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RESPONSE OF TOMATO TO VARIABLE IRRIGATION AND LATERAL SPACING

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Abstract

Field experiment was conducted to study the response of tomato to variable irrigation and lateral spacing at the irrigation research farm of SHAITS (formerly Allahabad Agricultural Institute) - Deemed University, Allahabad, (U.P), India, during the winter crop growing season of November to April on clay loam soil in order to evaluate the effect of irrigation levels (25%, 75%, 125%, 175% and 225%) and lateral spacing (0.5 m and 1.0 m) on marketable fruit yield, irrigation production efficiency, total cost of production, gross return, net return and benefit-cost-ratio of tomato under semi-arid climate of Allahabad region. The irrigation during the crop growing season was applied when sum of last five years of daily pan evaporation from USWB class A pan reaches approximately to predetermined value of 16.3 mm, after accounting the rainfall. Irrigation at 175% of pan evaporation replenishment resulted in significantly higher marketable fruit yield, gross return, net return, and benefit cost ratio, further increase in irrigation level reduced the marketable fruit yield, gross return, net return and benefit cost ratio for both 0.5 m and 1.0 m lateral spacing. The higher irrigation production efficiency was observed at 25% of pan evaporation replenishment, when laterals were placed at 0.5 m spacing. The higher mean marketable fruit yield was observed at 175% of pan evaporation replenishment and higher mean irrigation production efficiency was observed at 25% of pan evaporation replenishment. The lateral spacing 0.5 m gave higher mean marketable fruit yield and higher mean irrigation production efficiency as compared to 1.0 m lateral spacing. The relationship between seasonal water applied and marketable fruit yield, gross return, net return and benefit cost ratio exhibit a strong quadratic relationship for both 0.5 m and 1.0 m lateral spacing. The overall results reveal that the drip irrigation for tomato crop is economically profitable in Allahabad region.

Keywords: Lateral Spacing, Pan Evaporation Replenishment, Tomato, Variable Irrigation.

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INTRODUCTION

India is a leading vegetable producing country in the world. Presently it occupies 6.76 million hectare area with the annual production of 101.43 million tones. The country being blessed with the unique gift of nature of diverse climate and distinct seasons, make it possible to grow an array of vegetables number exceeding more than hundred types. Tomato, one of the most important vegetable crops, is one of them. The production share of the tomato in country's vegetable production is 8.5%. However, the average yield of tomato is considerably low due to lack of information on scheduling and economic variability of drip irrigation system. Irrigation scheduling is a critical management input to ensure adequate soil moisture for optimum plant growth, yield, quality, water use efficiency and economic return. Irrigation scheduling which determine the frequency and amount of irrigation water is governed by many complex factors but microclimate plays the most vital role. Therefore it is important to develop irrigation scheduling techniques under prevailing climatic conditions in order to utilize scare and expensive water resource efficiently and effectively for crop production. The principal of drip irrigation scheduling is to maintain a moist segment of root zone with relatively small application of water applied continuously or intermittently. Therefore, the management strategy in case of drip irrigation changes from an extraction dominance of the soil water balance to one where water infiltration and redistribution are of primary importance (Rawlins, 1973). Numerous studies were carried out in the past on the development and evaluation of irrigation scheduling techniques under a wide range of irrigation system and management, soil, crop and climate conditions (Jensen *et al.,* 1968; Imtiyaz *et al*., 1992, 2000d). The meteorological based irrigation scheduling approach such as pan evaporation replenishment, cumulative pan evaporation and ratio between irrigation water and cumulative pan evaporation etc. were used by many researchers due to its simplicity, data availability and higher degree of adaptability at the farmers level (Singh, 1987; Singh and Mohan, 1994; Srivastava *et al*., 1994; Imtiyaz *et al.,* 1995; Imtiyaz *et al*., 1996; Singh *et al.,* 1997; Imtiyaz *et al*., 2000 a, b, e, 2002, 2004). Drip irrigation system, has revolutionized agriculture in many countries of the world. It is an appropriate technique of water application for row crops especially for wide spaced high value plantation, fruit and vegetable crops. The inherent characteristics of this system are frequent, slow and low volume of water application directly into the plant root zone or on the land surface beneath the plant. It is based on the fundamental concept of irrigating only the root zone of the crop and maintaining the soil moisture near the optimum level.

