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Original article

Light extinction coefficient and radiation use efficiency in different growth stages of tomato exposed to different irrigation regimes

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Extended abstract

Introduction

A prerequisite to model crop growth is an appropriate quantification of crop canopy structure in response to management and environmental conditions. Under water stress, the light distributions over canopy depth are more complicated because water stress affects not only appearance and elongation of leaves, but also morphological aspects of leaf positioning, leaf angle and azimuth angle (Archontoulis et al., 2011). Water stress reduces RUE by preventing effective photosynthesis for growth due to lower intercepted PAR as a result of reduced leaf area and leaf rolling or wilting (Wilson and Jamieson, 1985; Xianshi et al., 1998; Ngugi et al., 2013).

We devised a two-year field experiment under different irrigation regimes at the two stage growths tomato with the aims of quantifying and describing the response of canopy light extinction coefficient, radiation use efficiencies, leaf area index and yield to reduced water at vegetative and reproductive stages of tomato in order to obtaining the best yield .

Materials and methods

A field experiment was conducted over two consecutive seasons (2016-2017) in the experimental field of Ferdowsi University of Mashhad located in Khorasan Razavi province, North East of Iran. The experiment was laid out in a split plot design with different irrigation regimes at the reproductive and at the vegetative stage as the main and subplot factors, replicated thrice. The following experimental factors were studied: three irrigation regimes (100= 100% of water requirement, 75= 75% of water requirement, 50= 50% of water requirement) and two crop growth stages (V= vegetative stage and R= Reproductive stage). The drip irrigation method was used for irrigation. The tomato water requirement was calculated using CROPWAT 8.0 software. The irrigation water was supplied based on total gross irrigation and obtained irrigation schedule of CROPWAT. In the both growing seasons, plant growth and physiological parameters were assessed in two weekly intervals on two plants per plot starting 45 days after transplanting (DAT) up to 145 DAT .

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Results

Leaf area index (LAI) of tomato varied between irrigation regimes. According to ANOVA, the treatments had a significant effect on maximum LAI in both years (Table 5).

The fraction of PAR intercepted by tomato canopy, measured in two years of study, increased from a few days after transplanting (May) onwards, reaching its maximum value in mid-August (around 100 DAT) in all treatments and later on decreased with progress of season till final measurement except 75V-100R and 50V-100R where the fraction of intercepted PAR raised up to the end of growing season (Fig. 5). As shown in Fig. 4, with increasing LAI, the transmitted fraction of radiation through the canopy decreased exponentially in all treatments. The highest and lowest k value was recorded by full irrigation treatment with 0.69 and 50V-50R treatment with 0.41, respectively. k values were strongly variable among different irrigation regimes.

RUE altered according to amount of water applied at different growth stages. In this research, RUE values ranged from 0.38 to 0.9 g MJ^{-1}. However, applying irrigation during vegetative stages could accelerate increase in leaf area, light interception and photosynthesis (Comas et al., 2019) and, thus, improve RUE.

Timing of water stress had a significant effect ($P<0.01$) on total fresh and dry fruit yield in both years of the experiment (Table 6). In general, tomato yield increased as the amount of irrigation water increased, however it was severely affected by timing applied irrigation. In 2016 and 2017 total fresh fruit approached 99.81 and 101.01 t ha^{-1} under full irrigation (100V-100R), significantly greater than that produced under full deficit irrigation (50V-50R) with 22.2 and 15.66 t ha^{-1}, respectively (Fig. 7).

Conclusion

The experiment results clearly indicate adverse effect of water shortage on tomato yield, so that the highest fresh yield was obtained with full irrigation. However, the results suggest that this adverse effect can be reduced by a proper irrigation management at different growth stages. We showed that the effect of water provided at sensitive growth stage on the productivity of tomato was largely due to the positive effect of water apply on RUE.

