf weight and LAI at the flowering growth stage (8.40; 289.52 cm^2; 9.41 g $plant^{-1}$; 1.3) and at the fruit formation growth stage (10.98; 613.80 cm^2; 20.12 g $plant^{-1}$; 2.7) of seedlings grown under 17°C was higher compared to the ones grown under 27°C (respectively 8.25; 263.93 cm^2; 8.59 g $plant^{-1}$; 1.2 at the flowering stage and 10.38; 576.03 cm^2; 19.02 g $plant^{-1}$; 2.5 at the fruit formation stage). The differences were not significant and fell within statistical error limits (Table 1 and 2). Based on these results we can conclude that seedling growth temperature regime ranging between 17°C and 27°C has no significant effect on the vegetative growth and development of the tomato plant. These findings are in harmony with the observations of Ferreira *et al*. 2013 - when the plants were brought out to uniform greenhouse conditions, all reached identical growth and development parameters.

Potassium is one of the vital elements required for plant growth and physiology. Split potassium fertilizer application during the growth period has proven to be beneficial by simultaneously lowering the loss of potassium by leaching and by raising the use efficiency of the K fertilizers applied (Kolar and Grewal, 1994; Römheld and Kirkby, 2010). This hypothesis is also supported by other researchers, who also reported that split potassium fertilization achieved maximum nutrient efficiency and improved the available potassium status in the root zone (Armstrong, 1998; Vasileva and Dinev, 2021).

Kasinath *et al*. (2014) and Mohammed *et al*. (2021) highlighted that vegetative growth of tomato plants was influenced by different rates of potassium application methods. Our results indicate that splitting the potassium fertilization did not have a significant effect on the tomato vegetative growth parameters, except for fresh leaf weight measured at the flowering stage, which was significantly affected, P≥5% (±1.003). Leaf area and fresh leaf weight at the flowering growth stage (287.55 cm^2; 9.53 g $plant^{-1}$) and leaf number per plant and leaf area at the fruit formation growth stage (10.76; 595.15 cm^2) of plants fertilized with K_{450} was higher compared to the ones subjected to $K_{225+225}$ fertilization. The remaining parameters were higher in plants fertilized with to $K_{225+225}$, however the differences fall within statistical error limits. A possible explanation for this result may be that potassium nutrient uptake is not intensive during early tomato growth phases and the initially applied fertilization treatments (K_{450} and K_{225}) are sufficient to meet the plant nutrient demands. Our results share number of similarities with Melton and Dufault's (1991) findings, who reported that potassium did not significantly influence the growth parameters.

Plant growth parameters are reported and believed to be genotype-determined, Heuvelink (2005) suggested that leaf growth and canopy characteristics for tomatoes depend on genetic traits and management practices. The values we obtained are in line with these limitations and suggest that biomass development is a genetic characteristic for tomato plants. At both the flowering and the fruit formation stage we did not notice a clear trend and none of the tested

Table 1: Growth parameters of tomato plants measured at the beginning of flowering growth stage.

	Flowering stage			
	Leaf number	Leaf area cm^2	Fresh leaf weight g plant^{-1}	LAI
17°C	8.40a	289.52a	9.41a	1.3a
27°C	8.25a	263.93a	8.59a	1.2a
LSD	0.853	26.910	1.003	0.119
$N_{300+300}P_{300}K_{450}$	8.08a	287.55a	9.53b	1.3a
$N_{300+300}P_{300}K_{225+225}$	8.57a	265.90a	8.48a	1.3a
LSD	0.853	26.910	1.003	0.119
Bersola F_1	9.42c	318.04bc	11.07c	1.4bc
Atak	9.33c	259.00ab	8.75ab	1.1ab
Sadeen F_1	9.00bc	335.06c	11.05c	1.5c
E26.33342	8.75abc	262.93ab	8.93abc	1.2ab
E27.32927	8.75abc	227.14a	8.11ab	1.0a
Sheena F_1	7.17ab	229.32a	7.72ab	1.0a
3830	7.58abc	261.62ab	7.03a	1.2ab
3093	7.00a	261.79ab	7.92ab	1.2ab
Miliana-VF	7.75abc	300.99bc	9.92bc	1.3bc
Nikolina F_1	8.50abc	311.36bc	9.51bc	1.4bc
LSD	1.9082	60.172	2.242	0.265

Means within each column followed by the same letter are not significantly different at P≤5%.

Table 2: Growth parameters of tomato plants measured at the beginning of fruit formation growth stage.