The design criteria and standards applied in case of drip irrigation are different from those used for the conventional methods of irrigation. Thus crop water requirement for this system is expected to be different from systems where the entire surface is wetted during irrigation and water is applied at larger intervals. Particular importance is the accurate estimate of the crop water requirement for the accurate design of drip irrigation system and irrigation scheduling. Drip irrigation method with its ability to apply less but frequent water application have been found superior in terms of water economy, yield, quality and water use efficiency (Srivastava *et al.,* 1994; Hanson *et al.,* 1997; Imtiyaz *et al*., 2000 d)

MATERIALS AND METHODS

The field experiment was conducted during the winter crop growing period November – April in order to examine the effect of variable irrigation and lateral spacing on marketable fruit yield, irrigation production efficiency and economic return of tomato. The climate in this part of country has been classified as semi-arid with cold winter and hot summer. The soil of the field was fertile clay loam with 55.5% sand, 25.8% silt, 38.6% clay, with an average density of 1.31g/cm^3. The moisture content at field capacity (-1/3 bar) and wilting point (-15 bar) was 19.5% and 9.1% on an oven dry weight loss basis respectively. The plant available soil moisture was 136.2 mm/m.

Test Crop

The test crop selected for the study was Tomato (*Lycopersicon esculentum*) of Top-48F$_1$ hybrid variety, seeds produced by Indo-American Hybrid Seeds (India) Pvt. Ltd. Tomato (*Lycopersicon esculentum*) a rich source of minerals, vitamins and organic acids, is most important and remunerative vegetable in India. It provides 3- 4% total sugar, 4-7% total solids, 15-30 mg/100 g ascorbic acid, 7.5-10 mg /100 ml. titrable acidity and 20-50 mg /100 gm fruit weight of lycopene.

Raising of seedling and transplanting

Before sowing the seeds of tomato, the soil was prepared by mixing 70% of field soil and 30% compost. Tomato (Top-48 F$_1$ Hybrid) seeds were sown on November in the nursery at a depth of 5 cm with a spacing of 10 cm between the rows. The seed bed was irrigated regularly and covered with dry straw of 6 cm thickness and treated with Gamaxene in order to facilitate good emergence. The seedlings were transplanted on December at a spacing of 0.5 m plant to plant. A buffer zone spacing of 1.0 m was provided between the plots. Before transplanting, experimental field of tomato was well irrigated, properly ploughed, well pulverized and leveled to provide good tilth. Prior to transplanting, 72 kg/ha N, 21 kg/ha P_2O_5 and 90 kg/ha K_2O were applied to the experimental field of tomato.

Experimental set up

The Drip system consisted of a centrifugal pump, screen filter, main pipe-line, sub main pipe-line, PVC control valve, laterals, drippers, pressure gauge and end plug etc. The irrigation water was pumped directly from borehole to the concrete tank. Then water was lifted from the concrete tank with the help of centrifugal pump driven by electric motor, to the drip irrigation system. Screen filter was installed on the main line to minimize dripper blockage. The experiment was laid out in a two factor complete randomized block design with three replications. It comprises of 10 treatments with five irrigation levels (I_1, I_2, I_3, I_4 and I_5) and two lateral spacing (LS_1 = 0.5 m, LS_2 = 1.0 m). The area of each experimental plot was 9 m^2 (3 m x 3 m). The experiment consisted of five irrigation levels and two lateral spacing. The details of the treatments are as follows:

Irrigation levels:

I_1: Irrigation at 25% of pan evaporation replenishment,
I_2: Irrigation at 75% of pan evaporation replenishment,
I_3: Irrigation at 125% of pan evaporation replenishment,
I_4: Irrigation at 175% of pan evaporation replenishment,
I_5: Irrigation at 225% of pan evaporation replenishment.