***Keywords*:** Absorbed radiation, CropWat software, Deficit Irrigation, Drip irrigation, light extinction coefficient

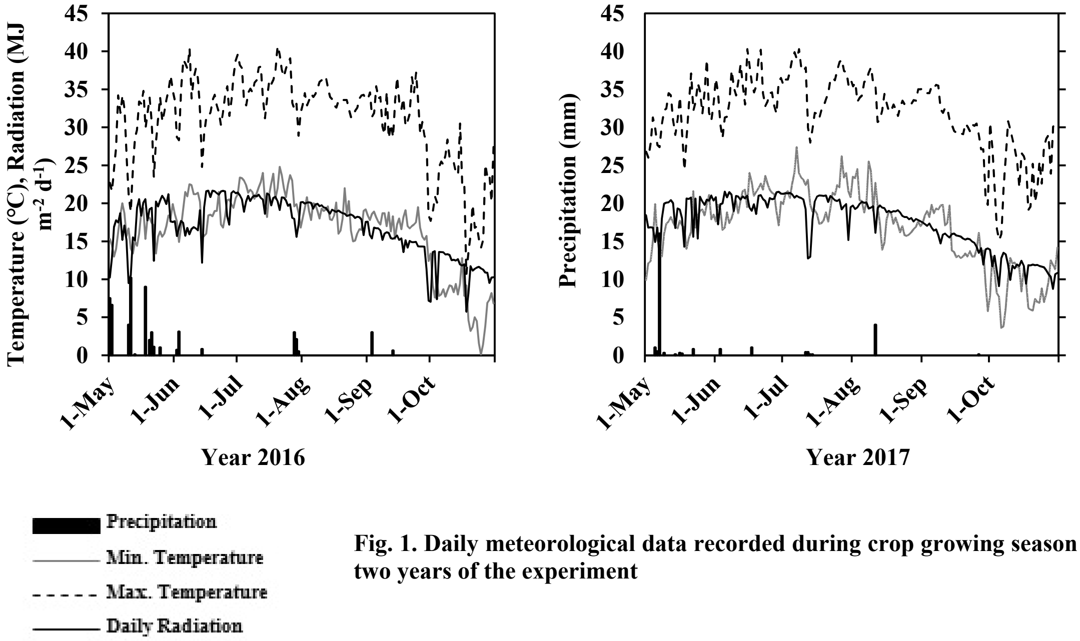


Fig. 1. Daily meteorological data recorded during crop growing season in the two years of the experiment

Table 1. Physical and chemical characteristics of the soil

Depth	Texture	K	P	Total N	EC	OC	OM	pH
cm		------mg/kg-------		%	dS/m	------- % ---------		
0-30	Silty clay loam	289	13.5	0.076	6.75	0.65	1.12	8.15

Table 2. Description of experimental treatments

irrigation regimes	Description
100V-100R	Irrigation applied 100% water requirement at the all growth stages (full irrigation)
100V-75R	Irrigation applied 100% water requirement at the vegetative stage and 75% water requirement at the reproductive stage
100V-50R	Irrigation applied 100% water requirement at the vegetative stage and 50% water requirement at the reproductive stage
75V-100R	Irrigation applied 75% water requirement at the vegetative stage and 100% water requirement at the reproductive stage
75V-75R	Irrigation applied 75% water requirement at the vegetative stage and 75% water requirement at the reproductive stage
75V-50R	Irrigation applied 75% water requirement at the vegetative stage and 50% water requirement at the reproductive stage
50V-100R	Irrigation applied 50% water requirement at the vegetative stage and 100% water requirement at the reproductive stage
50V-75R	Irrigation applied 50% water requirement at the vegetative stage and 75% water requirement at the reproductive stage
50V-50R	Irrigation applied 50% water requirement at the vegetative stage and 50% water requirement at the reproductive stage

Table 3. Characteristics of manure used in the experiment

K	P	N	EC	OC	OM	pH
---------mg/kg--------		%	ds/m	%	%	
8215	7893	2.31	6.81	27.43	47.29	7.38

Table 4. Amount of water applied in different irrigation regimes

Treatment (irrigation regimes)	Vegetative stage	Reproductive stage	Total growing season
	-----------------------	mm	-------------------------
100V-100R	253.4	951.1	1204.5
100V-75R	253.4	713.3	966.7
100V-50R	253.4	475.6	729.0
75V-100R	190.1	951.1	1141.2
75V-75R	190.1	713.3	903.4
75V-50R	190.1	475.6	665.6
50V-100R	126.7	951.1	1077.8
50V-75R	126.7	713.3	840.0
50V-50R	126.7	475.6	602.3

