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Evaluation of deficit irrigation regime, row spacing and dual plantation of drip irrigated tomato under high tunnel

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ABSTRACT

The present study was carried out at Water Management Research Centre, University of Agriculture, Faisalabad, Pakistan, to investigate the effect of row spacing, deficit irrigation and dual plantation on tomato yield grown in high tunnel under polyethylene black mulch and drip irrigation system. The field experiment layout comprised of three rows spacing (S1, S2 and S3) as (0.45, 0.60, and 0.75 m respectively) and two irrigation levels (I1 and I2) as (100% and 75% of required irrigation respectively). In addition, a dual plantation treatment spaced at 0.45 m was also investigated under both irrigation levels. Results showed that the total fruit yield was significantly influenced by row spacing and irrigation level, however, their interaction was non-significant. The 100% irrigation gave 6.53, 4.49, and 5.94% more yield than 75% irrigation treatment under 0.45, 0.60, and 0.75 m row spacing, respectively. However, the irrigation water use efficiency was found to be higher in deficit treatment (75% irrigation) by 25.16, 27.60, and 25.86% than full irrigation treatments under 0.45, 0.60, and 0.75 m row spacing, respectively. The results of single and dual plantation showed that dual plantation increased the fruit yield by 7.62 and 11.28% than the single plantation under full and deficit irrigation respectively and covering approximately the same area.

Keywords: deficit irrigation, dual plantation, high tunnel, row spacing, tomato yield

INTRODUCTION

The growing water crises coupled with sustainable use of water in agriculture has become a serious concern. In many parts of the world, water is gradually becoming a scarce commodity and its availability reduce in agriculture due to rapid population growth, urbanization and industrialization. This scarcity situation become worsen due to improper management. To prevent the water shortage scenarios, irrigated agriculture requires intensive management of limited and expensive water supplies. Insufficient water supply for irrigation will be the norm rather than the exception, and irrigation management will shift from emphasizing production per unit area towards maximizing the production per drop of water. Drip irrigated deficit water supplies is the leading approach with the most efficient water use in irrigated agriculture. Numerous researches had been carried out about advantages of drip irrigation over the other methods in cotton (Hussein et al., 2011), wheat (Ansari et al., 2019a, 2019b), maize (Sandhu et al., 2019), tomato (Zhai et al., 2010), pepper (Edossa and Emana, 2011) and cucumber (Kirnak and Demirtas, 2006). It reduces water use without significant yield reduction thus maximizing farmers profit (Kirda et al., 2005).

Vegetable crops are the eminent source of human nutrition and represent a dynamic segment of Pakistan's agriculture. Despite high returns, non-availability of irrigation water is hampering the expansion of vegetables cultivated area (Iqbal et al., 2014). Commercial production of vegetable is not possible without adequate water availability throughout the growing season. Tomato occupies a distinct place among all vegetable crops in Pakistan and ranks second next only to potato in area and production. It grown over an area of 58,359 hectare which produced 5,50,979 metric tons of tomato (GOP, 2019).

Optimum row spacing is very important for higher productivity of tomato and significantly affected fruit yield in both processing and fresh market tomatoes (Rashid et al., 2016; Assefa et al., 2015; Law-ogbomo and Egharevba, 2008). It helps in efficient use of available resources such as water, light and soil nutrients (Assefa et al., 2015; Law-ogbomo and Egharevba, 2009). The optimum spacing allows to use maximum space while maintaining air circulation, reducing risk of fungal diseases including botrytis and leaf mold (Eaton, 2016).

A high tunnel without a permanent electrically powered heating or ventilation system, covered with one layer of plastic, and sited on field soil was installed in this study. This tunnel may not be able to protect crops from temperature up to the same extent as electrically powered green houses, however they are inexpensive to build and operate (Rashid et al., 2016). It not only creates and maintain a controlled environment which fosters optimum crop production, but also increases irrigation water use efficiency and produces yields that are about five to ten times greater than in the field (Vox et al., 2010). Numerous researchers have reported the use of row covers and plastic tunnels over the row crop for temperature augmentation, better moisture conservation, abolition of insects, and decrease in plant desiccation (Cowan et al., 2014; Eaton, 2016; Rashid et al., 2016).

