

Effect of drip irrigation and mulching on yield, water-use efficiency and economics of tomato

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ABSTRACT

This study investigated the combined effects of drip irrigation and mulches on yield, water-use efficiency and economic return of tomato. The treatments of the study comprised different combinations of three drip irrigation levels (100, 75 and 50% of crop water requirement, Etc) and two mulches (black polyethylene sheet and paddy straw). The yield and yield-contributing characters in the mulched treatments for all levels of irrigation were significantly higher compared to those in the unmulched treatments. The yield of tomato increased with the increasing amount of irrigation water in unmulched treatment. The trend was reversed when drip irrigation was coupled with mulches. The highest yield for each mulch (81.12 t/ha for polyethylene and 79.49 t/ha for straw) was obtained when 50% of water requirement was applied. With 100% water application, polyethylene-mulched treatment produced lower yield than the straw-mulched treatment. The highest water use efficiency of 592 kg/ha/mm was obtained with 50% water application under polyethylene mulch. The highest net return (US\$ 7098/ha), incremental net return (US\$ 1556/ha), and incremental benefit-cost ratio (7.03) were found for 50% water application with straw mulch. The study thus reveals that drip irrigation with mulch has an explicit role in increasing the land and water productivity of tomato.

Keywords: fertigation; crop water requirement; fruit; hydrothermal regimes of soils; benefit-cost ratio

Drip irrigation system, a relatively new technology in Bangladesh, is being used for growing vegetable crops. It has created interest because of decreased water requirement and possible increase in production (Jain et al. 2000). The system has proved its superiority over other conventional methods of irrigation. This is especially so for irrigating fruit and vegetable crops owing to its precise and direct application of water in the root zone with a considerable saving in fertilizer and water. It also has the potential to increase the yield of crops even at reduced irrigation water application (Yohannes and Tadesse 1998). A field experiment in USA by Pruitt et al. (1984) demonstrated that drip irrigation increased yield of tomato and water use efficiency (WUE) by 19% and 20%, respectively as compared to furrow irrigation. Other investigators reported high yields and WUE for tomato and other crops under drip irrigation

(Grimes et al. 1976, Sammis 1980). Some fertigation experiments with tomato and brinjal gave encouraging results in terms of growth, yield, and economic return in Bangladesh (Anonymous 2004). Besides, increased growth and yield of vegetable crops under fertigation were reported by many investigators (Bresler 1977, Bhella 1988, Malik et al. 1994). Among the water management practices for increasing WUE, there are several practices, one of them being mulching. Different types of materials such as straw, plastic film, grass, hyacinth, gravel, sand etc. are used as mulches. Mulching with an overhead irrigation system considerably increased the total recovery of applied nitrogen in tomato (Sweeny et al. 1987). Mulching also contributed to the crop production by influencing soil productivity; weed control, etc., depending upon the type of mulches (Asiegbu 1991). The use of polyethylene mulch in vegetable production

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was reported to control weed incidence, reduce nutrient loss and improve hydrothermal regimes of soils (Asworth and Hurrison 1983). The response of tomato crop to drip irrigation was found to be different in different agro-climatic and soil conditions (Shrivastava et al. 1994). It is therefore imperative to test the performance of drip irrigation in conjunction with mulch in Bangladesh condition that is characterized by different soil and climate. Hence, this experiment was undertaken to evaluate the feasibility of drip irrigation with mulches for tomato cultivation in terms of yield, water use efficiency and economics.

MATERIAL AND METHODS

Experimental site. The experiment was conducted during the winter seasons (November–March) of 2007–2008 and 2008–2009 at the experimental field of Bangladesh Agricultural Research Institute, Gazipur, Bangladesh (24.00°N, 90.25°E, 8.4 m a.s.l.). The soil of the experimental field was silt clay loam having a field capacity of 28.6%, wilting point 13.5% (dry weight basis) and bulk density of 1.46 g/cm³.