Table 5. Cumulative dry weight and Leaf area index in tomato affected by different irrigations regimes during two growing seasons (2016 and 2017)

Irrigation regimes at Vegetative	Irrigation regimes at Reproductive	Cumulative dry weight ($g\ m^{-2}$)		Maximum LAI	
		2016	2017	2016	2017
100V	**100R**	1546.69^{a}	1546.53^{a}	5.35^{a}	5.28^{a}
	75R	954.91^{bc}	912.49^{cd}	2.27^{c}	2.35^{c}
	50R	634.75^{e}	590.38^{fg}	1.91^{cd}	2.06^{c}
75V	**100R**	1079.04^{b}	1083.44^{b}	4.06^{b}	3.88^{b}
	75R	800.17^{cd}	792.73^{de}	2.17^{c}	2.17^{c}
	50R	562.65^{e}	521.92^{gh}	1.39^{de}	1.33^{d}
50V	**100R**	996.97^{b}	1006.94^{bc}	3.50^{b}	3.58^{b}
	75R	721.11^{de}	718.95^{ef}	1.98^{c}	1.85^{cd}
	50R	374.36^{f}	369.09^{h}	1.08^{e}	1.43^{d}
ANOVA					
V		**	**	**	**
R		**	**	**	**
V*R		*	**	*	*
LSD of V*R		74.56	70.95	0.266	0.276

ns, * and **: are non- significant and significant at 5 and 1% probability levels, respectively.
In each column means different letters indicate statistically significant differences (P<0.05). Data are averages observed for the two experiment year because there was no significant difference between two experiment years.
V= Vegetative stage, R= Reproductive stage, 100= apply 100% water requirement, 75= apply 75% water requirement, 50= apply 50% water requirement

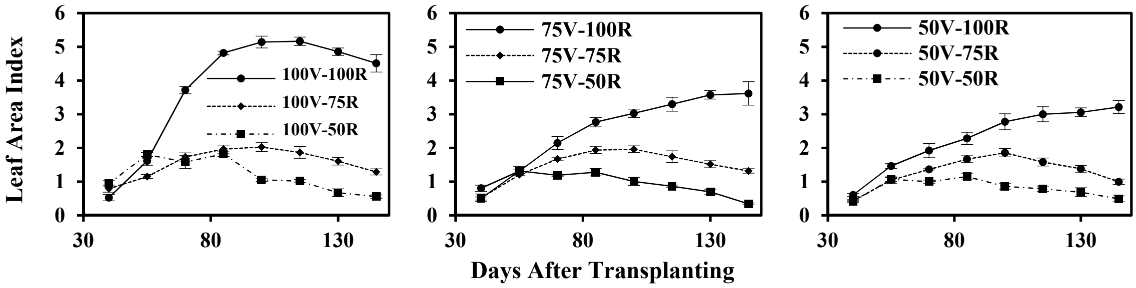
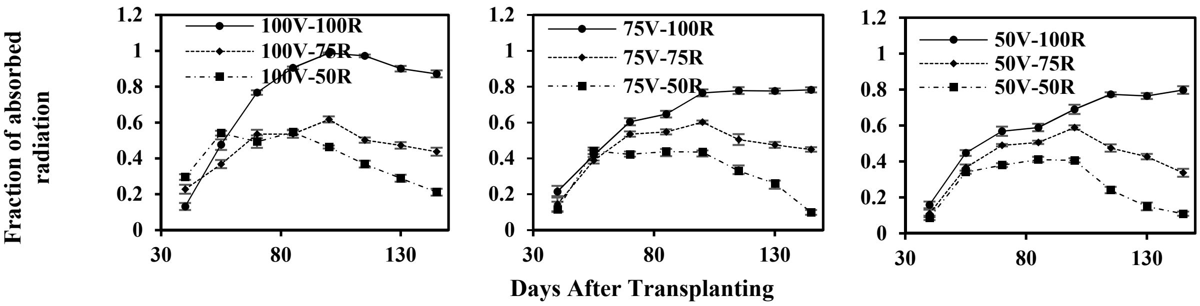


