

Fruit yield, water and nitrogen use efficiency of tomato under drip irrigation in unheated greenhouse

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Abstract

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This study aimed at investigating the effects of two irrigation regimes (full and deficit irrigation), combined with four different fertilizer rates on fruit yield, irrigation water and fertilizer use efficiency of tomato (*Solanum lycopersicum*), grown in unheated greenhouse under mulched drip irrigation and fertigation. For two consecutive years (2019–2020), experiments were conducted on the experimental field in Chelopechene of ISSAPP „Nikola Pushkarov“, in Sofia, Bulgaria. Two irrigation rates (100% and 60% of crop evapotranspiration (ET_c)), under four fertilizer rates (unfertilized, 80% NPK, 100% NPK, 120% NPK), have been served as a treatment. The results showed that greater fruit yields were obtained in fully irrigated treatments. Application of the highest fertilizer rate (120% NPK) results in highest average total yield, both in fully irrigated (104.37 t ha⁻¹) and deficit irrigation (78.02 t ha⁻¹) treatments. Irrigation water use efficiency was higher under deficit irrigation and its maximum value (34.87 kg m⁻³ for 2020) was obtained with the highest fertilizer rate through fertigation. The highest nitrogen use efficiency (672.14 kg kg⁻¹) was obtained in the fully irrigated treatment with the highest fertilizer rate. The experimental results obtained in both years indicated that drip fertigation technology with appropriately selected levels of irrigation and fertilization could improve fruit yield and water and nutrient use efficiency of greenhouse tomatoes.

Keywords: tomato; drip irrigation; fertigation; mulch; water use efficiency; nitrogen use efficiency.

Introduction

Tomatoes are one of the most popular vegetable crops grown in the world. They are a healthy food both for fresh consumption and in processed form, due to their high nutritional value, vitamin C and lycopene content, which protect human health. Tomatoes are also one of the most preferred and consumed vegetable crops in Bulgaria. They are one of the most commonly grown crops in greenhouses. Unheated greenhouses are usually used for cultivation of tomato, in which the vegetable crop is cultivated directly into the soil. Unheated greenhouses rely on sunlight as only energy source and have a simplified design, making them inexpensive to build and maintain (Yuan et al., 2001). They are coated with plastic foil materials and provide a protected environment for

growing plants, in which some of the adverse weather factors can be eliminated, or reduced to plant-tolerable levels. Yield and quality of plant production exceed those obtained under open cultivation (Mahajan & Singh, 2006; Mitova et al., 2019).

Irrigation technology and the method of fertilizer application are the most important factors influencing the yield of the greenhouse crops. In recent years, drip irrigation is widely used in greenhouses, due to the possibility of frequent supplies of small amounts of water to be applied directly to the root zone of the plant, which significantly reduces evapotranspiration, improves water use efficiency and increases productivity (Machado et al., 2003). Fertigation has the advantage of improving the absorption of nutrients from the soil by crops, which includes preventing the loss of

fertilizer in the root zone. Fertigation through drip irrigation has a potential to improve irrigation yield and fertilizer use efficiency (Çetin & Akalp, 2019)

Efficient use of resources is of particular importance for obtaining sustainable production in greenhouse cultivation. To improve yields and water use efficiency, it is very important tomato plants to be supplied with the necessary amounts of water and fertilizers in different stages of their development. Proper irrigation practice should be based on an assessment of the actual water needs of crops. Evapotranspiration (ET), is most often used to assess water requirements of agricultural crops. There are various methods for estimating ET in greenhouse production. The FAO Penman-Monteith and Pan evaporation methods are suitable for determining the reference evapotranspiration in low-tech polyethylene greenhouses (Fernandez et al., 2010).

Recent studies in many countries around the world have shown that the precision management of water and fertilizers applied through drip irrigation system is a prerequisite for achieving optimal yields of high quality tomato. Many studies have focused on the effects of irrigation and fertilizer application on tomato yield, efficiency of use of water and fertilizers (Xiukang & Yingying, 2016, Du et al., 2017, Wang & Xing, 2018).

The present study aimed to analyze the effects of two irrigation regimes (full and deficit irrigation), combined with different levels of fertilization on yield and efficiency of use of water and mineral fertilizers of drip irrigated tomatoes grown in a unheated greenhouse.