Lateral Spacing:

LS_1 = 0.5 m (Lateral in every row), LS_2 = 1.0 m (Lateral in alternate row).

The daily evaporation data from USWB class A open pan for a period of last five years were collected from Meteorological station, AAIDU. Crop was irrigated when the sum of the daily mean of pan evaporation reached approximately to a pre-determined value of 16.3 mm {rooting depth (m) x plant available soil moisture (mm / m) x readily available soil moisture in fraction}. The crop was irrigated by the surface drip irrigation method. The drip irrigation system was designed and installed to meet the objectives of the proposed research work. PVC pipes of 50 mm and low-density polyethylene pipes (LDPE) of 12 mm diameter were used for sub-main and lateral lines respectively, the lateral line was laid to each crop row as well as in alternate rows. Plants of tomato were watered by 4 l / hr non-pressure compensated on line drippers. The space between drippers was 0.5 m. The sub-main line was connected to a water meter and a control valve in order to deliver the desired amount of water to the respective treatments. Standard cultural practices were adopted during the crop growing seasons. The crop was harvested from March to April in four segments. In order to assess the economic viability of drip irrigation system under variable irrigation and lateral spacing, both fixed and operating costs were included.

Total cost of production, gross return and net return under different irrigation levels was estimated on the following assumptions:

Salvage value of the components	= 0
Useful life of tube well, pump, motor and pump house	= 25 years
Useful life of drip irrigation systems	= 10 years
Useful life of weeding and spraying equipments	= 7 years
Interest rate	= 10%
Repair and maintenance	= 2.5 %
No. of crops / year	= 2

The fixed cost including water development (tube well, pump, motor, pump-house and other accessories) and irrigation systems {Polyvinyl chloride (PVC) and low density polyethylene pipes (LDPE) for main, sub-main and laterals, filters, fertilizer unit, pressure gauges, control valves, water meter, drippers and other accessories} was calculated for different irrigation levels and lateral spacing by the following approach:

$$CRF = \frac{i\,(1 + i)^{n}}{(1 + i)^{n\,-1}}$$

Where,

CRF = capital recovery factor,
i = Interest rate (fraction),
N = Useful life of the component (years),

$$\text{Annual fixed cost/ha} = \text{CRF x fixed cost / ha}$$

$$\text{Annual fixed cost/ha/season} = \frac{\text{Annual fixed cost / ha}}{2}$$

The operating cost including labor (system installation, irrigation, planting, weeding, cultivation, fertilizer and chemical application and harvesting etc.), land preparation, fertilizers, chemicals, water pumping and repair and maintenance (tube-well, pump, electric motor, pump-house, irrigation systems etc.) was estimated. The gross return was calculated taking into consideration the marketable yield and current whole sale price of tomato. Subsequently, the net return for tomato was calculated considering total cost of production and gross return.

The benefit cost ratio (B/C) was calculated as follows:

$$B/C = \frac{\text{Gross return (Rs / ha)}}{\text{Total cost of production}}$$

RESULTS AND DISCUSSION

Marketable Fruit Yield and Irrigation Production Efficiency

The marketable fruit yield and irrigation production efficiency of tomato as influenced by irrigation levels and lateral spacing are presented in Table.1. The irrigation levels significantly influenced the marketable fruit yield of tomato. The mean marketable fruit yield for different irrigation levels ranged from 29.16 t / ha to 59.34 t / ha. The highest mean marketable fruit yield (59.34 t / ha) was recorded, when irrigation during the crop growing season was applied at 175% of pan evaporation replenishment. A further increase in irrigation level resulting from 225% of pan evaporation replenishment reduced the marketable fruit yield significantly, due to poor aeration caused by excessive soil moisture. The percentage reduction in marketable fruit yield was 50.86, 26.27, 18.30 and 5.54, when irrigation during the crop-growing season was applied at 25, 75, 125 and 225% of pan evaporation replenishment, respectively. The lateral spacing has significant effect on marketable fruit yield of tomato (Table.1). The highest marketable fruit yield (60.90 t / ha) was obtained, when laterals were placed at 0.5 m spacing due to better water distribution in the field. At all levels of pan evaporation replenishment lateral spacing of 0.5 m produced higher fruit yield in respect of lateral spacing of 1.0 m.