The use of black plastic mulch in high tunnel tomato production is common practice as it increases soil temperature, shorten growth period, controls weeds and conserves soil moisture which can improve crop yields and quality, and consequently, the economic sustainability of vegetable production (Jett, 2004; Cowan et al., 2014; Eaton, 2016). For maximum effectiveness, black plastic mulch should be in good contact with the surface of the bed for effective transfer of heat.

Keeping in view the importance of tomato and water scarcity, the present study was undertaken with the objective to investigate an optimum row spacing and drip irrigated deficit level for obtaining maximum yield and irrigation water use efficiency of tomato under high tunnel condition.

MATERIALS AND METHODS

Experimental Site

The experiment was conducted during period of winter 2014-2015 at Water Management Research Centre, University of Agriculture Faisalabad, Faisalabad, located in Rachna Doab (land between rivers Chenab and Ravi), latitude of 31.250 N and longitude of 73.090 E and altitude of 184.4 m above mean sea level (MSL). The local climate of the area is semi-arid with an average rainfall of 350 mm, concentrated mostly over the months of June–August. The soil in the area is medium texture and texturally structurally homogeneous up to a depth of 1 to 4 m. The physical and chemical properties of the soil at the experimental crop field are given in (Table 1).

Crop husbandry

The selected field was first tilled with disk plough and cultivator, and then leveled properly. Beds were constructed with the help of bed planter and covered with black plastic mulch tightly over the beds for effective transfer of heat. Although the white or clear mulch will increase soil temperature significantly more than black mulch, however weeds will emerge under the clear film (Jett, 2004). A 55 m long, 9 m wide and 3.5 m high tunnel was erected with the PVC pipe material and covered with plastic of 12 guage. The suckers of already cultivated tomato (*Lycopersicon Esculentum*, cultivar Sahil F1) under tunnel were used as nursery for the cultivation of new crop. Sahel is an indeterminate saladette hybrid tomato for fresh market with medium-strong vigour and can be sown in winter and spring. Seedling of tomato was transplanted to raise beds on November 20, 2014 after 30 days of nursery raising in double row planting geometry and row to row distance on each bed was kept according to three spacing treatments (0.45, 0.60, and 0.76 m). While planting, small holes were made in the soil for each transplant. The seedling has placed one by one in the hole produced by auger. Four types of fertilizers i) Urea ii) Di-Ammonium Phosphate (DAP) iii) Muriate of Potash (MOP) and iv) Sulfate of Potash (SOP) were applied through fertigation to provide N-P-K @ 135-60-100 kg/ha. Plant protection measures including spray and all other cultural practices were also carried out during its growth period whenever required for all the treatments.

Experimental design and treatments

The experiment was laid out in randomized complete block design (RCBD) with split plot arrangements by keeping three rows spacing (S1, S2, S3) and two irrigation levels (I1, I2) in main plots and sub plots respectively. Apart from these six treatments, a dual plantation treatment spaced at 0.45 m was also investigated under both irrigation levels. All eight treatments were replicated thrice. The total tunnel area was 500 m^2, divided into 24 plots of equal size. All plots will receive direct irrigation through drip lateral lines. The layout of the experimental units is shown in (Figure 1).

Row Spacing	**Irrigation**
S1 = 0.45 meter	I1 = 100% Irrigation
S2 = 0.60 meter	I2 = 75% Irrigation
S3 = 0.75 meter	

Description of drip irrigation system

Irrigation was applied after every two days through drip irrigation system. Depth of irrigation was calculated by using following equation:

$$Depth=((FC-MC)/100) \times B.D \times RD$$

where, FC is field capacity, MC is moisture content, B.D is bulk density in (g/cm^3) and RD is rooting depth in (cm). Moisture content was measured with the help of time domain reflectometer (TDR).

Application rate (AR) was calculated by using following equation:

$$AR=ED/(ES \times LS)$$

where, ED is emitter discharge in (L/hr), ES is emitter spacing in (m) and LS is lateral spacing in (m).

