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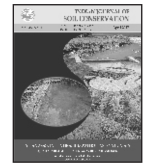

Effect of drip fertigation levels on soil water dynamics, water use efficiency, yield and quality parameters of broccoli (*Brassica oleracea* L.*var. italica*) in wet temperate zone of Himachal Pradesh

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ABSTRACT

The present study was conducted at experimental farm of CSK HPKV, Palampur, during the year 2012-2013 with the objectives to evaluate the effects of drip irrigation levels and different methods of fertilizer application on soil water retention and transmission, plant water and water use efficiency, quality parameters, growth, productivity and nutrient uptake by broccoli. The treatments comprised of (a) three drip irrigation levels *viz.,* $I_{0.4}$-Drip at 40% CPE, $I_{0.6}$-Drip at 60% CPE and $I_{0.8}$-Drip at 80% CPE (b) three fertilizer application levels *viz.,* F_{100}-100% recommended dose of fertilizer through fertigation, $F_{C25+F75}$-25 % recommended dose of fertilizer through conventional method as a basal dose and 75% through fertigation and F_{CF}-100% of recommended dose of fertilizer through conventional method and fertilizers, (c) control-Flood irrigation of 4 cm at 8-10 days interval + 100% recommended dose of fertilizer and (d) absolute control- No fertilizer and flood irrigation of 4 cm at 8-10 days interval. The broccoli cv. Palam Samridhi was transplanted on October 31, 2012. The results indicated that $I_{0.8}$ and I_{Rec} treatment had higher soil water content, soil water stock, profile water recharge in comparison to $I_{0.4}$ and $I_{0.6}$. The $I_{0.8}$ treatment due to favorable soil moisture regimes led to better root and shoot growth, higher relative leaf water content, marketable curd yield, TSS, ascorbic acid, chlorophyll content, NPK uptake, fertilizer use efficiency with respect to N, P and K and water use efficiency in comparison to $I_{0.4}$, $I_{0.6}$ and I_{Rec}. Likewise, F_{100} and $F_{C25+F75}$ treatment had higher root and shoot growth, relative leaf water content, marketable curd yield, TSS, ascorbic acid, chlorophyll content, NPK uptake and water use efficiency in comparison to F_{CF}. The marketable curd yield obtained under $I_{0.4}F_{100}$ was at par with $I_{0.6}F_{100}$ treatment, which resulted in saving of 20% irrigation water. The study concluded that drip based irrigation scheduling resulted in higher water use efficiency (44.68% to 54.88%) and saving in irrigation water (43.25% to 48.90%) in comparison to conventional method of irrigation.

1. INTRODUCTION

Water availability for agriculture is under challenge in the world as well as in India. Today, it is more important to use water resources wisely and to irrigate intelligently. With increasing population in India, food grain demand by 2030 will be 345 M mt and by 2050 will be 494 M mt (Soman, 2012). To meet the increasing food grain demand, productivity is to be increased from 2.3 to 4.0 t ha^{-1} under irrigated conditions and 1.0 to 1.5 t ha^{-1} under rainfed conditions (Kumar, 2011). To achieve the target productivity, there is stiff competition for water from different sectors. In 2025, water demand will be 1093 BCM and out of this, 910 BCM will be required for agriculture, thus other sectors will be under stress (Kumar, 2011).

Himachal Pradesh is a hilly state and the majority of the people are engaged in farming profession. This state has made major strides in horticulture and off season vegetable cultivation and has earned a niche for itself in national scenario but the potential for off-season vegetable cultivation has not been harnessed fully owing to irrigation constraints. Moreover, conventional irrigation methods are not feasible due to mountainous terrains. Some parts of Himachal Pradesh receive annual rainfall up to 3000 mm and about 85% of it occurs during June to September. Most of monsoon rainfall goes waste as runoff due to uneven terrain of the region. The months of October, November and December are generally dry, due to which *rabi* crops fail frequently and yield levels are very low. Under such circumstances rainwater harvesting and application of harvested water by micro irrigation system is the most feasible option.