Fig. 2. Time trend of tomato LAI as affected by different irrigation regimes during two growing seasons (Average of 2016 and 2017). Vertical bars indicate standard error of the mean (SEM). V= Vegetative stage, R= Reproductive stage, 100= apply 100% water requirement, 75= apply 75% water requirement, 50= apply 50% water requirement



ig. 3. Changes in fraction of absorbed radiation by tomato as affected by different irrigations regimes during two growing seasons (Average of 2016 and 2017). Vertical bars indicate standard error of the mean (SEM). V= Vegetative stage, R= Reproductive stage, 100= apply 100% water requirement, 75= apply 75% water requirement, 50= apply 50% water requirement

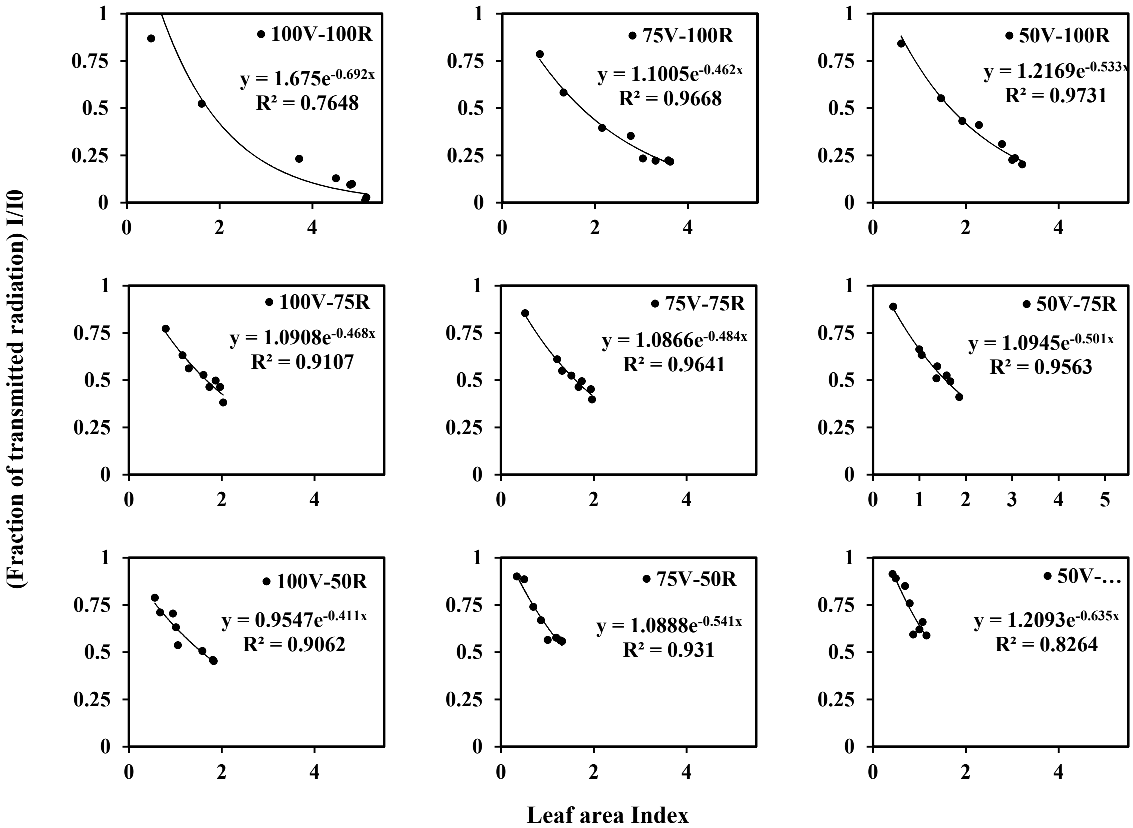


Fig. 4. Exponential decrease of the fraction of transmitted radiation against tomato leaf area index in different irrigation regimes at different growth stages during two growing seasons (2016 and 2017). (In curve equations, the exponent demonstrate light extinction coefficient). Data are averages observed for the two experiment year because there was no significant difference between two experiment years. V= Vegetative stage, R= Reproductive stage, 100= apply 100% water requirement, 75= apply 75% water requirement, 50= apply 50% water requirement