The irrigation production efficiency of tomato was significantly influenced by irrigation levels and lateral spacing (Table.1). The mean irrigation production efficiency at different irrigation levels ranged from 6.50 kg/m^3 to 30.38 kg / m^3. The highest mean irrigation production efficiency (30.38 kg / m^3) was recorded at 25% of pan evaporation replenishment because reduction in yield was less as compared with seasonal water applied. Irrigation at 225% of pan evaporation replenishment resulted minimum irrigation production efficiency (6.50 kg / m^3) because it increased the seasonal water application but decreased the marketable fruit yield. The percentage reductions in irrigation production efficiency were 49.84, 66.69, 70.84 and 78.60, when irrigation was applied at 75%, 125%, 175% and 225% of pan evaporation replenishment, respectively. The significantly higher irrigation production efficiency (14.80 kg / m^3) was observed at 0.5 m lateral spacing as compared to 1.0 m lateral spacing, due to significant difference in marketable yield. The mean reductions in irrigation production efficiency were 51.28% and 55.10% when laterals were placed at 0.5 m and 1.0 m respectively. At all irrigation levels the maximum irrigation production efficiency was recorded when lateral were provided for each row of crop as compared with lateral at every alternate row. Imtiyaz *et al.* (2000, a) reported the higher marketable fruit yield and irrigation production efficiency of vegetable crops at 80% of pan evaporation replenishment under agro-climatic conditions of northwestern Botswana.

Economic return

The total cost of production, gross return, net return and benefit cost ratio of tomato under different irrigation level and lateral spacing are presented in Table.2. The total cost of production increased with increase in irrigation level. The total cost of production of tomato for 0.5 m and 1.0 m lateral spacing under different irrigation levels ranged from 71319 Rs/ha to 79937 Rs / ha and 60575 Rs/ha to 69193 Rs / ha respectively. The total cost of production increased slightly with an increase in pan evaporation replenishment because the pumping cost was insignificant as compared to the total cost of production. The total cost of production was considerably higher for 0.5 m lateral spacing as compared to 1.0 m lateral spacing due to higher fixed cost (41.33%) resulted from considerably higher number of drippers/ha and lateral length.
The gross return increased sharply from 25% to 175% of pan evaporation replenishment due to significant increase in marketable yield. Irrigation at 225% of pan evaporation replenishment reduced gross return due to significant reduction in marketable fruit yield. At all the irrigation levels, lateral

Table 1. Effect of irrigation levels and lateral spacing on marketable yield and irrigation production efficiency of tomato

Pan evaporation replenishment (%)	Mean marketable fruit yield (t / ha)	Mean irrigation production efficiency (kg / m^3)
25	29.16	30.38
75	43.75	15.24
125	48.48	10.12
175	59.34	8.86
225	56.05	6.50
LSD (5%)	0.93	0.37
Lateral spacing (m)		
0.5	49.09	14.80
1	45.62	13.64
LSD (5%)	0.57	0.23
Interaction LSD (5%)	1.31	0.52

Table 2. Economic analysis for Tomato under different irrigation levels and lateral spacing

