Arab Gulf J. Scient. Res. **13**(3), pp.511-520 (1995)

Yield Response of Tomatoes to Soil Moisture Regimes[1]

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ABSTRACT. The effect of two irrigation frequencies (daily and every 3 days) and three water application rates (3,6 and 9 mm day^{-1}) on the growth and yield of tomatoes were investigated under the relatively warm and humid winter conditions of Oman in the Gulf region. The three water application rates were 0.6, 1.2 and 1.8 times the reference evapotranspiration as computed by the Penman modified method, and corresponding to maximum soil moisture tensions of more than 100 K Pa, less than 80 K Pa and field capacity, respectively. Daily - and every 3-day irrigations did not produce any statistically detected effects on fruit weights, numbers, dry matter content and total yield or on root volume of tomatoes. Significant differences were obtained in total yield and fruit weights when the application rates were increased from 3 mm day^{-1} (0.6 ET_0) to 6 mm day (1.2 ET_0) with no significant increase in yield or fruit weight when further increasing the application rate to 9 mm day (1.8 ET_0). Maintaining less than 80 K Pa soil moisture tensions optimized yield and fruit numbers, whereas maintaining field capacity levels maximized fresh fruit weights. Fruit setting, percent dry matter and root weight and volume of tomatoes were not affected by any of the soil moisture regimes adopted.

Tomato (*Lycopersicon esculentum* Mill.), although not among the most valuable crops in nutrients per gram, is an improtant contribution to dietary needs. The substantial per capita consumption is probably exceeded only by that of potatoes.

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[1]Journal Article No. SW 9401. College of Agriculture, Sultan Qaboos University.

Mitchell *et al.* (1991) found that deficit irrigation reduced the fruit water accumulation and fresh fruit yields of tomatoes but increased fruit soluble solids levels. Fruit set and marketable soluble solids (marketable red fruit yield x percent soluble solids) were generally unaffected by the irrigation practiced. Sammis and Wu (1986) reported that a 50% reduction in yield of tomatoes caused by moisture stress resulted in a 64% reduction in marketable yield. Sanders *et al.* (1989) in a study of tomato response to irrigation rate and schedule found that total yields of tomatoes increased with increasing trickle irrigation rates of 35% ET, 70% ET, and 105% ET, which did not differ in water use efficiency, Locascio *et al.* (1989) obtained higher fruit yields with 0.5 than with 1.0 times pan evaporation on a fine sand in Florida, USA. On a fine sandy loam soil, fruit yields obtained were higher with a higher rate of irrigation in a relatively dry season, but was not influenced by the water quantity applied in the second relatively wet season. The number of daily water applications (one *vs.* three) at both locations had no effect on fruit yields. Pitts and Clark (1991), in a comparative study of drip irrigation to subsurface (seepage) irrigation, found that the yield and quality of tomato fruits were not significantly different for the two irrigation methods. There was a significant reduction in water required by drip irrigation, which averaged 50% of pan evaporation. May *et al.* (1990) also reported that moisture stress in tomatoes reduces yields and increases solids and conclucded that a good moisture stress management program enables maintaining yield while increasing solids without decreasing viscosity. Calado *et al.* (1990) obtained some statistically significant correlations between stem diameter changes and leaf water potential of processing tomatoes with five levels of water stress: 0.4, 0.6, 0.8, 1.0 and 1.2 times the crop evapotranspiration. Clark *et al.* (1991) conducted field studies on a sandy soil to compare micro-irrigation with buried drip lines on a sandy soil with subirrigation (seepage) production of tomatoes. Maintaining the soil water tension between 5 and 10 K Pa gave greater yields than did soil water tensions of 10 to 15 K Pa during the spring crop, but not during the fall. Yields from the micro-irrigated plots were equivalent to those from the sub-irrigated plots.

Assessement of crop-water requirements is an essential prerequisite in planning and development of water resources in arid regions, where increasing demands and limited resources of water have necessitated adoption of different conservation and augmentation methods (Abdel Rahman and Abdel Majid 1993). This study was conducted to establish the optimum crop-water requirements of tomatoes under the prevailing warm and humid winter conditions of the Sultanate of Oman.

