Indian Journal of Agricultural Sciences **85** (2): 224–8, February 2015/Article

Gas exchange, chlorophyll fluorescence, biomass production, water use and yield response of tomato (*Solanum lycopersicum*) grown under deficit irrigation and varying nitrogen levels

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Received: 23 December 2013; Revised accepted: 10 November 2014

ABSTRACT

A field experiment on irrigation schedulings and nitrogen rates was conducted to study the physiological, growth and yield responses of tomato (*Solanum lycopersicum* L.) under deficit irrigation and various N levels. Results obtained indicated that irrigation at 10 or 20 days (I_1 and I_2) interval had significantly higher gas exchange (photosynthesis rate, stomatal conductance and transpiration rate), photochemical efficiency of PS II (F_v/ F_m), RWC, leaf area, chlorophyll content and fruit production over 30 days irrigation interval (I_3). Nitrogen application had also significant effects on most of the physiological, growth and yield traits at 45 and 75 DAT, however N at 120 kg/ha had noticed maximum gas exchange, $F_v/F_{m,}$ leaf area, CCI and fruit production over other two N levels. Interaction of I × N had exhibited significant effect on few parameters such as; photosynthesis rate, stomatal conductance, leaf area and weed growth, particularly at 45 DAT. Biomass production and partitioning in various plant parts were varied significantly, and under moderate water deficit with higher N levels (I_2 N_1 and I_2 N_2), an optimum allocation of biomass (less in roots and stems and higher in fruits) was registered. The maximum WUE (14.19 q/ha/cm) was reported with irrigation scheduling at 20 days, besides 36% water savings over I_1. For realisation of higher WUE, tomato should be irrigated at 20 days intervals with N application at 120 kg/ha.

Key words: Deficit irrigation, Gas exchange, N level, Tomato, Water use efficiency

Soil water deficits constitute a primary limitation to crop productivity in many regions of the world. In India, around 83% of fresh water is being used for agricultural purposes and even a minor reduction in irrigation water could substantially increase the water productivity. Appropriate irrigation management strategies such as, deficit irrigation is the best means for effective utilization of the scarce water resources for irrigating crops, particularly in arid, semi-arid and sub-humid regions. Deficit irrigation, under which water is supplied less than the crop evapo-transpiration demand can reduce the production costs, conserve water and minimize leaching of nutrients. Deficit irrigation maximizes yields per unit of water used in a given crop, under water scarce and drought conditions (Basal *et al*. 2009). This is especially true for tomato (*Solanum lycopersicum* L.), which has the maximum acreage of any vegetable crops in the world. Tomato crop has also high water requirement, and deficit irrigation may lead to significant savings of irrigation water (Costa *et al*. 2007). Kirda *et al*. (2004) reported that deficit irrigation practice in tomato increased water use efficiency (WUE) with only marginal yield reduction. On the contrary, May and Gonzalerz (1999) reported that tomato plants grown under conventional deficit irrigation exhibited water stress and significant decrease in gas exchange rate, which led to significant reductions in tomato yield.

Since irrigation and fertilization are intrinsically linked, an appropriate irrigation management is required in order to avoid nitrate leaching, groundwater pollution, and enhancing water and nutrient use efficiency in tomato production, which require substantial amount of water (450-550 mm) and nitrogen fertilizer (120-180 kg/ha) (Shukla and Naik 1993). In spite of the relationships between water and N on crop plants being well documented, relatively few studies have been associated with the concomitant effects of both factors on photosynthesis, stomatal conductance, photochemistry of PS-II and WUE, particularly in furrow irrigated raised bed planted tomato. The objective of this work was therefore to assess physiological and yield responses of tomato under varying levels of irrigation and N rates, and to optimize the irrigation interval and N quantity to realize maximum WUE.