Pan evaporation replenishment (%)	0.5 m Lateral spacing (LS_1)				1.0 m Lateral spacing (LS_2)			
	Total cost of production (Rs / ha)	Gross return (Rs / ha)	Net return (Rs / ha)	Benefit cost ratio	Total cost of production (Rs / ha)	Gross return (Rs / ha)	Net return, (Rs / ha)	Benefit cost ratio
25	71677	150333	78656	2.10	60575	141250	80675	2.33
75	73826	236067	162241	3.2	62724	201383	138659	3.21
125	75986	253717	177731	3.34	64884	231033	166149	3.56
175	78135	304500	226365	3.90	67033	288850	221817	4.31
225	80295	282600	202305	3.52	69193	277900	208707	4.02

spacing 0.5 m gave the higher gross return (150333 Rs / ha to 304500 Rs / ha) due to higher marketable yield as compared with 1.0 m lateral spacing (Table.2). The net return for both 0.5 m and 1.0 m lateral spacing increased sharply from 25% to 175% of pan evaporation replenishment due to sharp increase in marketable yield. A further increase in irrigation level resulted from 225% of pan evaporation replenishment decreased the net return because it increased the total cost of production and decreased the gross return. The net return for 0.5 m and 1.0 m lateral spacing ranged from 78656 Rs / ha to 226365 Rs / ha and 80675 Rs / ha to 221817 Rs / ha respectively. The net return at 175% of pan evaporation replenishment for 0.5 m lateral spacing (226365 Rs / ha) and 1.0 m lateral spacing (221817 Rs / ha) were approximately close because yield reduction at 1.0 m lateral spacing was compensated due to considerable reduction in system cost (Table.2).

The benefit cost ratio for both 0.5 m and 1.0 m lateral spacing increased considerably from 25% to 175% of pan evaporation replenishment due to sharp increase in gross return. The irrigation at 175% of pan evaporation replenishment resulted the maximum benefit cost ratio for 0.5 m (3.9) and 1.0 m (4.31) lateral spacing because of the increase in gross return was higher as compared to total cost of production. Irrigation at 225% of pan evaporation replenishment decreased the benefit cost ratio because it increased the total cost of production and decreased the gross return. However, the benefit cost ratio for 1.0 m lateral spacing at 25%, 75%, 125%, 175%, and 225% of pan evaporation replenishment was higher due to considerable reduction in system cost (Table.2). The overall result under different lateral spacing revealed that irrigation at 175% of pan evaporation replenishment gave the maximum gross return, net return and benefit cost ratio. Similar results were reported by some researches under wide variety of irrigation system and regimes soil, crop and climatic conditions (Srivastava *et al.,* 1994; Singh *et al.,* 1997; Imtiyaz *et al.,* 2000, a, b, d, e, 2002, 2004).

Seasonal Water Applied and Marketable Fruit Yield

The relationship between the marketable fruit yield of crop and seasonal water applied to the crop for 0.5 m and 1.0 m lateral spacing are presented in Fig.1a. The seasonal water applied ranging from 96 mm to 862 mm, where as marketable fruit yield for 0.5 m and 1.0 m lateral spacing ranged from 30.07 t / ha to 60.90 t / ha and 28.25 t / ha to 57.77 t / ha, respectively. The seasonal water applied and marketable fruit yield of tomato for 0.5m (R^2 = 0.96278) and 1.0 m (R^2 = 0.96575) lateral spacing exhibit a strong quadratic relationship. Tomato attained the maximum marketable yield at seasonal water applied of 725 mm and 862 mm for 0.5 m and 1.0 m lateral spacing respectively, thereafter it tended to decline (Fig.1a). The result revealed that the higher seasonal water application did not increase marketable yield, but it increased nutrients leaching through deep percolation. In spite of some variation, the over all result showed the quadratic relationship between seasonal water applied/irrigation level and marketable fruit yield of tomato, which can be used for allocating water resources within the crop efficiently. (Imtiyaz *et al.,* 2000, a, b, d, e) reported the quadratic relationship between seasonal water applied and marketable yield of vegetable crops under both drip and sprinkler irrigation systems. Many researchers have reported a quadratic relationship between yield and seasonal irrigation/seasonal water applied for Vegetable and field crops under a wide range of irrigation systems and regimes soil and climactic condition (Singh, 1987; Howell *et al.,* 1997; Tiwari and Reddy 1998; Zhang and Oweis, 1999; Imtiyaz *et al.,* 2002).