Experimental design and field management. Three levels of irrigation viz. 100, 75 and 50% of crop water requirement (ETc) with three mulches viz. no mulch (NM); black polyethylene mulch (PM) and paddy straw mulch (SM) were tested. There were nine treatment combinations as follows: T₁ – drip irrigation at 100% ETc; T₂ – drip irrigation at 75% ETc; T₃ – drip irrigation at 50% ETc; T₄ – T₁ + PM; T₅ – T₂ + PM; T₆ – T₃ + PM; T₇ – T₁ + SM; T₈ – T₂ + SM; T₉ – T₃ + SM.

The experiment was laid out in randomized complete block design (RCBD) with three replications. Recommended fertilizer doses (N₁₀₀, P₁₀₀, K₈₀ kg/ha) for fertigation were used for all treatments. Total amount of P in the form of triple super phosphate

(TSP) was applied at the time of final land preparation while N and K in the form of urea and muriate of potash (MOP), respectively, were applied with drip irrigation into four equal splits at 15 days intervals. The tomato (cv. BARI Tomato-3) seedlings 30 day old were transplanted in unit plots of 4 m × 2.4 m with 60 cm × 40 cm spacing on 24 November 2007 and 28 November 2008. For mulching, 10 µm black polyethylene sheet having holes of 50 mm diameter at a distance of 60 cm × 40 cm was spread over the beds and tomato seedlings were transplanted in the holes. For straw mulch, paddy straw at 10 t/ha was used after 7 days of transplanting. For irrigation application, nine water tanks (each tank for each treatment combination) with drip system having a capacity of 250 L each were installed at a height of 1 m above the ground surface to irrigate 27 plots by gravitational flow. One plant was provided with a dripper of 3.5 L/h discharge capacity. Ripened tomato was harvested 9–10 times starting from the first week of February up to the second week of March.

Estimation of crop water requirement. The actual crop evapotranspiration was (ETa) computed by multiplying the reference evapotranspiration (ETo) with crop coefficient (Kc) for different growth stages of the crop (Table 1). ETo was calculated on a daily basis from daily meteorological data (maximum and minimum temperature, relative humidity, wind speed and sunshine hours) using the CROPWAT 8.0 model (Rome, Italy). The model uses FAO Penman-Monteith equation, which was accepted as standard method to calculate reference evapotranspiration (Allen et al. 1998). The Kc for different growth stages of tomato determined locally by lysimeter study were used in the calculation of actual crop evapotranspiration. Thus, volumetric water required for a tomato plant was computed as:

$$ETa \text{ (m}^3\text{)} = Kc \times ETo \text{ (m)} \times \text{projected area (0.4} \times \text{0.6 m}^2\text{)}.$$

Table 1. Estimated water requirement for different growth stages of tomato

Crop stage	Duration (day)	Kc	ETo	ETa	Area occupied by a plant (m ²)	ETa (L/day)	Dripper discharge (L/h)	Time of operation over 2 days (min)
			(mm/day)					
Initial	20	0.46	2.46	1.13	0.24	0.271	3.5	9.30
Development	30	0.83	2.05	1.70	0.24	0.408	3.5	13.98
Mid season	40	1.08	3.14	3.39	0.24	0.813	3.5	27.90
Late season	25	0.86	3.87	3.32	0.24	0.796	3.5	27.31

Kc – crop coefficient; ETo – evapotranspiration; ETa – actual crop evapotranspiration

Economic analysis. The cost of cultivation of tomato includes expenses incurred on land preparation, seeds, transplanting, cost of fertilizer, manure and their application, mulching, weeding, crop protection measures, irrigation water, and cost of harvesting. The cost for full irrigation (100% ETc) was considered as US\$ 65/ha. The cost of drip irrigation system includes depreciation, current bank rate of interest, and repair and maintenance cost of the system. The useful life of the drip system and plastic mulch were considered to be 3 years and 1 year, respectively. The gross return from the produce was estimated from prevailing average market price of US\$ 115/t.

Statistical analyses. Treatment effects were analyzed using a one-way ANOVA followed by the Duncan's multiple range test to calculate the least significant difference (*LSD*) between means. In all cases, differences were deemed to be significant if $P < 0.05$.

