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ANALYSIS OF VEGETATIVE AND REPRODUCTIVE GROWTH OF GREENHOUSE TOMATOES CULTIVATED UNDER DRIP IRRIGATION AND FERTIGATION WITH INCREASING FERTILIZER RATES

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Abstract

An experiment was conducted in the experimental field in Chelopechene, Sofia, Bulgaria in 2019-2020 with tomato (Solanum lycopersicum variety "Big Beef" F1) cultivated under drip irrigation and fertigation. Two levels of irrigation (100% ETc and 60% ETc) with four fertilization levels (0, 80 %, 100 %, and 120 % of the fertilizer rate) have been served as treatment. In the phase 4-6th inflorescence, main growth parameters like plant height, stem diameter, number of leaves, number of inflorescences and number of fruits of tomato plants were measured. Analysis of variance (ANOVA) was performed to analyze the effect of irrigation and fertilization on vegetative and reproductive growth of plants. Under full irrigation, the plants have the thickest stems; they are leafier, with more inflorescences and formed more fruits than average. Of all the studied growth parameters, only for the number of inflorescences for both experimental years 2019 and 2020, a statistically proven difference was found for the influence of irrigation.

Key words: *greenhouse, growth parameters, drip fertigation, tomato.*

INTRODUCTION

Tomatoes are one of the most preferred and consumed vegetable crops in Bulgaria, due to their high nutritional value and content of vitamin C and lycopene, protecting human health. Although the annual production of tomatoes in the country has been declining in recent years, tomatoes have the largest share in greenhouse vegetable growing. In 2019, the greenhouse production in Bulgaria was developed over 9220 acres, with the majority of the production being tomatoes.

Greenhouses used for cultivation of tomato, are usually heated glass or unheated coated with plastic constructions in which the vegetable crop is cultivated directly in the soil (Jinliang Chen, 2013; XING Ying, 2015; Çebi et al., 2018).

Unheated greenhouses rely on sunlight as only source of energy and have a simple structure, making them inexpensive to build and maintain (Yuan et al., 2001). They are coated with polymeric foil materials, which have a relatively short useful life between 6-45 months, depending on the UV stabilizers (Espi et al., 2006). Nevertheless, unheated greenhouses are valuable as cultivation facilities in which some of the adverse weather factors can be eliminated or reduced to plant-tolerable levels, and the yields and quality of production exceed those obtained from the field (Mahajan & Singh, 2006; Mitova et al., 2019).

Tomato is one of the most demanding crops in terms of growing conditions (Sharmasarkar et al., 2001; Kiymaz & Ertek, 2015) and nutrient and water regime are the main factors influencing production during most of the growing season.

Tomato plants require a lot of water, especially during the flowering and fruiting. In greenhouse cultivation, only the irrigation system is relied on to supply the necessary water for the plants, so the question of its effective operation is of particular interest. The application of an irrigation schedule to meet the full water requirements of the crop leads to an increase in yield and product quality (Ankush and Sharma, 2017, Patamanska et al., 2020).

Plant development and fruiting are also strongly influenced by environmental factors, such as light and temperature during different growth stages (Hou et al., 2017; Tijskens et al., 2016).

This study aims to analyse the effect of irrigation and fertilization on the vegetative and reproductive growth of tomatoes cultivated under unheated conditions in a protected environment.

MATERIALS AND METHODS

The study was conducted in the Chelopechene experimental field of the Institute of Soil science, Agrotechnologies and Plant Protection in town of Sofia, Bulgaria in an unheated polyethylene greenhouse with dimensions of 7.9 x 53 m and a total area of 420 m^2 in 2019-2020. The experimental field with geographical coordinates: 42°44′22.8″N, 23°28′3.7″E is a part of the Sofia Field, located at 550 m above sea level. This area has continental climate characterized by cold winter. The soil type of the experimental site is *Chromic Luvisol* which can be defined as moderate to strong water-permeable with an average filtration capacity.

The object of the study are tomato variety *"Big Beef" F1*.

A two-factor experiment was performed with experimental factors - irrigation (V) and fertilization (T).

The factor irrigation was applied in two levels: V1 - full irrigation at irrigation rate estimated by evapotranspiration (100% ETc), V2 - deficit irrigation (60% ETc).