Materials and Methods

Tomato (*Lycopersicon esculentum* Mill., Var. Access) seeds were sown on 7th October and transplanted into a pre-irrigated field on 3rd November for both the

1991/92 and 1992/93 seasons. The seeds were first sown into a speedling tray containing peatmoss mixture as a germination media and the trays were kept in a nursery wiht agryl cover. Harvesting started on the first week of January and lasted through the first week of March for both season. The soils were classified as sandy loams to the 30 cm depth, underlain by a sanday skeleton and havign a bulk density of about 1.4 Mg m^{-3} with field capacity and permanent wilting points of 20.4 and 7.5 percent, repectively. The 1:5 soil water extract had an Electric Conductivity (EC) and a Sodium Adsorption Ratio (SAR) of 1, 560 μS cm^{-1} and 3.12, respectively. Irrigation water had an EC adn SAR of 600 μS cm^{-1} and 1.78, respectively.

Two irrigation frequencies and three water quantities were replicated three times in completely randomized block design. Drip irrigation lines were laid 1 m apart with 0.5 m between emitters. Each line (10-m long) constituted a separate plot with 20 plants spaced 0.5 m meters apart. The pressure compensating emitter discharges were gravimetrically calibrated and an average discharge of 3.6 liters per hour was obtained at the 138 K Pa pump pressure. The two frequencies of irrigation used were: every day (F_1) and every 3 days (F_2). The three quantities (Q_1, Q_2 and Q_3) were applied by operating the lines for 10, 20 and 30 minutes with the corresponding application rates of 3, 6 and 9 mm , respectively. The total amount of water actually applied on the day of irrigation was the product of the rate times the irrigation interval. Twelve irrometer-type tensiometers were randomly installed in 2 replicates of the 6 treatments to a depth of 15 cm to monitor soil moisture tensions. Daily readings of the tensiometers were recorded throughout the experiment. All treatments received the same cultural practices. Urea fertigation was used to start the growth at concentrations of 100-300 ppm. Fertilizer applications were continued with Potassium Nitrate (KNO_3) concentrations of 100-450 ppm followed by spraying for the micronutrients (5 g/1) to correct any unforeseen deficiencies. White flies were controlled by Afflix pesticides to combat leaf curl viruses. Plants were unsupported and freely growing. Fruits were collected when about 70% red and their numbers, fresh weight, dry matter content and total yield were determined and analyzed statistically. Roots were carefully dug out with a hand tool under running water at about 35 K Pa, and the volume was determined by immersion in a graduated cylinder.

Results and Discussion

Agro-metorological data

Table 1 gives the average climatic data obtained from Seeb International Airport weather station (15 km) averaged over a 15-year period (1977-91) and the reference evapotranspiration ET_o computed using the Modified Penman method (Doorenbos and Pruitt 1977). It can be seen from the meteorological data, that the area is characterized by relatively warm and humid winter conditions. The average temperature during the growing season, which extended for 4 months, was about 23°C, with maximum and minimum mean daily temperatures of 27.4 and 19.8 °C, repectively. The average relative humidity was 62.6%. Mild wind conditions prevailed with little rainfall during the span of study. Based on the information available on the crop reference evapotranspiration, the three application rates selected (3, 6 and 9 mm day^{-1}) were 60, 120 and 180 percent of the average ET_o, respectively. The corp-water requirements of tomatoes has been estimated at 900-1000 mm for 170 days growing period in the region (JICA 1990). The actual water application, however, is much higher, especially under furrow irrigated practices. Daily applications of 9 ha-mm ha^{-1} are very common on the loamy sands to sandy loams of the region.

Table 1. Meteorological data and reference evapotranspiration (1977-1991) over the growing season

Month	Temperature °C			Relative Humidity %			Wind-Speed U_2 m/sec	Sun-shine hrs day^{-1}	Rain-fall mm day^{-1}	Piche evapn mm day^{-1}	ET_o mm day^{-1}
	Max	Mean	Min	Max	Mean	Min					
Nov.	30.6	25.8	21.1	76.1	59.7	40.7	2.2	9.8	0.207	8.4	5.65
Dec.	26.9	22.7	18.5	79.0	65.1	48.7	2.1	8.6	0.310	6.0	4.30
Jan.	25.7	21.4	17.4	78.5	63.6	47.6	2.0	8.7	0.313	6.9	4.32
Feb.	26.4	22.0	17.8	81.0	62.1	41.5	2.4	8.7	0.714	7.1	5.05

Source: Directorate of Meterology, Department of Civil Aviation, Muscat, Oman.