MATERIALS AND METHODS

The experiment was carried out at the research farm of Indian Institute of Vegetable Research, Varanasi located at

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25° 182 N latitude and 83° 02 E longitude. Tomato (cv. Kashi Vishesh) was grown during *rabi* 2010-11 and 2011-12 with 3 irrigation schedulings, i.e. irrigation at 10 days (no stress, I_1), 20 days (moderate stress, I_2) and 30 days (severe stress, I_3), and 3 nitrogen rates (N_1= 120, N_2 = 80 and N_3 = 40 kg/ha) in a split-plot design with irrigation treatments in main block and N rates as sub-plot. The soil of experimental plot was a Typic Ustochrept (Inceptisol) having silt loam texture, *p*H 7.2, EC 0.23 dS/m, organic carbon 0.46% and available N, P_2O_5 and K_2O were 258, 20.5 and 225 kg/ha, respectively. Moisture content (0.30 m depth) at 0.33 bars (field capacity) and 15 bars (permanent wilting point) was 23.3% and 8.1%, respectively; whereas bulk density of soil was 1.42 Mg/m^3. The average values of weather parameters during the experiment period (15 October to 26 March) were; maximum temperature 27.1°C, minimum temp. 14.4°C; maximum RH 81%, minimum RH 41%; sunshine hour 7.3, open pan evaporation 3.2 mm and total rainfall 33 mm.

Soil moisture (0-15, 15-30 cm) was recorded gravimetrically just before irrigation. Photosynthetic rate (P_n), stomatal conductance (g_s) and transpiration (E) were measured between 1100 to 1300 hours using Li-6200 Portable Photosynthesis System (LICOR Bioscience, Nebraska, USA). During the measurement, the photosynthetically active radiation incident at the leaf cuvette ranged between 965 to 1075 µmol/m^2/s, and the ambient CO_2 varied between 280 to 340 µmol/mol. Chlorophyll content index (CCI) of leaf was measured with the CCM-200 Portable Chlorophyll Meter (Opti-Sciences, Tyngsboro, MA) at the ratio of 655/940 nm. Chlorophyll fluorescence in terms of F_v/F_m was measured by Plant Efficiency Analyzer (Hansatech Instrument Co, Norfolk, UK) at the adaxial surface of top third leaf adapted for 30 minutes in dark. The gas exchange parameters and chlorophyll fluorescence were taken on fully expanded upper third or fourth leaf at 45 and 75 days after transplanting (DAT), just before release of stress. Relative leaf water content (RWC) was measured as per the method suggested by Barrs and Weatherley (1962). Leaf area was measured with Li-3000 Portable Leaf Area Meter -Li-3000 A (LICOR Bioscience, Nebraska, USA).

Biomass production and its allocation in various plant parts were worked during fruiting stage (110 DAT). For estimation of dry matter partitioning, different plant parts were separated from the collected plant samples and oven dried at 65°C for 24 hr or till constant weight, and its allocation in various plant parts was worked out on a percent weight basis. Observations of yield parameters were recorded using the standard procedures. Weed biomass recorded at 90 DAT by removing weeds from 1 m^2 area, dried and the result was presented on dry weight basis. Two hand weedings were carried out, 30 and 60 DAT. Data from the experiment were analysed statistically using SAS software (Ver. 9.3). The critical difference at P=0.05 was used to test the difference between means of individual treatments.

RESULTS AND DISCUSSION

Soil moisture content

Irrigation scheduling had remarkable effect on soil moisture content at 15-30 cm depth. The maximum moisture (14.8%) was observed under I_1 at 30 cm depth. The moisture content before irrigation in I_2 at 15-30 cm depth, where most of the active roots are confined was higher (10.9%) than the wilting point (8.1%) at corresponding depth, but under severe drought stress (I_3), the moisture content was close to the permanent wilting point (PWP) at 15 cm (5.8%), and below the PWP at 30 cm depth (6.8%). Irrigating tomato crop at every 20 days could maintain enough soil moisture in 30 cm soil profile to sustain the plant life without significant reduction in plant growth and yields. The higher soil moisture under I_1 was obviously due to less gap in irrigation interval.