RESULTS AND DISCUSSION

Effect of irrigation levels on yield and yield components. The growth, yield and yield contributing characters like plant height, fruit length, fruit diameter, and unit fruit weight were influenced significantly by different levels of irrigation (Table 2). The plant height varied significantly with different levels of irrigation and was maximum with 100%

ETc and minimum with 50% ETc without mulch. The results were reverse when mulches were used with drip irrigation. The fruit size and the unit fruit weight responded significantly to different levels of irrigation; it was however, at par when drip irrigations were used with mulches.

All the drip treatments with mulch resulted in significantly higher yield than unmulched drip treatments. The yield of tomato increased with the increase in water supply without mulch. The effect was reverse when drip irrigation coupled with either polyethylene or straw mulch; there was a decrease in tomato yield with the increase in irrigation regime. This result complies with that of Shrivastava et al. (1994). Drip irrigation at 50% ETc with mulch produced better tomato yield over 75% and 100% ETc irrigation levels. Irrigation with 50% ETc and PM produced slightly higher yield than the same irrigation regime with SM. The increased yield under polyethylene mulch with lower water regime might have resulted from better water utilization, higher uptake of nutrient and excellent soil-water-plant relationship. Irrigation of the same level without mulch produced the lowest yield. However, 100% irrigation supply produced lower yield when mulched with polyethylene than mulched with straw. The yield under all levels of drip irrigation with SM was at par while with PM, significant yield difference was observed between 50% and 100% irrigation levels.

Table 2. Yield components and yield of tomato as influenced by different levels of drip irrigation and mulches during 2007–2009 (average)

Treatment	Plant height	Fruit length (cm)	Fruit diameter	Unit fruit weight (g)	Fruit/plant	Fruit yield (t/ha)	Yield increase over corresponding control (%)	Yield increase over T ₁
T ₁	115.80	53.32	66.80	114.62	27.65	63.84	–	–
T ₂	110.68	51.95	64.39	108.51	27.33	54.38	–	–14.81
T ₃	106.10	49.58	64.54	105.34	20.53	50.60	–	–20.73
T ₄	114.72	52.86	67.64	113.63	30.06	66.06	3.47	3.47
T ₅	117.80	52.69	67.88	116.14	37.56	70.63	29.88	10.63
T ₆	126.23	53.18	69.60	118.32	44.90	81.12	60.31	27.07
T ₇	116.14	53.03	67.61	114.48	38.76	74.29	16.36	16.36
T ₈	122.97	53.66	67.54	115.77	43.29	78.34	44.06	22.71
T ₉	125.90	54.71	67.735	117.18	43.02	79.49	57.60	24.51
CV (%)	3.44	3.66	2.72	4.02	5.59	7.96	–	–
<i>LSD</i> _{0.05}	4.62	2.24	1.84	5.66	3.51	9.09	–	–

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Effect of mulches on yield components and yield. The yield components and yield were significantly greater at all levels of irrigation in mulched treatments as compared to unmulched treatments. Mulches had a significant positive effect on plant height and the effect was more pronounced in lower water regime treatment than higher water regime treatment. Fruit size and fruit weight were found the maximum in drip irrigation with mulches. The yield and yield components were statistically at par between PM and SM with 75% and 100% ETc. However, yield was slightly greater in PM with 50% ETc.

Mulches had a greater effect on tomato yield when compared to the corresponding levels of drip irrigation without mulch. The PM treatments T₄, T₅, and T₆ resulted in 3.47, 29.88 and 60.31% higher yield, respectively, over the corresponding irrigation treatments without mulch. Even when compared with only irrigation treatments meeting 100% ETc, the yield increase in T₄, T₅, and T₆ was 3.47, 10.63 and 27.07%, respectively. Drip irrigation with SM treatments T₇, T₈, and T₉ produced 16.36, 44.06, and 57.60% higher yield, respectively, than the corresponding drip treatments without mulch. Beneficial responses of vegetable crops to mulch in terms of growth and yield have been reported by many investigators (Asiegbu 1991, Shrivastava et al. 1994, Tiwari et al. 1998). SM showed identical performance at all levels of irrigation while PM performed significantly better when 50% ETc demand was met through drip system. The rate of water loss from soil surface through evaporation was much lower in case of PM than SM. This resulted in poor aeration with high moisture regime beneath the PM, which might not be good for giving higher yield.