Material and Methods

Experimental site and design: Experiments were conducted during the growing season (May-September), 2019 and 2020, in an unheated polyethylene greenhouse with dimensions of 7.9×53 m and a total area of 420 m² in the Chelopechene experimental field of the ISSAPP „Nikola Poushkarov”, in town of Sofia, Bulgaria. 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 of the experimental site is *Haplic chromic luvisol*, which can be defined as moderate to strong water-permeable with an average filtration capacity. The soil reaction is slightly acidic $\text{pHH}_2\text{O} - 6.1$; $\text{pHKCl} - 5.2$. The soil in the experimental plot has a low content of mineral nitrogen – 11.5 mg N / kg and medium to well stocked with mobile forms of phosphorus $\text{P}_2\text{O}_5 - 8.1$ mg P / 100g and potassium $\text{K}_2\text{O} - 18.0$ mg K / 100g. The terrain of the greenhouse is flat with a weak microrelief with a total slope of 1.0%.

The object of the study was tomato (*Solanum lycopersicum*) suitable for growing in the spring-summer period in unheated greenhouses.

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) and V2 – deficit irrigation (60% ETc). The factor fertilization was applied at four rates of NPK fertilization: T0 – without fertilization, T1 – suboptimal fertilization: 89.5 N–118.2 P_2O_5 –138.7 K_2O kg ha⁻¹; T2 – optimal fertilization: 115.9 N–158.4 P_2O_5 –177.4 K_2O kg ha⁻¹; T3: 145 N–201.3 P_2O_5 –218.8 K_2O kg ha⁻¹).

The experimental treatments V1T0, V1T1, V1T2, V1T3, V2T0, V2T1, V2T2, V2T3, were arranged, according to the method with long plots. Each plot has a surface of 24 m² and consisted of twin rows of tomato with a total of 81 plants. Tomato seedlings variety “Big Beef” F1 were planted „checkerboard“ at a spacing of 0.6 m and at a distance between rows of 0.5 m.

Fertilization: In the autumn of 2018, storage fertilization with 450 kg ha⁻¹ P_2O_5 and 500 kg ha⁻¹ K_2O was carried out was performed on the whole area of the experimental plot. Before planting the tomato seedlings, preplant nitrogen fertilization with ammonium nitrate NH_4NO_3 (450 kg ha⁻¹) was performed. A preplant dry fertilizer $\text{N}_{20}\text{P}_{20}\text{K}_{20}$ was applied on the whole experimental plot with a rate of 400 kg ha⁻¹ in 2020. Compared to the application of ammonium nitrate, superphosphate and potassium chloride separately in 2019, the application of the combined fertilizer in 2020, aimed to provide a balanced ratio of N: P: K to more fully meet the specific needs of tomato plants.

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 the following nutrients were applied: mineral fertilizer containing 16% N, 69% P_2O_5 and 16% K_2O after planting tomato; fertilizer containing 27% N, 27% P_2O_5 , 27 % K_2O during the vegetative development and in the period of fruiting the applied fertilizer contains 18% N, 11% P_2O_5 , 59% K_2O . The fertilizer rate was changed from 20 to 60 kg ha⁻¹.

In order to apply the exact fertilizer rate, a MixRite 2.5 hydraulic fertilizer injector and a water meter were used. During the growing season of tomato, fertigation with recommended fertilizer rate 120:100:80:0 NPK was given according to the treatments – a total of nine times at 7 days interval beginning 10 days after transplanting.

Irrigation: Immediately, after planting the tomato seedlings in a permanent place (April 23, 2019 and April 30,

2020), a watering of 1-2 l per plant was carried out to intercept seedlings. The irrigation started 7 days later. Watering was carried out with a frequency of 3-7 days depending on the growth stage of tomato plants. Deficit irrigation began to apply from the beginning of fruit setting.

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. Irrigation pipelines with built-in 60 cm drippers with a flow rate of 1.5 l/h were used. The volume of water supplied to the batteries was controlled by water meters mounted on the main pipelines. Mulching with black polyethylene mulch (UV 15 mic/1.20 m) was applied to further reducing evaporation.

Estimation of crop water requirement: In this study, the evapotranspiration of tomato was used to estimate current irrigation water requirements. The amount of water needed to irrigate the tomato plants was determined by the sum of daily values of evapotranspiration of tomato for the irrigation interval. Evapotranspiration of tomato was calculated by multiplying reference evapotranspiration with crop coefficient k , values (Doorenbos & Pruitt, 1977):

$$ETc = kc \sum_1^n ETo \quad (1)$$

where ETc is crop evapotranspiration of tomato, mm day^{-1} , ETo is reference evapotranspiration, mm day^{-1} , kc is crop coefficient, n is the number of days between waterings.