	Fruit formation stage			
	Leaf number	Leaf area cm^2	Fresh leaf weight g plant^{-1}	LAI
17°C	10.98b	613.80a	20.12a	2.7a
27°C	10.39a	576.03a	19.02a	2.5a
LSD	0.552	39.759	1.420	0.175
$N_{300+300}P_{300}K_{450}$	10.76a	595.15a	19.36a	2.6a
$N_{300+300}P_{300}K_{225+225}$	10.62a	594.68a	19.77a	2.6a
LSD	0.552	39.759	1.420	0.175
Bersola F_1	11.00cd	731.03b	24.03e	3.2b
Atak	12.08d	682.61b	20.20cd	3.0b
Sadeen F_1	9.33a	720.36b	22.33de	3.2b
E26.33342	10.92bcd	747.42b	25.31e	3.3b
E27.32927	11.75cd	539.18a	18.37abc	2.4a
Sheena F_1	11.50cd	498.09a	16.62ab	2.2a
3830	10.63bc	474.03a	15.62a	3.3a
3093	11.08cd	548.21a	17.63abc	2.4a
Miliana-VF	9.75ab	524.00a	18.94bc	2.3a
Nikolina F_1	8.83a	484.24a	16.62ab	2.1a
LSD	1.264	88.905	3.175	0.392

Means within each column followed by the same letter are not significantly different at P≤5%.

Table 3: Growth parameters of tomato affected by temperature, potassium fertilization and cultivars.

Source	Leaf number			Fresh leaf weight			LAI		
	F-ratio	P-value	S	F-ratio	P-value	S	F-ratio	P-value	S
				Flowering stage					
Main effects									
A: temperature	0.12	0.727	NS	2.65	0.108	NS	3.58	0.062	NS
B: fertilization	1.27	0.263	NS	4.35	0.040	*	2.56	0.113	NS
C: cultivars	1.70	0.103	NS	3.00	0.004	*	3.05	0.003	*
Interactions									
AB	6.00	0.017	*	0.42	0.521	NS	0.94	0.336	NS
AC	0.79	0.629	NS	2.67	0.009	*	2.26	0.026	*
BC	1.00	0.451	NS	2.23	0.028	*	2.26	0.026	*
ABC	0.75	0.660	NS	0.73	0.677	NS	1.58	0.136	NS
				Fruit formation stage					
Main effects									
A: temperature	4.56	0.036	*	2.38	0.127	NS	3.57	0.062	NS
B: fertilization	0.26	0.611	NS	0.33	0.565	NS	0.00	0.981	NS
C: cultivars	5.97	0.000	*	8.68	0.000	*	12.44	0.000	*
Interactions									
AB	3.36	0.070	NS	0.93	0.338	NS	0.55	0.459	NS
AC	3.46	0.001	*	2.10	0.039	*	2.74	0.008	*
BC	1.37	0.215	NS	1.18	0.320	NS	1.29	0.256	NS
ABC	0.98	0.461	NS	1.56	0.142	NS	1.66	0.112	NS

Means within each column followed by the same letter are not significantly different at P≤5%.
NS, *- Non significant or significant at p<0.05%.

cultivars was showing prominent biomass development. Interestingly, the F1 hybrids - Bersola F_1, Sadeen F_1, Sheena F_1 and Nikolina F_1 measured the highest leaf area, fresh leaf weight and LAI (Table 1 and 2). In plant breeding, F1 hybrids are the first filial generation of offspring of distinct parental types and heterosis manifestation in tomato is reported to be in the form of the faster growth and development and increased productivity (Yordanov, 1983).

Table 3 summarizes the statistical significance of the examined factors and the relationship between them as per Fisher's exact test. All P-values (excluding the fresh leaf weight measured during flowering stage) are greater that the default significance level of 0.05 used in this research, hence we conclude that the Potassium fertilization as a single factor, does not have a significant effect on the evaluated growth parameters (number of leaves, fresh leaf weight and LAI), on the other hand, the cultivar genetic factor has most significant effect on the growth parameters both as a single factor and in relationship with the temperature during the fruit formation stage and in relationship with the Temperature and the Potassium fertilization factors during the flowering stage (Table 3).

Based on the degree of their ecological adaptation and low requirements for phytoperiod and growth temperature, tomatoes are considered a cosmopolitan crop that could be grown in various climate zones (Mitova and Dinev, 2010). In our experiment during the vegetation period, all ripe fruits were picked and the total yield is presented on Fig 1. Seedlings grown at 27°C (104.65 g pot^{-1}) generally yielded better, yet no statistically significant results were observed (±16.664 g), so we can conclude that the seedling temperature regime did not have a significant effect on the crop yield.

Fruit yield is the function of the growth, photosynthetic activity and nutrients uptake. The role of potassium for tomato plant is well studied, Santos (2013) demonstrated that the effect of applying potassium before planting affects the total market weight of the fruit and in a study Hartz (2007) summarized that potassium fertilization proved to be most effective on tomato plants, if applied before flowering. The results of our research confirm significant effect of split potassium fertilization on tomato productivity. Total tomato fruit yield obtained from plants subjected to split potassium fertilization ($K_{225+225}$) - 109.98 g pot^{-1} was higher compared to the yield obtained from plants that received a single dose treatment (K_{450}) - 86.50 g pot^{-1} (Fig 1). This substantiates the findings of our previous extensive field experiment that splitting the potassium fertilization positively affects tomato productivity (Vasileva, 2015).