Water use and water use efficiency. The average seasonal water use for all the drip treatments at 50, 75 and 100% irrigation levels was 137, 206 and 274 mm, respectively. Figure 1 shows that WUE varies both with irrigation regimes and mulches. Mulches with irrigation gave higher WUE over irrigation alone under all levels of irrigation. A larger effect of mulches on WUE was observed when it was combined with lower irrigation regime. At irrigation level of 50% ETc, irrigation to tomato plot mulched with polythene produced better WUE (592 kg/ha/mm) than that of paddy straw mulched (581 kg/ha/mm) or unmulched treatment. However, at 75% ETc level of irrigation,

SM performed better than any other treatment; the unmulched treatment remaining always behind the mulched treatment. At high irrigation level of 100% ETc, all mulched and unmulched treatments performed similarly to produce WUE of about 240 kg/ha/mm. Mulches reduced the rate of water loss through evaporation from soil surface. So, the soil-water-plant relationship was better in low irrigation regime than high irrigation regime that might help produce higher yield and thereby higher WUE. In drip alone treatment, the highest WUE was also recorded in low irrigation regime treatment. In general, the trends for the WUE related to the total water use for various drip treatments showed that the lower the amount of water use, the higher was the WUE. Besides, low irrigation regime reduced deep percolation and increased water use from root zone soil (Ayars et al. 1999).

Economic analysis. The highest net return (US\$ 7098) and the incremental net return (US\$ 1556) were recorded in SM with 50% irrigation regime. In case of PM with the same irrigation regime, these returns were US\$ 6881 and 1339, respectively, though the gross return was recorded to be the highest (US\$ 9405) in this treatment (Table 3). Incremental benefit-cost ratio (BCR) values were recorded higher in SM under all levels of irrigation than that of PM treatments. This was due to higher cost incurred by PM than the SM. The incremental BCR was recorded the highest (7.03) for the treatment with 50% ETc and SM while it was 3.02 for the corresponding PM treatment. It may be suggested that US\$ 1556/ha could be earned additionally by cultivating tomato through drip irrigation with SM while it could be US\$ 1339/ha for PM treatment.

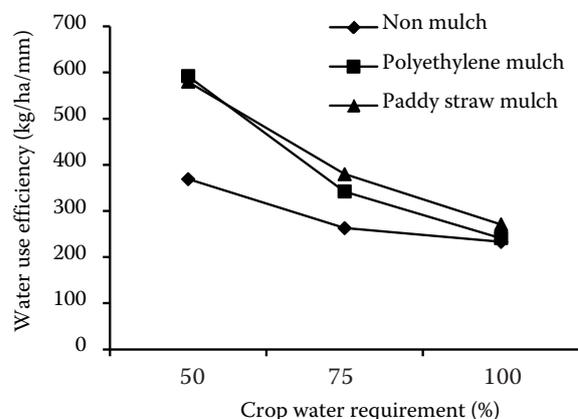


Figure 1. Water use efficiency of tomato under different management practices

Table 3. Economic analysis of tomato production (US\$/ha)

Treatment	Total cost of production	Gross return	Net return	Incremental cost over T ₁	Incremental return over T ₁	Incremental net return over T ₁	Incremental BCR
T ₁	1860	7402	5542	–	–	–	–
T ₂	1844	6305	4461	–16	–1097	–1081	–
T ₃	1829	5867	4038	–31	–1535	–1504	–
T ₄	2556	7659	5103	696	257	–439	0.37
T ₅	2540	8189	5649	680	787	107	1.16
T ₆	2524	9405	6881	664	2003	1339	3.02
T ₇	2150	8613	6463	290	1211	921	4.18
T ₈	2134	9083	6949	274	1681	1407	6.14
T ₉	2118	9216	7098	258	1814	1556	7.03

BCR – benefit-cost ratio

In conclusion, the use of mulch with drip irrigation is a good option not only for water saving but also for improved yield. The maximum yields of 81.12 and 79.49 t/ha were obtained under polyethylene and straw mulch, respectively, with water supply of 50% crop water requirement through drip system. This system economized 50% of irrigation water and increased about 25–27% of fruit yield compared to unmulched control treatment. Similarly higher WUEs were obtained from mulch treatments with 50% crop water requirement. Although polythene mulch performed better in terms of yield and water use efficiency, straw mulch gave the higher economic return. So, in situations where land and water productivity get priority, polyethylene mulch may be the option. Yet, in case of economic profitability, straw mulch is preferable.