The reference evapotranspiration was calculated for each day of the vegetation period by the Penman-Monteith equation (Allen et al., 1998):

$$ETo = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2)$$

where: T is mean air temperature ($^{\circ}\text{C}$), Δ is slope of the saturated vapor pressure curve ($\text{kPa}/^{\circ}\text{C}$); R_n is net radiation flux

($\text{MJ m}^{-2} \text{day}^{-1}$); G is sensible heat flux into the soil ($\text{MJ m}^{-2} \text{day}^{-1}$); γ is psychrometric constant ($\text{kPa}/^{\circ}\text{C}$); u is wind speed at 2 m above the ground (m s^{-1}); e_a is mean daily ambient vapor pressure (kPa) and e_s is mean saturated vapor pressure (kPa).

In the present study, the single crop coefficient approach was used to determine the crop coefficient for different crop growth stages (Doorenbos & Pruitt, 1977; Allen et al., 1998). The linear curve for the crop coefficient k , was constructed on the basis of three values: $kc = 0.6$ for the initial period of tomato plant development from planting to the formation of 10% leaf mass, $kc = 1.19$ for the middle season and $kc = 0.85$ for the late season, identified from literature data (Allen et al., 1998).

Meteorological data required for the calculations of the evapotranspiration – temperature, relative humidity of the air and the solar radiation in the greenhouse, were collected from an automatic weather micro station and recorded in a data logger (HOBO USB Micro Data Logger, USA). The micro station was located in the center of the greenhouse.

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 in the greenhouse were favourable for medium early cultivation of tomato. They were characterized by optimal values of air temperature throughout the growing season. Due to similar climatic conditions, the length of the growing season of tomatoes in the two experimental years was the same – 17 weeks.

Fruit Yield: Harvesting tomatoes was carried out periodically during the fruiting, picking up all fruits that have reached full maturity. The fruit yield was read by weight (kg) and data were presented as ton per hectare ($\text{t}\cdot\text{ha}^{-1}$).

Irrigation water use efficiency (IWUE) was calculated from the total fruit yield divided by total water volume applied for irrigation (Sinclair et al., 1984):

Table 1. Average monthly solar radiation, maximum and minimum temperature and relative humidity, during the growing season 2019-2020

Parameter	Solar radiation		Temperature				Relative humidity,	
	W/m ²		Min, $^{\circ}\text{C}$		Max, $^{\circ}\text{C}$		%	
Year Month	2019	2020	2019	2020	2019	2020	2019	2020
May	108.7	132.98	7.1	2.64	25.8	41.14	62	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

$$IWUE = Y/W \quad (3)$$

where: IWUE is irrigation water use efficiency, kg m^{-3} , Y is total yield, kg ha^{-1} , W is total water volume utilized, $\text{m}^3 \text{ha}^{-1}$.

Nitrogen use efficiency (NUE) was calculated using the following equation (Aujla et al., 2007):

$$NUE = Y/N \quad (4)$$

where: NUE is nitrogen use efficiency (kg kg^{-1}), N is total fertilizer applied (kg ha^{-1}).

Statistical analysis: The experimental data were subjected to the analysis of variance (ANOVA) to evaluate the effects of different level of irrigation and fertilisation on yield, IWUE and NUE of tomato. SPSS Statistics (Version 21.0; IBM SPSS, NY, USA) and MS EXCEL were used to conduct the analysis. The significance of the effects of the applied irrigation regimes and fertilization rates and their interaction was statistically assessed at a significance level of $p < 0.05$. Comparison of treatment means was carried out using Duncan's multiple range test at significance level of $p < 0.05$.

Results and Discussion

Tomato evapotranspiration: Daily evapotranspiration of tomato for the entire growing season was calculated based on meteorological data: temperature, humidity and solar radiation in the greenhouse. Reference evapotranspiration ranged from 3.55 mm to 4.28 mm in 2019, and from 3.44 mm to 4.44 mm in 2020. An intensive increase of tomato evapotranspiration was observed during the vegetative phase of development in June for both experimental years. While in the first decade of June, the average daily evapotranspiration of tomato was 3.01 mm day^{-1} for 2019 and 2.94 mm day^{-1} for 2020, at the end of the month the evapotranspiration was 4.81

mm day^{-1} for 2019 and 4.02 mm day^{-1} for 2020. Evapotranspiration of tomato was highest during the fruiting period in July and August 2019- 2020. Average daily evapotranspiration was 4.76 mm day^{-1} for 2019 and 4.68 mm day^{-1} for 2020 in July and 4.63 mm day^{-1} for 2019 and 4.95 mm day^{-1} for 2020 in August.