Operational time (OT) was calculated by using following equation:

$$OT=depth/AR$$

Table 1. Physical and Chemical Properties of soil

Properties	**Parameters**	**Soil Depth Layers (cm)**		
		0-15	**16-30**	**31-45**
Physical Properties	Sand (%)	63	67	66
	Silt (%)	23	19	18
	Clay (%)	14	14	16
	Soil Type	Sandy Loam	Sandy Loam	Sandy Loam
	Bulk Density (g/c^3)	1.54	1.56	1.55
	Field Capacity (%)	21.7	21.3	21.8
	Wilting Point (%)	8.42	8.00	8.45
Chemical Properties	pH	8.40	8.27	8.25
	EC (dS/m)	1.32	1.30	1.33
	Organic Matter (%)	0.45	0.43	0.46
	Potassium (ppm)	1.80	1.70	1.50
	Phosphorous (ppm)	100	87	73

Spacing	Single Plantation						Dual Plantation	
	S1		S2		S3		S1	
Irrigation	I1	I2	I1	I2	I1	I2	I1	I2
R1	S1I1R1	S1I2R1	S2I1R1	S2I2R1	S3I1R1	S3I2R1	(S1I1R1)d	(S1I2R1)d
R2	S1I1R2	S1I2R2	S2I1R2	S2I2R2	S3I1R2	S3I2R2	(S1I1R2)d	(S1I2R2)d
R3	S1I1R3	S1I2R3	S2I1R3	S2I2R3	S3I1R3	S3I2R3	(S1I1R3)d	(S1I2R3)d

Figure 1. Field layout of experimental units

Data collection

Data regarding yield, water used, tunnel inside and outside temperature were recorded during the experiment. Fifteen plants were selected randomly from each treatment for determination of plant height, and tomato yield. The ratio of tomato yield to total water applied to crop was measured to estimate irrigation water use efficiency (IWUE).

Statistical Analysis

The collected data was statistically analyzed using Analysis of variance (ANOVA) with comparison of means using Least Square Distance (LSD) test at $P \leq 0.05$.

RESULTS AND DISCUSSION

Tunnel Temperature Management

Tomato temperature tolerance for extreme heat or cold snaps is one of the most critical components of successful tunnel farming especially to the development of flowers and subsequent fruit set (Jett, 2004; Kotei et al., 2019). For this purpose, average daily temperature inside and outside of the tunnel was monitored throughout the season by placing thermometer at different locations in the tunnel at the height of the tomato canopy. Shade was provided to thermometer to avoid false high readings due to direct exposure to sunlight. The average daily temperature inside and outside of the tunnel is shown in (Figure 2). The vents were adjusted to maintain an optimum temperature. The optimum temperature for growth of the tomato plant is 21-24 °C and average daily temperatures should not be lower than 18.5 °C (Jett, 2004). Temperatures below 13 °C during flowering can reduce fruit set and produce misshapen fruit (Jett, 2004; Amy, 2018; Kotei et al., 2019). Inside of the tunnel, temperature was monitored at three locations i-e start, mid and end of the tunnel length. The temperature was maximum at mid of the tunnel and minimum at the start