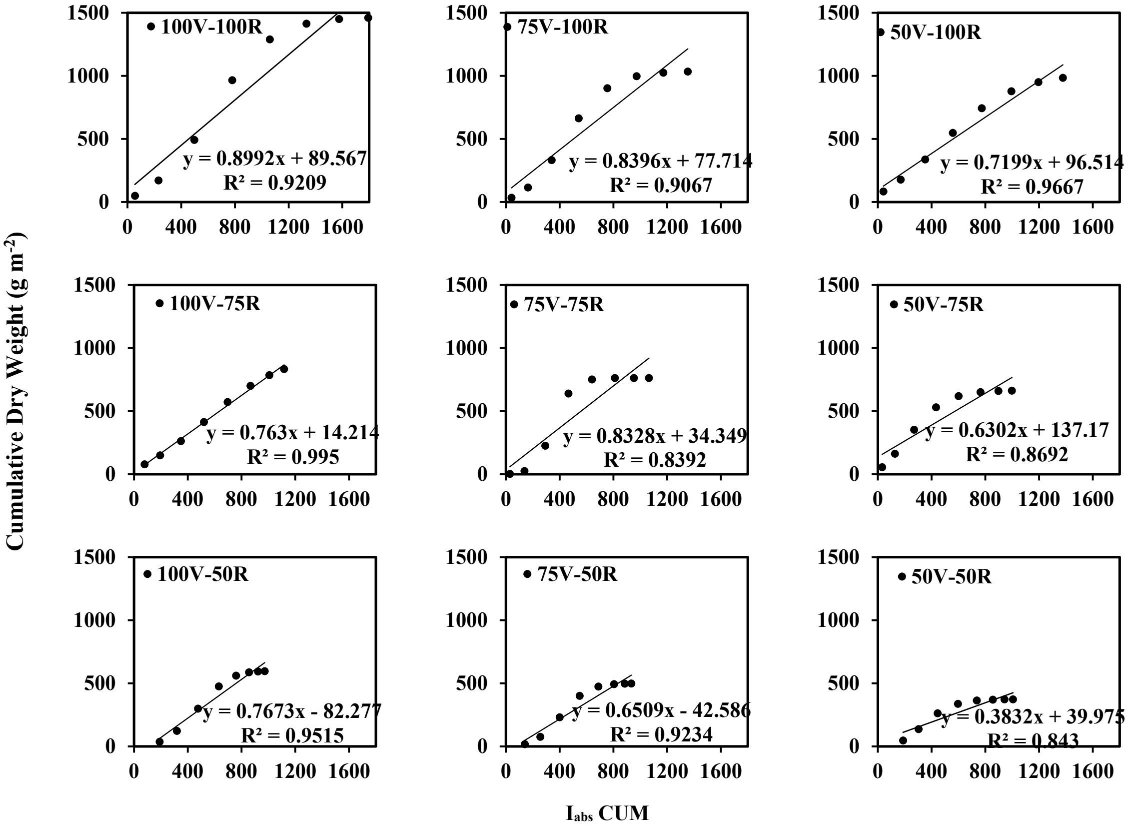


Fig. 5. Tomato dry matter accumulation as a function of accumulated radiation affected by different irrigation regimes at different growth stages during two growing seasons (2016 and 2017). (The slope of regression lines indicates radiation use efficiency). Data are averages observed for the two experiment year because there was no significant difference between two experiment years. V= Vegetative stage, R= Reproductive stage, 100= apply 100% water requirement, 75= apply 75% water requirement, 50= apply 50% water requirement