In the phase of ripening, when the harvest began (July 15-17), evapotranspiration of tomato increased, and after each harvest it decreased. The highest daily evapotranspiration of tomatoes was observed in late July and early August – 5.1 mm day^{-1} for 2019, and – 5.18 mm day^{-1} for 2020. After mid-August, evapotranspiration began to decrease, and at the end of the growing season in September was 4.05 mm day^{-1} for 2019 and 4.31 mm day^{-1} for 2020.

Fruit yield: Experimental results for tomato fruit yield by treatments are given in Table 2. Yields in 2020 were higher than those in 2019, but identical responses of tomato plants subjected to irrigation and fertilization with different rates were observed in both experimental years.

Significantly higher tomato fruit yields were obtained in the fully irrigated treatments. The highest total yield (80.41 t ha^{-1} for 2019 and 128.33 t ha^{-1} for 2020) and yield per plant (2.38 kg for 2019 and 3.8 kg for 2020), were obtained from tomato plants receiving full irrigation ($100\% \text{ ET}_c$) and maximum fertilizer rate ($120\% \text{ NPK}$). The total yields of tomato plants under deficit irrigation were lower and the highest total yield (65.98 t ha^{-1} for 2019 and 90.7 t ha^{-1} for 2020), and yield per plant (1.95 kg for 2019 and 2.7 kg for 2020) were obtained again, when applying the maximum fertilizer rate.

The total yield of the tomato plants subjected to full irrigation was by 26-28% on average higher than the yield of the tomato plants subjected to deficit irrigation. Full irrigation, combined with optimal and luxury fertilization, main-

Table 2. Fruit yield and yield per plant as they are affected by different levels of irrigation and fertilization

Parameter	Total yield, t ha^{-1}			Yield per plant, kg		
	2019	2020	avg	2019	2020	avg
Year Treatment	2019	2020	avg	2019	2020	avg
V1T0	69.03	89.21	79.12	2.05	2.64	2.35
V1T1	71.01	89.88	80.44	2.10	2.66	2.38
V1T2	72.93	106.10	89.52	2.16	3.14	2.65
V1T3	80.41	128.33	104.37	2.38	3.80	3.09
V2T0	47.08	69.66	58.37	1.39	2.06	1.73
V2T1	47.10	70.15	58.62	1.40	2.08	1.74
V2T2	50.82	77.37	64.10	1.51	2.29	1.90
V2T3	65.98	90.07	78.02	1.95	2.67	2.31
V	0.007**	0.042*	0.019*	0.007**	0.043*	0.019*
T	ns	ns	ns	ns	ns	ns
VxT	0.012*	0.028*	0.019*	0.0084**	0.001**	0.006**

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

tain about 30% higher yield than the yield from the tomato plants grown under reduced irrigation and the same fertilization. Fruit yield differ significantly depending on the level of fertigation. The highest yield was achieved, when applying fertigation with a maximum fertilization rate, while fertigation with 80% of the fertilizer rate registered a significantly lower yield – from 10% to 30% – compared to higher levels of fertigation. The positive response of tomato to luxury fertilization at both levels of irrigation is likely due to the fact that the maximum fertilization rate best meets their nutrient needs. This may be considered the appropriate fertilisation rate for high tomato yield under low water supply.

The analysis of the variance of the experimental yield data for the two experimental years showed that the tomato yield was significantly affected by irrigation ($p < 0.05$), but was not affected by fertilization ($p > 0.05$) (Table 2). It was also found that the tomato yield of was affected by interaction of the irrigation and fertilization ($p < 0.05$).

Irrigation water use efficiency: The irrigation water use efficiency of tomato was determined by treatments to assess the effects of the irrigation regime, combined with different levels of fertilization. The results for IWUE are shown in Table 3. The irrigation water use efficiency was within 17.00 kg m^{-3} to 23.83 kg m^{-3} for 2019, and within 24.15 kg m^{-3} to 34.87 kg m^{-3} for 2020. IWUE increased more in the deficit irrigation treatments. This is because the reduction of the tomato yield in case of deficit irrigation is at a lower rate than the reduction of the amount of water delivered for irrigation.