Gas exchange and other physiological traits

Gas exchange parameters, like photosynthesis rate (P_n), stomatal conductance (g_s) and transpiration rate (E) were significantly varied with irrigation scheduling and N levels. The maximum and significantly higher P_n at 45 DAT was recorded under I_2 (12.63 ± 0.46 µmol/m^2/s), whereas at 75 DAT, irrigation scheduling did not influence P_n. Application of various levels of N had significant influence on photosynthesis rate. At both stages, N_1 and N_2 recorded significantly higher P_n rate over N_3, however, P_n under N_1 (N at 120 kg/ha) recorded maximum and significantly higher both at 45 and 75 DAT over both N_2 and N_3. Interaction between I × N levels was also found significant for photosynthesis rate during both the stages. At 45 DAT maximum P_n was observed in I_2N_1 (16.23 µmol/m^2/s), whereas at 75 DAT, it was maximum in I_1N_1 (16.68 µmol/ m^2/s). Stomatal conductance (g_s) under I_1 and I_2 was significantly higher than I_3 during both the observation periods. Application of N also had significant effect on g_s at 45 DAT, but it was non-significant at 75 DAT. At 45 DAT, significantly higher g_s were observed in both N_1 and N_2 over N_3. Interaction between irrigation scheduling and N levels was found non-significant during both growth stages. Irrigation scheduling had significant effect on transpiration (E) rate at 45 DAT only, and maximum E was noticed in I_3 (13.19 ± 0.49 µmol/m^2/s). Since about 75% of leaf N is allocated to the photosynthetic apparatus, the correlation between maximum Pn and leaf N concentration is fairly strong (Evans 1989). Garcia *et al.* (2007) reported that water stress tolerance in tomato plants was altered by N fertilisation. Plants fertilised with optimum N were more drought-tolerant than plants fertilised with low or high N. They noticed that plants were able to maintain higher leaf water potentials, preventing the large reduction in g_s under moderate water deficit with optimum N supply. Similar to our findings, Topcu *et al.* (2007) also noticed significant reduction in stomatal conductance in tomato due to deficit irrigation. Terashima and Evans (1988) reported that in addition to influencing P_n through effects on g_s, N limitation may also lower P_n by decreasing the content of

Table 1 Effect of irrigation schedule and N rate on physiological traits in tomato

	P_n (μmol/m²/s)		g_s (mol/ m²/s)		E (μmol/m²/s)		F_v/F_m		RWC (%)
	45 DAT	75 DAT	45 DAT	75 DAT	45 DAT	75 DAT	45 DAT	75 DAT	75 DAT
Irrigation intervals									
10 (I_1)	9.72	12.54	0.659	0.650	10.38	13.58	0.761	0.771	82.70
20 (I_2)	12.63	11.36	0.554	0.627	9.84	14.00	0.764	0.677	74.60
30 (I_3)	6.62	9.95	0.400	0.457	13.19	12.16	0.581	0.465	66.20
SEm±	0.46	0.67	0.038	0.031	0.49	1.04	0.014	0.005	0.73
CD (P = 0.05)	1.81	2.17	0.151	0.135	1.92	NS	0.056	0.020	2.87
N rate (kg/ha)									
120 (N_1)	11.93	14.20	0.602	0.657	12.27	14.10	0.744	0.681	75.3
80 (N_2)	9.27	10.78	0.558	0.566	11.04	12.34	0.695	0.656	75.2
40 (N_3)	7.77	8.88	0.454	0.511	10.10	13.29	0.667	0.576	73.0
SEm±	0.27	0.56	0.030	0.036	0.81	0.80	0.012	0.011	1.27
CD (P = 0.05)	0.82	1.74	0.093	0.110	2.50	NS	0.037	0.034	NS
I × N	S	S	S	NS	NS	NS	NS	NS	NS