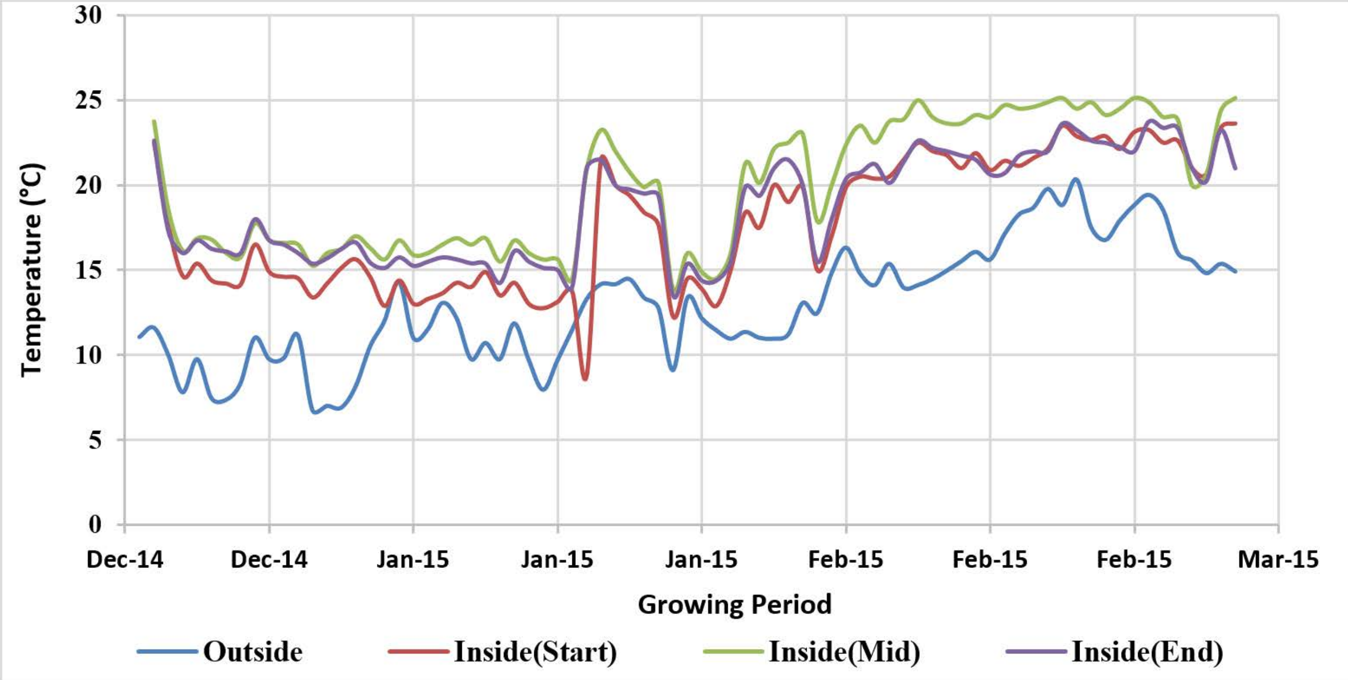

Figure 2. Temperature variations inside and outside of the tunnel for the growing period

of the tunnel. This slight difference in temperature is due to the opening of the tunnel door.

The difference between average daily temperature inside and outside of the tunnel was in the range of 4-12 °C. This increase in inside tunnel temperature attributed to the raised bed and plastic mulch. Jett (2004) also reported that average daily temperature of high tunnel was significantly increase by using raised beds, plastic mulch and row covers.

Regarding the inside tunnel temperature, it varies from 15 to 17 °C in the first half of the season and increased up to 22 to 25 °C in the end of the growing period as outside temperature increased significantly. Vents provided in the tunnel were used to prevent further increase in tunnel inside temperature as extremely high temperatures (above 32 °C) can cause tomato flowers of some cultivars to abscise and produce non-uniform red colour (Jett, 2004).

Plant Height

The data regarding plant height was measured from fifteen randomly tagged plants of each treatment at weekly interval and average final height of each treatment is shown in (Figure 3). The plants having more spacing (0.75 m) showed maximum height (2.45 and 2.38 m) and the least spaced (0.45 m) plants produce minimum height (2.28 and 2.26 m) under I1 and I2 treatments, respectively. Regarding to irrigation treatments, full irrigation treatments showed more heighted plants as compared to deficit treatments (75% irrigation). This may be due to the easily availability of enough space and water to plants for air circulation and growth. The tallest plants (2.45 m) were observed in plots having full irrigation and 0.75 m spacing, while the shortest plants (2.24 m) were observed by the plots having full irrigation and least spaced (0.45 m) treatment. The statistical analysis showed that spacing, irrigation levels and their interaction have non-significant effect on plant height at 5% significance level (Table 2). Since all treatments received nitrogen at the same rate which is a basic component of plant and important for vegetative growth, thus causing not considerable difference in plant height. Rashid et al. (2016) found that nitrogen levels had significant influenced on tomato plant height while row spacing had no significant effect. Berihun (2011) also stated non-significant effect of water stress on plant height.