Tomato yielding is to a large extent a genetic characteristic, which is cultivar specific. From all participating cultivars, Bersola F_1 (147.74 g pot^{-1}) was the highest yielding, yet the statistical analysis did not reveal significant differences compared to Sadeen F_1, Sheena F_1 and Nikolina F_1 (142.97 g pot^{-1}, 114.40 g pot^{-1} and 135.76 g pot^{-1}) (Fig 1).

LAI is directly associated with the plant's light interception efficiency and maintaining it at optimal levels is key for greenhouse tomato production, where extra financial

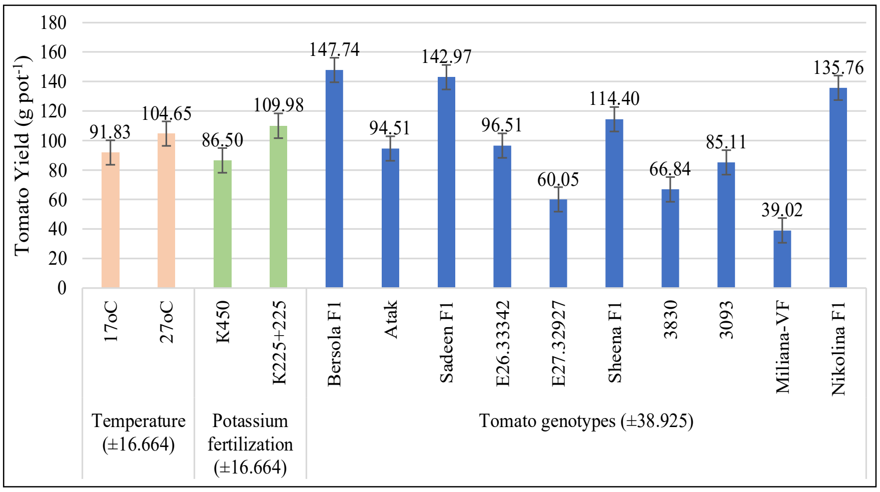

Fig 1: Tomato yield affected by temperature, potassium fertilization and cultivars.

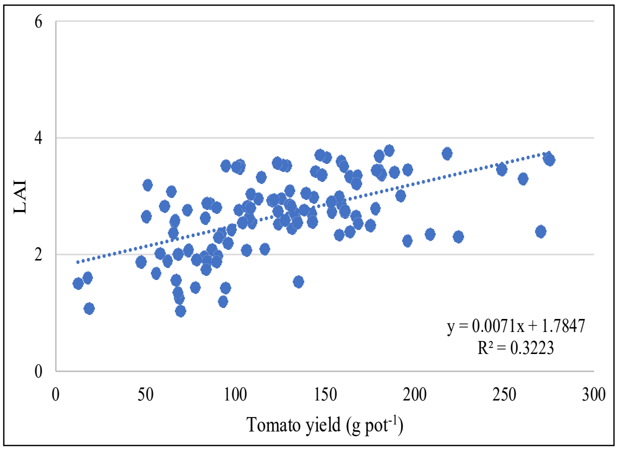

Fig 2: Relationship between LAI and tomato yield.

costs are incurred to maintain artificial environmental conditions. During the flowering stage, tomato plants had relatively low LAI (1.0-1.5), since they do not compete for light exposure (Table 1), while at fruit formation stage LAI was expectedly higher, with values in the range of 2.1 to 3.3, which is comparable to other studies (Table 2).

Our experiment is in line with previous results from Heuvelink *et al*. (2005) and Jo and Shin (2020), who reported that tomato yield (number of fruits) increase with the higher LAI treatment, however LAI higher than 4 LAI did not have further positive effect. Similarly, we observed positive correlation between LAI and tomato fruit yield as presented on Fig 2.

CONCLUSION

This study demonstrates that the seedlings growth temperature regime and splitting the potassium fertilization treatment do not have a significant effect on the development of leaf biomass in tomato plants. However, the experimental conditions: growth temperature of 17°C, phytoperiod of 16 hours, illumination intensity of 22 000 lx, soil humidity of 75% of field capacity (FC) and $N_{300+300}P_{300}K_{450}$ fertilization were proven beneficial for quality tomato seedling growth. Based on the results of the study, we can conclude that the cultivar genetic characteristic has the most significant effect on the evaluated parameters as a single factor and in relationship with the temperature during the fruit formation stage and in relationship with the Temperature and the Potassium fertilization factors during the flowering stage.

The statistical differences in the obtained tomato yield at different potassium fertilization treatments were significant, with highest yield noted at $N_{300+300}P_{300}K_{225+225}$ fertilization - 109.98 g pot^{-1}.Cultivars Bersola F_1, Sadeen F_1, Sheena F_1 И Nikolina F_1 measured the highest leaf area, fresh leaf weight and LAI and were also the highest yielding ones. A positive correlation (R^2=0.322) was observed between LAI and tomato fruit yield. Based on this experiment, we can conclude that appropriate leaf area management may be effective for increasing productivity in greenhouse tomato production and the relationship between leaf area and plant growth of the various tomato cultivars should be further researched.

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