chloroplastidal pigments and the synthesis of several enzymes involved in the Calvin cycle, particularly Rubisco. Chlorophyll content index (CCI) measured at 45 and 75 DAT were higher under I_1 (32.56 and 42.63, respectively) than the other irrigation schedulings. N application did not affect the CCI of leaves at 45 DAT, but it was about 47% and 30% higher in N_1 and N_2, respectively at 75 DAT over N_3. Interaction of I × N was insignificant at 45 DAT, but a significant variation in CCI was observed at 75 DAT, and it was maximum under I_1N_1 (52.1) followed by I_1N_2 (42.9). Chlorophyll content is strongly related to N supply. Guler and Buyuk (2007) also noticed significant correlation between leaf N and chlorophyll content in tomato. The photochemical efficiency of PS II estimated as the ratio between variable and maximal fluorescence (F_v/F_m), was significantly affected by irrigation schedulings during both the stages of crop growth. The maximum photochemical efficiency of PS-II (F_v/F_m) was observed in I_1 (0.761 and 0.771, respectively at 45 and 75 DAT). Irrigation at 20 days (I_2) also registered significantly higher F_v/F_m value over irrigation at monthly intervals. Among N levels, the maximum F_v/F_m was observed when N applied at 120 kg/ha (0.744 at 45 DAT and 0.681 at 75 DAT). Interaction of I × N was insignificant. Studies conducted by Lima *et al.* (1999) and Lu and Zhang (2000) have also shown that N deficiency decreases the quantum yield of photosystem II (PS II), electron transport and the maximum PS II photochemical efficiency suggesting that N deficit may cause damages to PS II photochemistry.

During drought stress, the plant water content play a key role in the activation and/or modulation of antioxidant defence mechanism. Hence, relative leaf water content (RWC) is considered a reliable indicator that reflects the water content in relation to maximum water content, or in other words, it indicates the level of hydration. In this study, RWC was found significantly higher in I_1 (82.7%) and I_2 (74.6%), however, application of N, and interaction of I × N did not affect the RWC of leaves. Since under I_1, crop was frequently irrigated, and plants never experienced water dearth, thereby leaf cells maintained higher turgidity. Application of nitrogen and I × N interaction did not affect the RWC parameter of the leaves. Earlier, Bahadur *et al.* (2009) also noticed higher leaf water potentials (-0.91 to -1.36 MPa) and RWC (78.6 to 83%) in spring-summer okra with irrigation schedulings at short intervals (4 or 7 days).

Leaf area and biomass production and its partitioning

Leaf area recorded in tomato under I_1 at 45 and 75 DAT was higher than the other irrigation treatments (Table 2). Similarly, N application @ 120 kg/ha (N_1) recorded maximum leaf area (1 285 and 3 887 cm²/ plant, respectively at 45 and 75 DAT), however it was not significantly superior over N_2. I × N interaction showed significant influence on leaf area only at 75 DAT, and the maximum leaf area was observed under I_1N_1 (4 850 cm²/ plant). Across the irrigation levels, leaf area increased with increasing N rates. Earlier, Tahi *et al.* (2008) also noticed lower shoot weight and leaf area in tomato under moderate water deficit than well-watered. The higher leaf area under frequent irrigation with higher dose of N was due to fact that optimum soil moisture in the rootzone was maintained, which facilitated better N utilization with sufficient water supply. Low N decreased the soluble protein (including Rubisco) content and the rate of protein synthesis. Lawlor *et al.* (1988) suggested that an adequate supply of N is crucial for leaf growth because of the role of proteins in the growth of cell walls and the cytoskeleton, and hence in cell expansion.