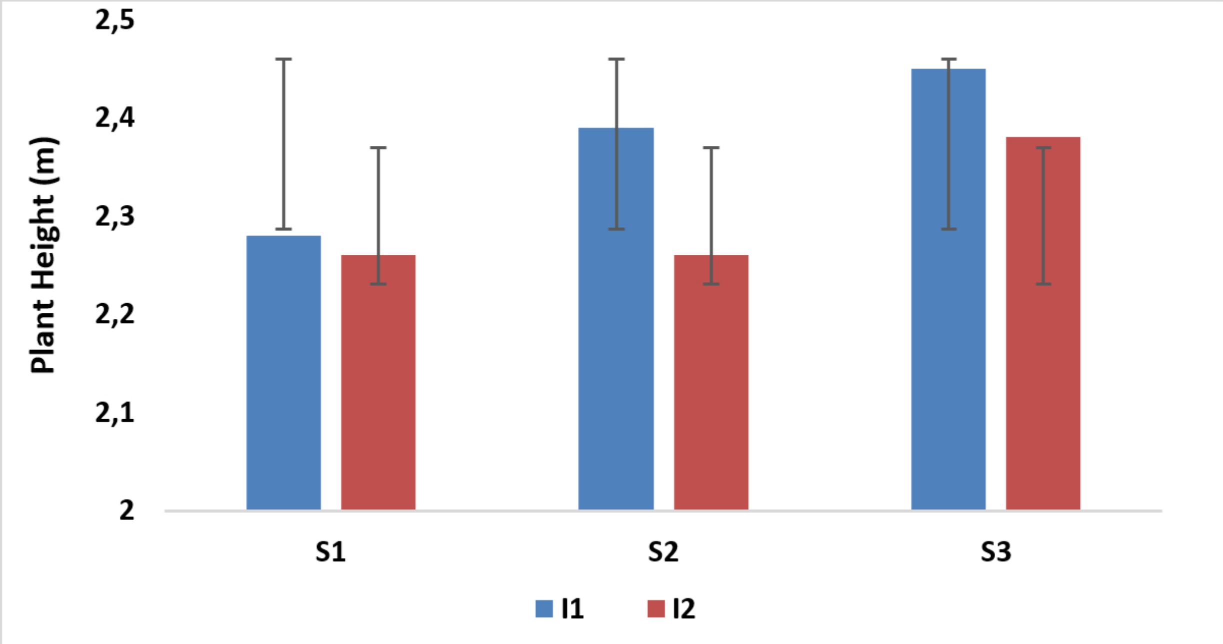

Figure 3. Effect of row spacing and irrigation level on tomato plant height

Table 2. ANOVA for tomato plant height

Source of Variation (SOV)	Degree of Freedom (D.F)	Sum of Square (SS)	Mean Sum of Square (MSS)	Fcal	Ftab
Spacing(S)	2	0.271	0.135	0.779$^{n.s}$	5.14
Error (Main plots)	6	0.313	0.052		
Irrigation (I)	1	0.079	0.079	0.22 $^{n.s}$	5.99
S×I	2	0.030	0.015	0.043 $^{n.s}$	5.14
Error (Sub plots)	6	0.63	0.0154		
Total	17				

^{ns} non-significant

Number of fruits per plant

Data for number of fruits per plant were collected from five randomly selected plants in each sub plots and then average them. The data regarding row spacing and irrigation levels for number of fruits per plant is shown in (Table 3). The maximum number of fruits per plant (56.2) was produced by the plots having more spacing (0.75 m), while the minimum number of fruits per plant (47.4) was recorded in least spaced plots (0.45 m) under I1 and I2 irrigation levels respectively. The 100% irrigation level produced a greater number of fruits per plant than reduced irrigation level (75%) under all spacing plots. The statistical analysis revealed that spacing and irrigation level significantly influenced the number of fruits per plant, however, their interaction showed non-significant effect at 5%. More number of fruits per plant recorded at most spaced plots might be due to the maximum uptake of nutrients as there was less competition among plants, more nutrients positively influenced vegetative growth and photosynthates production ultimately resulting increased store food. These stored foods in turn increase fruits per plant. Rashid et al. (2016) reported the greater number of fruits per plant at 0.90 m spacing while number of fruits per plant decrease in plots having spaced 1.20 m.

Table 3. Impact of row spacing and irrigation level on number of fruits per plant

Irrigation (%)	Row Spacing (m)			Mean (Irrigation Effect)
	0.45	0.60	0.75	
100	48.6	51.6	56.2	52.13[a]
75	47.4	49.0	53.4	49.93[b]
Mean (Spacing Effect)	48.0[b]	50.3[a]	54.8[b]	

LSD for row spacing: 2.519
LSD for row irrigation: 2.054
Means followed by the same letter(s) do not differ significantly from one another at 5% probability level, using LSD test

Fruit yield (tons/ha)