Other researchers have also reported maximum values of water use efficiency in irrigation with reduced irrigation rate. (Nuruddin et al., 2003, Patané et al., 2011, Chen et al., 2013, Wang et al., 2015, Qu et al., 2019). On the other hand,

it has been found, that the highest values of the water use efficiency (23.83 kg m^{-3} for 2019 and 34.87 kg m^{-3} for 2020), were obtained in both irrigation regimes, when applying fertigation with maximum fertilizer rate (120% NPK). It can be assumed that the higher IWUE values were due to the higher fertilization rate.

Duncan's multiple range test was used for any significant differences among treatments at significance level $p < 0.05$. According to the test, the treatments were divided into two homogeneous groups. It was also found that the treatments with luxury fertilization (120% NPK) that achieved the highest water use efficiency were significantly different statistically from the others treatments.

It can be concluded, an improvement of IWUE to the greatest extent can be achieved when applying a moderate water deficit combined with maximum fertilizer rate. This is consistent with the results obtained by Wang et al. (2015) and Wang & Xing (2018).

Nitrogen use efficiency: Table 3 shows also the nitrogen use efficiency of tomato determined by treatments for 2019 and 2020. The analysis of variance of data showed that the level of irrigation has a high significant effect on NUE ($p < 0.01$). For the same fertilizer rate, NUE was higher in fully irrigated treatments (100% ETC). The highest values of the nitrogen use efficiency (473.8 kg kg^{-1} for 2019 and $672.14 \text{ kg kg}^{-1}$ for 2020), were obtained in the fully irrigated treatments and applying of fertigation with a fertilizer rate of 80% NPK in 2019 and 120% NPK in 2020. It should be noted that the maximum values of NUE were at full irrigation. This means that, when tomato plants were properly irrigated with an amount of water corresponding to their water requirements, they can effectively use the nutrients supplied

Table 3. Irrigation water use efficiency and nitrogen use efficiency of tomato, as they are affected by different levels of irrigation and fertilization

Parameter	IWUE, (kg m^{-3})			NUE, (kg kg^{-1})				
	Year	Treatment	2019	2020	avg	2019	2020	avg
V1T0			17.25a	23.97a	20.61a	–	–	–
V1T1			17.75a	24.15a	20.95a	473.80a	559.69a	516.75a
V1T2			18.23ab	28.5ab	23.37a	453.44a	618.52a	535.98a
V1T3			20.1b	34.48b	27.29b	446.17a	672.14a	559.16a
V2T0			17a	26.97a	21.99a	–	–	–
V2T1			17.01a	27.16a	22.09a	314.29a	436.83a	375.56a
V2T2			18.35ab	29.96ab	24.15a	315.97a	451.03a	383.50a
V2T3			23.83b	34.87b	29.35b	366.11a	471.73a	418.92a
V			ns	ns	ns	0.003***	0.009**	0.001***
T			ns	0.013*	0.006**	ns	ns	ns
VxT			0.004**	0.04*	0.013*	0.013*	0.012*	0.038*

*, **, ***, indicate significance levels $p < 0.05$, $p < 0.001$, ns denotes no significance. Different letters at data under treatments indicate significant difference between treatment according to Duncan multiple range test at $p < 0.05$.