In drip irrigation, water is applied drop by drop on continuous basis through closed network of plastic pipes at frequent intervals near to the root zone for consumptive use of the crop. Drip irrigation enhances profitability, increases crop yield and improves crop quality. It reduces costs from water, energy, labour, chemical inputs and run- off. It improves plant vigor by delivering water and nutrients directly to the plant roots-the effective feeding zone, avoiding wetting of leaves which results in low disease incidence. It minimizes conventional losses of water by deep percolation, evaporation and run off (Narayanamoorthy, 2005). This method is very suitable under situations of water scarcity. The added advantage of drip system is that water soluble fertilizers can also be applied through this system and the process is known as fertigation. Soils with high as well as low water transmission characteristics can be irrigated by this method efficiently. Better crop establishment can be ensured under this system of irrigation since mechanical impedance for emerging seedlings is lowered by reducing the soil crusting phenomenon.

Broccoli (*Brassica oleracea var.* L. *italica*) is a member of the *Brassicaceae* family and its wild form is found along the Mediterranean region. It is a very delicious, nutritious and exotic vegetable grown. Broccoli is rich in vitamin A, C and dietary fibre and in terms of minerals; the value of broccoli includes Fe, Ca, P, Mg, Zn, K. It contains 2500 IU vitamin A in a 100 g edible portion. It also contains 103 mg calcium, 78 mg phosphorous, 382 mg potassium and 113 mg vitamin C (Kohli *et al.,* 2006). Broccoli is the upcoming cash crop in the country. It contains multiple nutrients with anti-cancer properties such as di-indolylmethane and sulphoraphane (Vivar *et al.,* 2009). Broccoli can prevent Alzheimer's disease, diabetes, Ca deficiency, colon cancer, malignant tumor, lung cancer, heart disease and arthritis.

Being a cool season crop, the optimum temperature requirement is 15-20°C for head production. It prefers a well drained, sandy loam soil with optimum pH of 5.5-6.8 (Kohli *et al.,* 2006). Keeping in mind its better nutritive character, more edible dry matter content, market price and its suitability to low temperature conditions it has a great potential in low hill conditions of Himachal Pradesh.

As such, limited information is available on the quantity of water to be applied through drip and on application of water soluble fertilizer through fertigation to broccoli, which have become recently available in the market. With this background, the study was planned under sub-humid Zone of the State of Himachal Pradesh to evaluate the effects of drip irrigation levels on soil and plant water behavior and to evaluate the effects of NPK fertigation, NPK fertilization and the combined method of fertigation and fertilization on productivity and nutrient uptake at varying drip irrigation levels.

2. MATERIALS AND METHODS

A field experiment was conducted at the experimental farm of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, during *rabi* season 2012-13 in an acid Alfisol. The area lies in Palam Valley (32°06'N latitude and 76°33'E longitude) at an elevation of 1290 m above msl of Kangra district of Himachal Pradesh and represents the mid hills sub humid agro-climatic zone of Himachal Pradesh in North Western Himalayas. Taxonomically, the soil is classified as Alfisols-Typic Hapludalf (Verma, 1979). The physico-chemical and chemical properties of the surface soil (0-0.15 m) were determined. The soil had a pH value 5.08. The soil was low in available N (198.76 kg ha^{-1}), high in available P (46.79 kg ha^{-1}) and medium in available K (224.88 kg ha^{-1}). The mean weight diameter of the aggregates for the surface layer was 1.919 mm with infiltration rate of 1.753×10^{-5} m s^{-1}.