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REFERENCES

- Allen R.G., Pereira L.S., Raes D., Smith M. (1998): Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements – FAO Irrigation and Drainage Paper 56. Rome, FAO – Food and Agriculture Organization of the United Nations, 1–13.
- Anonymous (2004): Annual Report, Irrigation and Water Management Division. Gazipur, Bangladesh Agricultural Research Institute.
- Ashworth S., Hurrison H. (1983): Evolution of mulches for use in the home garden. *Horticultural Science*, 18: 180–182.
- Asiegbu J.E. (1991): Response of tomato and eggplant to mulching and nitrogen fertilization under tropical conditions. *Scientia Horticulturae*, 46: 33–41.
- Ayars J.E., Phene C.J., Hutmacher R.B., Davis K.R., Schoneman R.A., Vail S.S., Mead R.M. (1999): Subsurface drip irrigation of row crops: A review of 15 years of research at the Water Management Research Laboratory. *Agricultural Water Management*, 42: 1–27.
- Bhella H.S. (1988): Tomato response of trickle irrigation and black polythene mulch. *Journal of the American Society for Horticultural Science*, 113: 543–546.
- Bresler E. (1977): Trickle-drip irrigation: Principles and applications to soil-water management. *Advances in Agronomy*, 29: 343–393.
- Grimes D.W., Schweers V.H., Wiley P.L. (1976): Drip and furrow irrigation of fresh market tomatoes on a slowly permeable soil. *California Agriculture*, 30: 8–13.
- Jain N., Chauhan H.S., Singh P.K., Shukla K.N. (2000): Response of tomato under drip irrigation and plastic mulching. In: *Proceeding of the 6th International Micro-irrigation Congress, Micro-irrigation Technology for Developing Agriculture*, 22–27 October 2000, South Africa.
- Malik R.S., Kumar K., Bhandari A.R. (1994): Effect of urea application through drip irrigation system on nitrate distribution in loamy sand soils and pea yield. *Journal of the Indian Society of Soil Science*, 42: 6–10.
- Pruitt W.O., Fereres E., Martin P.E., Singh H., Henderson D.W., Hagan R.M., Tarantino E., Chandio B. (1984): Microclimate, Evapotranspiration, and Water-use Efficiency for Drip and

doi: 10.17221/804/2014-PSE

- Furrow-Irrigated Tomatoes. International Commission on Irrigation and Drainage (ICID), 12th Congress, Fort Collins, 367–393.
- Sammis T.W. (1980): Comparison of sprinkler, trickles, subsurface, and furrow irrigation methods for row crops. *Agronomy Journal*, 72: 701–704.
- Shrivastava P.K., Parikh M.M., Sawani N.G., Raman S. (1994): Effect of drip irrigation and mulching on tomato yield. *Agricultural Water Management*, 25: 179–184.
- Sweeny D.M., Graetz D.A., Locascio S.J., Campbell K.L. (1987): Tomato yield and nitrogen recovery as influenced by irrigation method, nitrogen source and mulch. *HortScience*, 22: 27–29.
- Tiwari K.N., Mal P.K., Singh R.M., Chattopadhyay A. (1998): Response of okra (*Abelmoschus esculentus* (L.) Moench.) to drip irrigation under mulch and non-mulch conditions. *Agricultural Water Management*, 38: 91–102.
- Yohannes F., Tadesse T. (1998): Effect of drip and furrow irrigation and plant spacing on yield of tomato at Dire Dawa, Ethiopia. *Agricultural Water Management*, 35: 201–207.

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