The factor fertilization was applied at four levels: T0 - without fertilizer, T1 - suboptimal fertilization $N_{8.95}P_{11.82}K_{13.87}$, T2 - optimal fertilization $N_{11.59}P_{15.84}K_{17.74}$, T3 - luxury fertilization $N_{14.50}$ $P_{20.13}$ $K_{21.88}$.

The following treatments were tested: V1T0, V1T1, V1T2, V1T3, V2T0, V2T1, V2T2, V2T3.

The experimental treatments were arranged according to the method with long plots. Each plot has a surface of 24 m^2 and consisted of twin rows of tomato with a total of 81 plants. They are planted "checkerboard" at a spacing of 0.6 m and at a distance between rows of 0.5 m.

Irrigation was performed with a drip irrigation system, comprising a command unit and two batteries consisting eight laterals situated next to the each row of tomato. Mulching was applied to further reducing the evaporation. Black polyethylene mulch (UV 15 mic/1.20 m) was used.

Immediately after planting the tomatoes in a permanent place, a watering of 1-2 l per plant was carried out to intercept seedlings and next watering 7 days later. Depending on the growth stage of tomatoes, watering was carried out with a frequency of 3-7 days depending on stage of growth. Deficit irrigation began to be applied from the beginning of fruit setting.

Irrigation rate for the fully irrigated treatments V1T0, V1T1, V1T3 and V1T4 was determined by the sum of daily evapotranspiration for the irrigation interval. The microclimate parameters temperature, relative humidity of the air and the solar radiation required for the calculations of the evapotranspiration using the Penman-Monteith method (Allen et al., 1998) were measured with an automatic weather micro station located in the centre of the greenhouse.

In the autumn, storage fertilization with 450 kg/ha P_2O_5 and 500 kg/ha K_2O was carried out. When planting tomatoes, nitrogen fertilization with ammonium nitrate (450 kg per ha) was performed. During the growing season of tomato simultaneously with irrigation, 100% water-soluble fertilizers were introduced, which contain macronutrients (N, P, K) and micro-elements (Fe, Zn, Mn, Mg, B, Cu, Ca). Depending on the growth stage of tomato were applied: after planting tomato - mineral fertilizer containing 16% N, 69% P_2O_5 and 16% K_2O, during their vegetative development - fertilizer containing 27% N, 27% P_2O_5, and 27% K_2O and in the period of fruiting the applied fertilizer contains 18% N, 11% P_2O_5, and 59% K_2O. In order to apply the exact fertilizer rate, a MixRite 2.5 hydraulic fertilizer injector was used. Fertigation with 120:100:80:0 fertilizer dose was given in the treatments 9 times at 7 days interval beginning 10 days after transplanting.

Biometric parameters of five consecutively planted plants of each repetition of the treatment (4 repetitions) were measured in the morning - between 7^{00} and 9^{00} hours for the analysis.

The following parameters:

- plant height (cm),
- stem diameter (cm),
- number of leaves,
- number of inflorescences,
- number of fruits of tomato plants

were measured.

The obtained results were subjected to analysis of variance (ANOVA) and to Fisher's least significant difference (LSD) procedure for irrigation and fertilization.

RESULTS AND DISCUSSIONS

The average monthly data of the parameters of the microclimate in the greenhouse: solar radiation, relative humidity and maximum and minimum air temperature during the entire growing season from May to September for the two experimental years are shown in Table 1. The conditions are favourable for medium early cultivation of tomato. They are characterized by optimal values of air temperature throughout the growing season.

In May-June during the vegetative development of plants, the average air temperature in the greenhouse is 22-23ºC (2019) and 21-22ºC (2020), and in the period of mature fruiting in the months of July-August is 24-25ºC for both years. The temperature in the greenhouse during the vegetative development of the tomato plant in 2020 was lower than in 2019, but higher in the period of mature fruiting.

Optimal for the good development of tomato plants and fruiting (Genkova, 2009; Shaban, 2014; Shamshiri, 2018), moderate humidity - 60-67% - was registered in the greenhouse in both seasons, except for the months of August - September 2019, when the humidity was lower.

In 2020, tomato plants were subjected to greater temperature differences and have received more light energy. Solar radiation in 2020 is higher for all months of the growing season.

Due to similar climatic conditions in both years, the growing season of tomatoes was the same - 17 weeks.