Fresh fruit weight and percent dry matter

Table 2 gives the fresh fruit weight in grams and percent dry matter for both seasons, separately, and their combined effect with the statistical analysis. The frequency of irrigation had no significant effect on fruit fresh weight or the percent of dry matter, and irrigating every three days was as effective as irrigating every day. The quantity of water applied, on the other hand, significantly affected the fresh weight, whereas the dry matter content remained unchanged. Increasing the quantity of water applied from 3 to 6 mm day^{-1} significantly increased the fresh weight by about 32%, whereas increasing to 9 mm day^{-1} produced a significant increase of 50 and 38 percent in fresh weight for the 91/92 and 92/93 seasons, respectively. Increasing the rate from 6 to 9 mm day^{-1} did not yield any significant increase in fresh weights. With the percent dry matter content unchanged, increased water uptake by the plants was reflected by the increased fresh weights of the fruits. Interactions of the frequency and quantity of irrigation were not significant, with the indication that the quantity of water could be applied daily or as one dose per cycle of 3 days.

Table 2. Fresh fruit weight and dry matter content of tomatoes in two years

Treatment	Fresh Fruit Weight Per Plant (gm)			Fruit Dry Matter (%)		
	1991-92	1992-93	Combined	1991-92	1992-93	Combined
Irrigation Frequency						
F_1	58.10	68.56	63.33	6.04	7.77	6.90
F_2	54.89	63.93	59.41	5.97	8.04	7.01
SEd	3.78	3.20	2.49	0.377	0.369	0.318
Irrigation Quantity						
Q_1	43.72	54.37	49.04	6.42	7.47	6.95
Q_2	60.37	69.43	64.90	6.00	7.57	6.87
Q_3	65.40	74.93	70.17	5.60	8.50	7.07
SEd	4.63	3.92	3.05	0.461	0.453	0.390
L.S.D.	10.31	8.74	6.26	–	–	–
Significance						
F	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Q	**	**	**	N.S.	N.S	N.S.
FxQ	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

**Significant at $P = 0.01$

Fruit numbers and total yield

Table 3 shows the results of the average number of fruits per plant and the total yield (tons/ha). There wa no significant response of either the fruit numbers or the total yield to changing frequencies of irrigation. Even though increasing the quantity of water aaplication from 3 to 6 mm day^{-1} did not significantly affect the number of fruits, it did significantly increase the total yield by about 44%. Increasing the rate of water application to 9 mm day^{-1} had no significant effect, and the 3 mm day^{-1} application optimized both the fruit numbers and the total yield.

Table 3. Fruit number per plant and total yield of tomatoes (1991/92 season)

Treatment	Fruit Number/Plant			Total Yield (tons/ha)		
	1991-92	1992-93	Combined	1991-92	1992-93	Combined
Irrigation Frequency						
F_1	34.44	17.89	26.17	40.29	24.48	32.39
F_2	36.22	19.33	27.78	41.43	24.78	33.11
SEd	3.0	2.09	1.92	3.72	3.06	3.30
Irrigation Quantity						
Q_1	33.83	18.17	26.00	31.82	19.50	25.66
Q_2	40.17	19.00	29.58	47.77	26.28	37.03
Q_3	32.00	18.67	25.33	42.99	28.10	35.55
SEd	4.05	2.56	2.35	4.55	3.75	4.04
L.S.D.	–	–	–	10.15	–	5.84
Significance						
F	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Q	N.S.	N.S.	N.S.	**	N.S.	**
FxQ	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

**Significant at $P = 0.05$

Root weight and volume

Table 4 gives the root volume (ml) and weight (gm) for the 1991/92 season as affected by the irrigation frequency and quantity. As with the yield component measurements, the root weight and volume were not significantly affected by changing irrigation frequency. Increasing the quantity of water applied did not significantly affect root growth. Since root length was not determined, a decrease in the root length with increasing quantities of water available at the soil surface might have been compensated by an increase in thickness and more branching, thus maintaining the total volume and weight.