Table 4. Correlation matrix between fruit yield, WUE и NUE

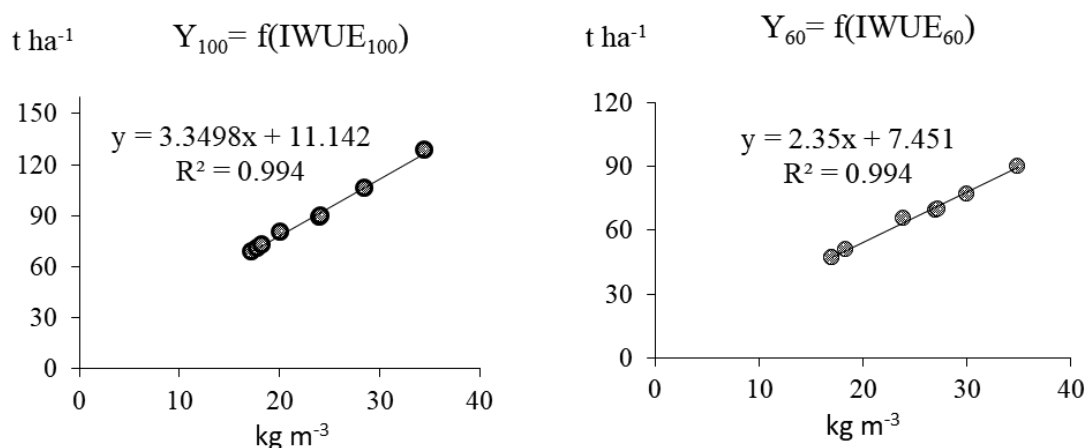
	Y100	Y60	IWUE100	IWUE60	NUE100	NUE60
Y100	1					
Y60	.955**	1				
IWUE100	.997**	.960**	1			
IWUE60	.960**	.996**	.969**	1		
NUE100	.953**	.881*	.968**	.919**	1	
NUE60	.907*	.956**	.927**	.974**	.917*	1

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Note: Y100, IWUE100, NUE100 are fruit yield, IWUE и NUE in fully irrigated treatments (100% ETc).

Y60, IWUE60, NUE60 are fruit yield, IWUE и NUE in deficit irrigation treatments (60% ETc).

**Fig. 1. Relationship between IWUE and fruit yield**

by the drip irrigation system. In the experiment in 2019, the highest value of NUE was obtained at the lowest fertilization level (80% NPK). Other researchers have also observed that maximum nitrogen use efficiency occur when applying a low level of fertilization (Zotarelli et al. 2009, Qu et al. 2019).

The nitrogen use efficiency was influenced by the level of nitrogen supplied. NUE increased with increasing fertilizer rate in deficit irrigation treatments in both experimental years, as well as in full irrigated treatments in 2020. Increasing the nitrogen use efficiency with increasing fertilizer rate shows the high response of tomato yield to nitrogen fertilization through fertigation.

Analysis of variance of the experimental results by treatments showed that the interactions between irrigation and fertilization for fruit yield, WUE and NUE were statistically significant ($p < 0.05$). Correlation analysis was performed to establish a relationship between fruit yield, WUE and NUE (Table 4.).

The correlation between IWUE and fruit yield, obtained under each of both studied irrigation regimes (100 and 60

% ETc) was positive and strong. The correlation coefficients were close to 1 ($R = 0.997$ for fully irrigated treatments and $R = 0.996$ for deficit irrigation treatments). Using linear regression analysis empirical dependences between IWUE and fruit yield have been derived. Figure 1 shows the obtained linear regression models. The equations were statistically significant at level $p < 0.05$. The coefficients in front of the independent variable, as well as the constants of the linear regression models were statistically significant at the same level of significance ($p < 0.05$). The results confirm that IWUE is strongly related to the applied irrigation regime. Irrigation water use efficiency increases when the amount of water applied for irrigation is reduced. This corresponds to a greater increase in yield achieved with smaller amounts of irrigation water.

Conclusions

The results indicate that full irrigation with an irrigation rate determined by evapotranspiration (100% ETc) was most

suitable for good development of the tomato plants and obtaining high yields. The average fruit yield was 104.37 t ha⁻¹ against 78.02 t ha⁻¹ under deficit irrigation. The results, obtained for both years also showed that the tomato yield was highest in both irrigation regimes, when applying fertigation with the highest fertilizer rate T3 (145N–201.3 P₂O₅–218.8 K₂O kg ha⁻¹). This study found similar results in terms of the water and fertilizer use efficiency. IWUE increased with decreasing irrigation level and was highest when applying deficit irrigation and fertigation with the highest fertilizer rate T3 (34.87 kg m⁻³ for 2020). The highest NUE (672.14 kg kg⁻¹ for 2020) was obtained under full irrigation (100% ETc) and fertigation with the highest fertilizer rate T3.

The obtained results show that if there is a need to save water, a reduction in the irrigation rate can be applied, and deficit irrigation can be optimized by applying a higher fertilizer rate.

Statistical analysis of data showed that the interaction between the individual experimental factors: irrigation and fertilization was statistically significant ($p < 0.05$) for all studied parameters: fruit yield, IWUE and NUE of tomatoes. This result shows that the application of drip fertigation technology with an appropriate combination between the water amount supplied for irrigation and a dose of nitrogen contribute to higher tomato yield and water and nutrient use efficiency.

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