In the second half of June of the both experimental years in the phase of 4-6th inflorescence the following growth parameters: plant height, stem diameter, number of leaves, number of inflorescences and number of fruits of tomato plants, were measured. The readings were taken for about 60 days after transplanting. The mean values of the biometric parameters of the tomato plants by treatments are shown in Table. 2.

Despite some differences in microclimatic conditions, the tomato plants reacted unidirectional in both experimental years. The higher growth parameters of the plants were observed in 2020 due to more favourable climatic conditions, compared to the previous 2019. With increasing fertilizer rate in both experimental years, the values of the studied parameters increase. In both irrigation regimes, in 2019 tomato plants with T3 fertilization have the highest values of the parameters. Exceptions to the observed trend in 2019, in 2020 make the following parameters: stem diameter of plants under deficit irrigation, height and number of leaves per plant under full irrigation, in which plants with T2 fertilization have optimal development.

At an average plant height of 121.19 cm for both years, those with full irrigation were slightly higher (0.9%) than tomatoes with deficit irrigation. The two-factor dispersion analysis of the average values of the studied parameters (Table 3) showed 70.64% share of fertilization and only 1.01% share of irrigation in the formation of plant height. The combined effect of fertilization and irrigation for the growth of tomatoes is minimal - 2.49%. The performed LSD test by the factor fertilization divides the treatments into 3 homogeneous groups with statistically proven differences between the treatments with luxury fertilization and the other levels of fertilization.

The average stem diameter for the two experimental years in deficit irrigation was only 0.78% larger than that of plants with full irrigation.

From the presented data on the different levels of fertilization it can be seen that with the exception of the deficit irrigation in 2020, in the other treatments the parameter the stem diameter varies greatly, i.e. does not prove reliable enough in this type of research.

Table 1. Average monthly data of the climatic parameters along the experiment for two experimental years

Parameter / Year / Month	Solar Radiation, W/m²		Temperature Min, °C		Temperature Max, °C		Relative Humidity, %	
	2019	2020	2019	2020	2019	2020	2019	2020
May	108.7	132.98	7.1	2.64	25.80	41.14	62.00	57.77
June	160.05	169.01	13.75	5.26	36.62	43.95	67.57	66.25
July	141.67	190.08	13.63	9.34	36.14	44.91	63.28	60.75
August	134.36	168.85	13.73	10.47	36.99	45.53	54.04	63.79
September	110.34	144.92	5.64	3.99	36.36	42.98	53.46	55.01

Table 2. Growth parameters of greenhouse tomato as affected by irrigation and fertilization

Parameter / Year / Treatment	Plant height, cm		Stem diameter, cm		Leaves number		Inflorescence number		Fruit number	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
V1T0	102.78	134.5	1.12	1.24	19.2	17	4.4	5.4	14.2	7.25
V1T1	112.36	134.8	1.18	1.36	20.6	16.4	5.6	6.4	15.6	8.4
V1T2	110.94	140.2	1.04	1.36	20.6	17.4	6.2	6.6	18	8.8
V1T3	119.52	137.2	1.32	1.43	22.4	18.4	7.6	6.2	18	13
Average	111.4	136.7	1.17	1.35	20.7	17.3	5.95	6.15	16.45	9.4
F-Ratio	11.71	7.61	5.38	2.28	3.25	4.87	5.8	5.03	15.69	30.5
P-Value	0.0000	0.002	0.0094	0.1189	0.0497	0.016	0.007	0.012	0.0001	0
LSD 95.0%	6.0147	2.872	0.1636	0.1586	2.1826	1.146	1.66	0.703	1.4221	1.3368
LSD 99.0%	8.287	3.957	0.2127	0.2185	3.0	1.579	2.28	0.969	1.9593	1.9602
V2T0	93.8	130	1.11	1.18	17.4	17	3.4	5.4	6.8	14
V2T1	99.3	128.6	1.23	1.48	18.4	16.4	4	5.6	8.8	15.2
V2T2	106.2	133.8	1.17	1.5	20.4	17.4	3.6	5.6	8.6	15.4
V2T3	119	136	1.26	1.42	21.6	18.4	4.4	6	11.8	18.4
Average	104.6	132.1	1.19	1.4	19.5	17.3	3.9	5.65	9.0000	15.75
F-Ratio	36.88	14.48	1.95	13.8	22.56	4.87	4.4	1.41	14.55	18.44
P-Value	0.0000	0.0000	0.1626	0.0001	0	0.016	0.0199	0.2771	0.0001	0
LSD 95.0%	5.3593	2.6815	0.1439	0.1189	1.1992	1.146	0.6359	0.636	1.6283	1.31
LSD-99.0%	7.384	3.6945	0.1983	0.1638	1.6523	1.579	0.8762	0.8762	2.2435	1.80