The effect of row spacing and irrigation levels on tomato fruit yield is given in (Table 4). The row spacing and irrigation level significantly influenced fruit yield, however, interaction was recorded non- significant. Maximum fruit yield (45.04 tons/ha) was produced by the plots having 0.45 m row spacing whereas; minimum yield (40.23 tons/ha) was produced by the plots having 0.75 m row spacing under full (100%) and deficit (75%) irrigation treatment respectively. Regarding to row spacing, plots having 0.45 m row spacing produce more yield than 0.60 and 0.75 m row spacing. Although the total fruit yield achieved was not very high but similar results were obtained by Aslam et al. (2018) on same tomato cultivar under high tunnel with little different practices. This may be attributed to the medium-strong vigour of cultivar along with adequate nitrogen rates enhanced vegetative growth of plants very well, however the low potassium contents in soil and its availability to plants effect the reproductive growth, lead to low fruit yield. To enhance the availability or/and extraction of micro and macronutrients to plants for higher and good quality fruit yield can be improved with the inoculation of bio fertilizer such as Plant growth promoting rhizobacteria and arbuscular mycorrhizae (Bakr et al., 2018; Le et al., 2018a, 2018b). Regarding to irrigation treatments, 100% irrigation gave 6.53, 4.49, and 5.94% more fruit yield than 75% irrigation treatment under 0.45, 0.60, and 0.75 m row spacing, respectively. However, the irrigation water use efficiency (IWUE) was found to be higher in deficit treatment (75% irrigation) by 25.16, 27.60, and 25.86% than full irrigation treatments under 0.45, 0.60, and 0.75 m row spacing respectively (Figure 4). Improving IWUE through deficit irrigation requires to either reduce water consumption without yield reduction or increase yield with an equal water consumption based on the physiological responses of crops. Previous studies had proved that deficit irrigation could decrease crop redundant growth, minimize water use and improve IWUE with little or no yield reduction (dos-Santos et al., 2007; Du and Kang, 2011; Yang et al., 2017). Water deficit increased leaf abscisic acid and then led to the closure of leaf stomata, therefore reduced the water loss through transpiration (Zhang et al., 2015). The findings of Wang et al. (2015) showed that lower water consumption and higher yield resulted in the highest IWUE of tomato in the deficit irrigation treatment. These findings indicated a slightly decline in fruit yield with reduction in irrigation water, however, the IWUE remained high in deficit treatments.

Single vs dual Plantation

In dual plantation plot, two plants were sown in a single hole on raised bed at 0.45 m row spacing and compared the fruit yield with single plantation plot having same row spacing under full and deficit irrigation level. The stems of two plants were stick together with tape and after 2-3 weeks they were like one plant at the bottom. The less vigorous stem of two plants were cut down and let this tomato tree grow approximately on the same area underground. The results are presented in (Figure 5) and it shows that dual plantation increased the fruit yield by 7.62 and 11.28% than the single plantation under full and deficit irrigation, respectively.

Table 4. Impact of row spacing and irrigation level on fruit yield (tons/ha) of tomato

Irrigation (%)	Row Spacing (m)			Mean (Irrigation Effect)
	0.45	0.60	0.75	
100	45.04	43.48	42.62	43.71[a]
75	42.28	41.61	40.23	41.37[b]
Mean (Spacing Effect)	43.66[a]	42.55[ab]	41.43[b]	

LSD for row spacing: 1.658
LSD for row irrigation: 1.558
Means followed by the same letter(s) do not differ significantly from one another at 5% probability level, using LSD test

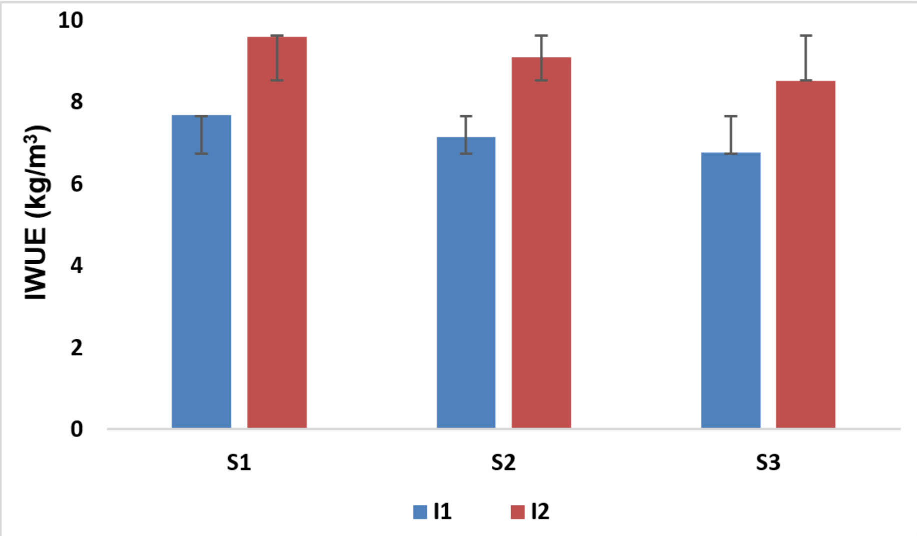

Figure 4. Effect of row spacing and irrigation level on tomato irrigation water use efficiency (IWUE)