Biomass production and dry matter partitioning into various plant parts varied significantly with irrigation scheduling and N levels. Irrigation at longer interval and lower N level resulted in allocation of more dry matter in leaves, stems and roots, whereas, under moderate water deficit with higher N levels (I_2N_1 and I_2N_2), there was an optimum allocation of dry matter in various plant parts, i.e. 28-31% in leaves, 31-35% in stems, 10-12% in roots and 25-30% in fruits. Total dry matter content was also higher in I_2N_1 and I_2N_2 (160 and 167 g, respectively). The reduction in total dry matter production was 8.7% and 25% under

Table 2 Effect of irrigation schedule and N rate leaf area, chlorophyll content, fruit production and weed growth

	Leaf area/plant (cm^2)		Chlorophyll content index		No. of	Yield	Weed growth (g/m^2)
	45 DAT	75 DAT	45 DAT	75 DAT	fruits/plant	(q/ha)	90 DAT
Irrigation intervals (days)							
10 (I_1)	1829	4399	32.56	42.63	41.0	455.26	139.9
20 (I_2)	1048	3573	25.28	34.53	42.9	434.19	91.7
30 (I_3)	741	2266	18.32	19.50	29.5	295.11	62.3
SEm±	19.71	32.10	1.7	0.44	1.47	15.01	1.58
CD (P = 0.05)	77.39	126.01	6.6	1.76	5.76	58.94	6.2
Nitrogen rate (kg/ha)							
120 (N_1)	1285	3887	27.90	37.81	44.2	468.97	116.2
80 (N_2)	1335	3327	25.11	33.21	37.2	393.78	96.3
40 (N_3)	997	3025	24.14	25.64	32.0	321.81	81.3
SEm±	49.17	63.18	0.74	1.166	2.63	20.42	2.38
CD (P = 0.05)	151.51	194.69	2.28	3.59	8.10	62.94	7.33
I × N	NS	S	NS	S	NS	NS	S

moderate and severe water stress, respectively, as comparison to well-watered plants. Similar to our findings, Sanchez-Rodriguez *et al.* (2010) reported 22-40% reduction in total biomass in tomato genotypes under moderate drought stress.

Weed growth

Irrigation had a remarkable and significant effect on weed growth (Table 2). The weed growth under I_1 was 51.6% higher than I_2, and 125.5% higher than I_3. Nitrogen application also showed significant effect on weed growth. Higher weed growth was noticed with increase in nitrogen doses irrespective of irrigation scheduling. Weed biomass under N_1 was 25.4% and 42.8% higher over N_2 and N_3, respectively. Interaction of I and N had significant effect and I_1N_1 had maximum weed growth (174.25±3.30 g/m^2) followed by I_1N_2 (data not given). Irrigation at monthly interval (I_3), irrespective of N rate registered significantly lower weeds (51.7 to 73 g/m^2) as compared to I_1 and I_2. Since, weeds compete with the main crop for water, nutrients and light, water deficit along with low N supply restricts the weed growth, as observed in present study.

Fruit yields, water savings and water use efficiency (WUE)

Plants irrigated at 10 or 20 days intervals registered significantly higher number of fruits and fruit yields over irrigation at monthly intervals, however both these schedules were statistically *at par* to one another. I_1 and I_2 had registered 54% and 47% higher fruit yields, respectively over I_3. Similarly, N had also significant effect on fruit number and yield. The maximum and significantly higher fruit yield of 468.97 q/ha was recorded with application of N @ 120 kg/ha (N_1). N_2 also noticed significantly higher yields over N_3, but lower than N_1. In present study, N_1 and N_2 have registered 45.7% and 22.4% higher fruit yield over N_3. Interaction (I × N) did not influence the fruit number as well yield in our study.

As for as water consumption was concerned, a total of 13, 7 and 4 irrigations were applied, respectively under I_1, I_2 and I_3 treatments, which was corresponding to 475 mm, 306 mm and 215 mm water. Thus, about 36% and 55% water saving were achieved under I_2 and I_3, respectively. The maximum WUE of 14.19 q/ha/cm was observed in I_2, and lowest WUE (9.58 q/ha/cm) was registered in I_1. In present investigation, the maximum WUE in I_2 was due to 36% less application of water with insignificant reduction in fruit yield (4.6%) as compared to I_1. Moderate water deficit with adequate N application (I_2N_1) resulted in maximum WUE, i.e. 18.99 q/ha/cm as moderate water deficit did not adversely affect the fruit yield, while adequate N supply significantly improved the photosynthesis, leaf area and ultimately fruit yield.

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