Seasonal Water Applied and Economic Return

The relationships between seasonal water applied and gross return of tomato for 0.5 m and 1.0 m lateral spacing are presented in Fig.1b. The seasonal water applied ranged from 96 mm to 862 mm, where as gross return for 0.5 m and 1.0 m lateral spacing ranged form 150333 Rs / ha to 304500 Rs / ha

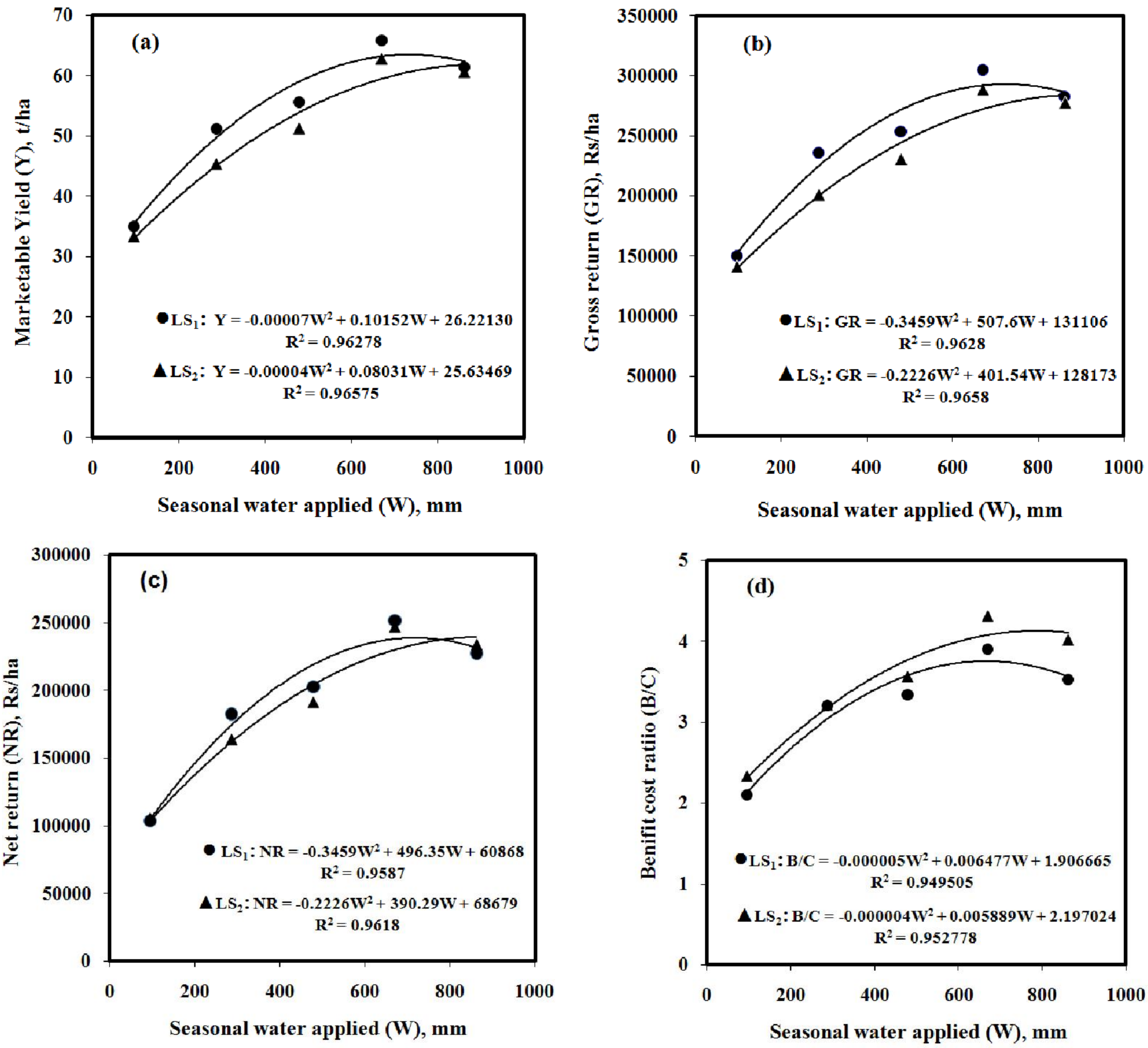

Fig.1a-d: Relationships between Seasonal water applied and Marketable fruit yield (a), Gross return (b), Net return (c) and Benefit cost ratio (d) of tomato, respectively for 0.5m (LS1) and 1.0m (LS2) lateral spacing

and 141250 Rs / ha to 288850 Rs / ha respectively. The seasonal water applied and gross return for 0.5 m (R^2 = 0.9628) and 1.0 m (R^2 = 0.9658) lateral spacing exhibit strong quadratic relationship. The gross return of tomato increased with an increase in seasonal water applied up to 734 mm and 862 mm for 0.5 m and 1.0 m lateral spacing respectively, thereafter gross return tended to decline. The result revealed that fitted regression model can be used for optimizing gross return of tomato under different irrigation levels and lateral spacing. The relationship between seasonal water applied and net return of tomato for 0.5 m and 1.0 m lateral spacing are presented in Fig.1c.

The seasonal water applied ranged form 96 mm to 862 mm, where as net return for 0.5 m and 1.0 m lateral spacing ranged from 79014 Rs / ha to 226723 Rs / ha and 80675 Rs / ha to 221817 Rs / ha respectively. The seasonal water applied and net return for 0.5 m (R^2 = 0.9587) and 1.0 m (R^2 = 0.9618) lateral spacing exhibits strong quadratic relationship. The net return of tomato increased with an increase in seasonal water applied up to 626 mm and 874 mm for 0.5 m and 1.0 m lateral spacing respectively and thereafter net return tends to decline. The result revealed that fitted regression models can be used for optimizing net return of tomato under different irrigation levels and lateral spacing. The relationship between seasonal water