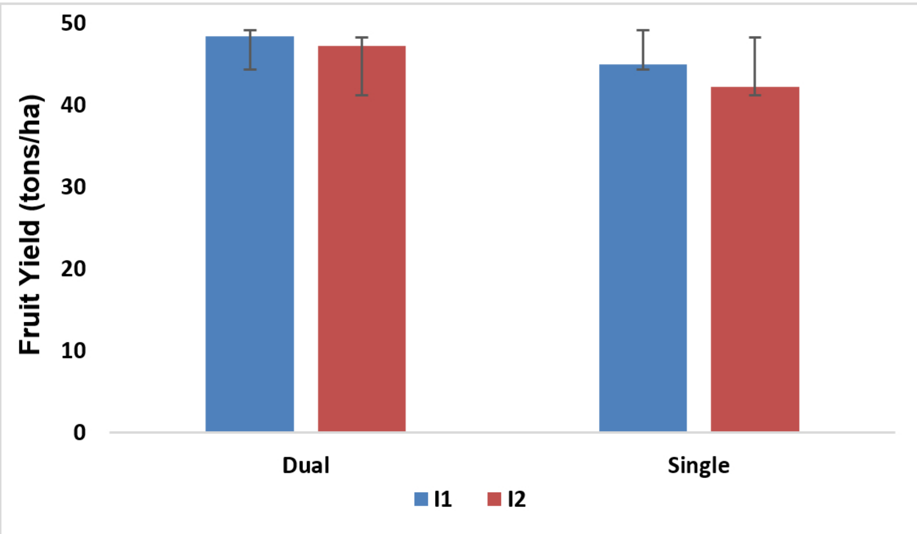

Figure 5. Effect of single and dual plantation at 0.45 m row spacing on tomato fruit yield

The increase in fruit yield of dual plantation plots is may be due to the fact that it reduced the direct exposure of sunlight to the plant. As the crop moves from cooler to hotter months, the increased light intensities and associated increase in temperature serves to put more stress on the plants (Government of Alberta, 2019). Increased stress directs the plants to become more generative and allow for more leaves to shade the fruit and reduced fruit quality problems associated with overheating, shrink cracking and blossom end rot. Not a single published experimental finding on dual plantation was found by authors, however, general discussion regarding two plants in a hole is available on Tomatoville, Gardening Forums Index (2006).

CONCLUSIONS

In summary, this study investigated the effect of row spacing and deficit irrigation on fruit yield and IWUE of plastic tunnel tomato under mulch and drip irrigation. Results showed that the total fruit yield was significantly influenced by row spacing and irrigation level, however, the effect on plant height was non-significant. Maximum fruit yield (45.04 tons/ha or 0.130 tons/28.83 m^2) was observed with 0.45 m row spacing whereas; minimum fruit yield (40.23 tons/ha or 0.116 tons/28.83 m^2) was observed with the plots having 0.75 m row spacing under full (100%) and deficit (75%) irrigation treatment respectively. In case of row spacing, the plots having 0.45 m row spacing gave best result for fruit yield while 0.75 m row spacing gave least fruit yield. Regarding to irrigation treatments, 100% irrigation gave more yield than 75% irrigation, however, IWUE was found to be high in deficit irrigation treatments under all row spacing. Hence, the use of deficit irrigation, as opposed to the adequate supply of water, produced slightly less tomato fruit yield but increase fruit yield per drop of water with optimum row spacing, making it a good alternative to use to extend water supplies. In addition, the nutrients management is vital to maintain the balance between vegetative and reproductive growth. The results of single and dual plantation showed that dual plantation increased the fruit yield by 7.62 and 11.28% than the single plantation under full and deficit irrigation respectively and covering approximately the same area.

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