Table 3. Summary of the two-way analysis of variance of average data for two experimental years

Parameter / Year / Treatment	Plant height, cm	Stem diameter, cm	Leaves number	Inflorescence number	Fruit number
	avg 2019-20	avg 2019-20	avg 2019-20	avg 2019-20	avg 2019-20
V1T0	118.64	1.18	18.1	4.9	10.7
V1T1	123.58	1.27	18.5	6	12.0
V1T2	125.57	1.2	19	6.4	13.4
V1T3	128.36	1.375	20.4	6.9	15.5
V2T0	111. 9	1.145	17.4	4.4	10.4
V2T1	113.95	1.355	18.4	4.8	12.0
V2T2	120	1.335	20.4	4.6	12.0
V2T3	127.5	1.34	21.6	5.2	15.1
V	ns	ns	ns	***	ns
T	***	***	***	***	***
VxT	ns	*	*	***	***

*, **, *** indicate significance levels $p<0.05$, $p<0.01$, $p<0.001$, ns denotes no significance

The influence of fertilization is also predominant at this parameter - fertilization has 93.93% share vs 6.06% share of irrigation in the formation of the thickness of stems of tomato plants. The combined effect of the two factors tested was also low, at only 0.03%. The treatments are divided into 4 homogeneous groups by fertilizer factor, and the differences between all treatments are statistically proven.

With an average of 18.992 leaves for the experiment, plants with full irrigation have only 0.9% more leaves than those with deficit irrigation. The performed two way ANOVA of the average data from the two years showed that the share of fertilization in the formation of the number of leaves is 78.83%, and - 0.46% share of irrigation. The combined effect of the two factors in the formation of the leaf structure is higher - 8.5%. The treatments are divided into 3 homogeneous groups by the factor fertilizer, but no statistical difference is proved between treatments by factor irrigation.

By number of inflorescences per plant, tomato plants under full irrigation formed more inflorescences in 2019 than those in 2020, although the climatic conditions were more favourable. In the better climate year 2020, tomato plants under deficit irrigation formed an average of 59.7% more inflorescences compared to 2019. For both experimental years, plants under full irrigation had 16% more inflorescences than those under deficit irrigation. ANOVA shows a high share of participation of both tested factors - 52.55% share of fertilization and 33.8% share of irrigation in the formation of inflorescences. The combined effect of both factors amounts to 9.77%. Regarding the formed inflorescences, the treatments are arranged in three homogeneous groups with proven differences between the treatments by factor fertilization. In addition, there are statistically proven differences between full and deficit irrigation treatments for this parameter.

The number of fruits per plant naturally increases with the fertilizer rate. With an average number of 12.64 fruits formed per plant for the two experimental years, the differences in the number due to the irrigation regime is insignificant - 1.43% in favour of the deficient irrigation. The share of fertilization in the formation of this important parameter is decisive - 91.09%, while the share of irrigation is only 2.42%. The combined effect of both factors on the fruit number is 4.18%. The treatments are arranged in four homogeneous groups with proven differences between all treatments by factor fertilization.

CONCLUSIONS

Obtaining sustainable yields is conditioned by the proper growth and development of tomato plants. The analysis of the growth process of tomato plants showed that the height and diameter of the stems, number of leaves, inflorescences and number of fruits of a plant are variable and are influenced mainly by the fertilization applied in the period of vegetative development. The tomato plants with a luxury fertilisation have the best development under both irrigation regimes.

Of all the studied growth parameters, only for the number of inflorescences for both experimental years 2019 and 2020, a statistically proven difference was found for the influence of irrigation. This finding is of great practical importance, as a priority of research in recent years is a determination of the best practice for the application of irrigation and fertigation for tomatoes to achieve optimal yield with maximum efficiency of fertilizers used and savings of irrigation water.

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