Table 4. Root weight and volume of tomatoes in one year

Treatment	Volume (ml)	Weight (gm)
Irrigation Frequency		
F_1	28.10	28.64
F_2	28.09	27.67
SEd	2.00	2.39
Irrigation Quantity		
Q_1	26.88	27.23
Q_2	28.43	28.05
Q_3	28.98	29.19
SEd	2.45	2.89

Soil moisture regime

The pre-irrigated field had a soil moisture tension (SMT) of 20 K Pa at the beginning of the experiment. Tensions increased steadily with time to a maximum which was then maintained. The maximum SMT attained, before the on-set of the next irrigation, was observed to be a function of the quantity of water applied and not the frequency of irrigation.

Applications of 9 ha-mm ha maintained tensions lower than 30 K Pa whereas 6 ha-mm ha^{-1} applications kept tensions within 80 K Pa. Thirty days after transplanting the tensions "broke" in the 3 ha-mm ha^{-1} applications, indicating tensions higher than 100 K Pa. Maintaining the SMT to a maximum of 80 K Pa optimized total yield and the fruit numbers. Maintaining field capacity levels maximized the fresh fruit weights per plant.

Conclusion

A two season field study conducted to evaluate the effect of frequency and quantity of irrigation on tomato growth and yield revealed that fruit numbers, percent dry matter content and root growth as detected by volume and weight, were not affected by any of the water application regimes. Fresh fruit weights and the total yield were significantly increased by increasing the water application rates from 3 mm day^{-1} to 6 mm day^{-1}. These findings are in conformity with those of Mitchell *et al.* (1991), Sammis and Wu (1986), and Sanders *et al.* (1989). Maintaining the SMT to a maximum of 80 K Pa with 6 mm day application optimized total yield and the fruit numbers. This is in agreement with Doorenbos and Kassam (1979), who reported a total water requirement after transplanting in the range of 400-600 mm over a 90-day growing period. Maintaining field capacity levels maximized the fresh fruit weights per plant without significantly affecting total yield. The practice of 9 mm day^{-1} proved to be an extravagant use of water. The study showed that 1.2 ET_0 could be applied on a daily basis or 3.6 ET_0 every 3 days. The phenological effects on evapotranspiration should be considered for a more precise estimate of the crop-water requirements essential in planning and water resources developement.

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(Received 21/03/1994;
in revised form 05/10/1994)

استجابة انتاجية الطماطم لأنظمة الرطوبة في التربة

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تم استقصاء تأثير ترددين للري (يومياً وكل ٣ أيام) وثلاثة معدلات للري (٣ ، ٦ و٩ مم/ اليوم) على نمو وإنتاج الطماطم في ظروف الشتاء الرطبة والدافئة نسبياً في سلطنة عمان .

معدلات الري الثلاثة كانت ٦ ,٠ و ٢ ,١ و ٨ ,١ ضعف البخر - نتح المرجعي والذي تم حسابه بطريقة بنمان المعدلة ، بما يوازي أكثر من ١٠٠ كيلو باسكال وأقل من ٨٠ كيلو باسكال والسعة الحقلية للتربة بالتوالي . لم يكن لتردد الري اي أثر احصائي يذكر على وزن الثمره واعداده والوزن الجاف والانتاج الكلي أو حجم الجذور . تم الحصول على فروقات معنوية في الانتاج الكلي ووزن الثمار عند زيادة معدل الري من ٣ إلى ٦ مم/ اليوم مع عدم وجود زيادة بزيادة معدل الري إلى ٩مم/ اليوم . أدت المحافظة على معدلات رطوبة في التربة أقل من ٨٠ كيلو باسكال إلى الانتاج الامثل في حين أدت المحافظة على معدلات السعة الحقلية إلى أقصى وزن للثمار . لم تتأثر عقد الثمار ، الوزن الجاف أو حجم الجذور وأوزانها بأي من معاملات الرطوبة المتبعة .