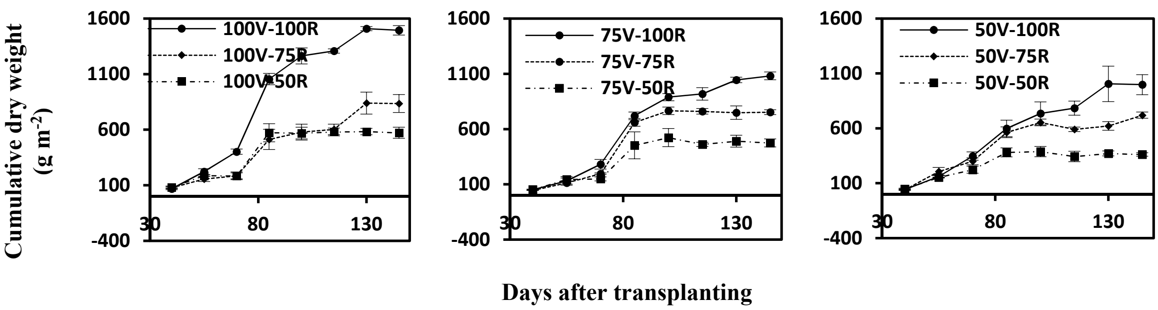


Fig. 6. Time trend of tomato total dry weight (leaf, stem and fruit) during two growing seasons as affected by different irrigation regimes. Vertical bars indicate standard error of the mean (SEM). V= Vegetative stage, R= Reproductive stage, 100= apply 100% water requirement, 75= apply 75% water requirement, 50= apply 50% water requirement

Table 6. Results of variance analysis for fresh and dry yield and ratio between fruit dry weight and plant total dry weight (harvest index – HI) of tomato in response to different water treatment, during the 2016 and 2017 growing seasons.

S.O.V	df	Fresh yield		Dry yield		HI	
		2016	2017	2016	2017	2016	2017
Replicate	2	161272^{ns}	503591^{ns}	1628.8^{ns}	4164*	24.202^{ns}	224.05*
Vegetative	2	20050445**	22870736**	79765.8**	99033**	98.677*	677.54**
Error a	4	347040	2647663	1827.1	10908	9.541	114.45
Reproductive	2	34938029**	63799821**	56355.6**	148948**	285.242**	265.17*
Veg × Rep	4	1299065**	1307341**	6342.5**	3306*	32.283^{ns}	136.67^{ns}
Error b	12	83118	213489	751.2	972	20.096	52.06
CV%		*4.88*	*8.70*	*7.04*	*8.96*	*12.92*	*16.13*

ns, * and **: are non- significant and significant at 5 and 1% probability levels, respectively

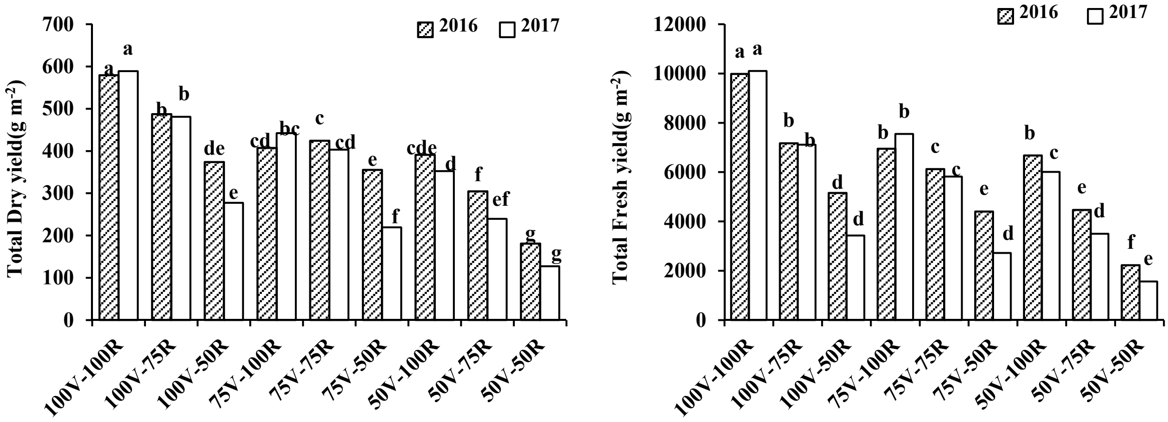


Fig. 7. Means comparison of fresh and dry yield of tomato in response to different irrigation regimes. Letters (a, b, c, d, e, f, g) indicate statistically significant differences between the means (P<0.05) using Fisher's Least Significant Difference (LSD) test. V= Vegetative stage, R= Reproductive stage, 100= apply 100% water requirement, 75= apply 75% water requirement, 50= apply 50% water requirement