applied and benefit cost ratio of tomato for 0.5 m and 1.0 m lateral spacing are presented in Fig.1d. The seasonal water applied ranged form 96 mm to 862 mm whereas benefit cost ratio for 0.5 m and 1.0 m lateral spacing ranged from 2.1 to 3.9 and 2.33 to 4.31 respectively. The seasonal water applied and benefit cost ratio for 0.5 m (R^2 = 0.949505) and 1.0 m (R^2 = 0.952778) lateral spacing exhibited strong quadratic relationship. The benefit cost ratio of tomato increased with an increase in seasonal water applied up to 862 mm and 658 mm for 0.5 m and 1.0 m lateral spacing respectively and thereafter it tends to decline. The results revealed that fitted regression models can be used for optimizing benefit cost ratio of tomato under different irrigation levels and lateral spacing. In spite of some variation, the overall results shows strong quadratic relationship between seasonal water applied/irrigation levels with gross return, net return and benefit cost ratio for tomato under varying lateral spacing. (Tiwari and Reddy, 1997) reported the similar results for banana.

Conclusion

Properly managed drip irrigation system is designed to provide frequent irrigation with slow and low volume of water application, to the plant root zone. In order to obtain maximum yield and net return daily pan evaporation data of previous years are used for proper irrigation scheduling of crop. Finally the overall results acquired suggest that, in order to obtain optimum yield and net return of tomato in the semi-arid climate of Allahabad region of northern India, the crop of tomato (Top-48F_1 hybrid) during winter season should be irrigated at 175% of pan evaporation replenishment either with 0.5 m or 1.0 m lateral spacing. The initial investment in drip irrigation method is high due to high cost of components of drip irrigation system even then the tomato production by drip irrigation method is highly profitable and feasible in Allahabad region of northern India.

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