The experiment was laid out in a randomized block design with eleven treatments comprising of (a) Three drip irrigation levels *viz.,* $I_{0.8}$ (0.8 CPE) *i.e.* Drip at 80% CPE (Cumulative Pan Evaporation), $I_{0.6}$ (0.6 CPE) *i.e.* Drip at 60% CPE and $I_{0.4}$ (0.4 CPE) *i.e.* Drip at 40% CPE (b) Three methods of fertilizer application levels *viz.,* (i) 100% through fertigation, (ii) 25% basal dose through conventional fertilization method and 75% through fertigation and (iii) conventional fertilization. The RDF (Recommended dose of fertilizer) *i.e.,* 150:100:55 was kept same in all the treatments. Besides this there was (c) one recommended practice (RP) *i.e.,* control (I_{Rec}) *i.e.* flood irrigation of 4 cm at 8-10 days interval along with 100% recommended dose of fertilizer and (d) absolute control where flood irrigation of 4 cm was given at 8-10 days interval and with no recommended dose of fertilizer. The treatments were replicated thrice. The broccoli cv. Palam Samridhi was transplanted on October 31, 2012 at 45 x 45 cm spacing in 6 × 2 m (12 m^2) plots. The averaged pan evaporation data (2004-05 to 2011-12) was used to determine the amount of water to be given in the ratio of 0.8, 0.6 and 0.4 cumulative pan evaporation (CPE). Irrigation water was applied through drip at 2 days interval as broccoli is a winter crop and evaporation rate is low. In NPK fertigation treatments, water soluble fertilizers *viz.*, 19:19:19+12:61:0+Urea was applied in different calculated proportions injected through overhead fertilizer tank at 8-10 days interval. In fertigation treatments NPK fertilizer doses calculated as per treatment were applied in 10 equal splits at 8-10 days interval through fertigation in 100% fertigation treatment and in seven equal splits at 8-10 days interval in 75% fertigation treatment. In conventional fertilization treatment and control, half of nitrogen fertilizer and full amount of phosphorous and potassium fertilizers were applied at the time of transplanting. The remaining half of nitrogen fertilizer was applied in two splits, first after 30 days of transplanting and second at head formation stage.

To undertake the study, drip laterals placed in all the 27 plots starting from first to last plot and 10 drippers were selected in each plot and the containers were kept at the respective drippers. The whole system was operated for one minute and water was collected in each container. The discharge variation was calculated by the following equation (El Nemr, 2012).

$$\text{Discharge variation (\%)} = \frac{Qmax - Qmin}{Qmax} \times 100$$

Where, 'Q_{max}' is the maximum discharge rate (lit h^{-1}) and 'Q_{min}' is the minimum discharge rate (lit h^{-1}).

The Uniformity Coefficient (UC) was calculated by the following equation (Christiansen, 1942).

$$UC\ (\%) = 100 \left[1 - \frac{\sum_{i=0}^{n} [q_i - \bar{q}]}{\bar{q}} \right]$$

Where, 'n' represents number of emitters evaluated, 'q_i' is the discharge through emitter and '$\bar{q}$' is the average discharge rate.

The overall averaged discharge rate and discharge variation was 4.05 lit h^{-1} and 17.11%, respectively. Also the overall averaged uniformity coefficient was 94.57%. Depth wise soil samples were collected from three replications at four places 15 cm away from the dripper. The changes in soil water content during the season at 0-0.15, 0.15-0.30, 0.30-0.45 and 0.45-0.60 m depths were determined one day after irrigation by thermo gravimetric method periodically during broccoli crop growth period. Volumetric water content (θ) for different depths was calculated by multiplying the gravimetric water content (w/w basis) with pre determined bulk density for that depth (Hillel, 1982). The aeration porosity was calculated by determining relation of air to water content on a particular day by the following equation.

$$fa\ (\%) = (f - \theta)$$

Where, 'f_a' is the aeration porosity, 'f' is porosity (%) and 'θ' is volumetric wetness (%).

The consumptive water use was calculated by the following equation:

$$\text{Consumptive Water Use} = I + ER \pm \Delta S$$

Where, 'I' is the amount of irrigation water applied, 'ER' is the effective rainfall during the crop period and 'ΔS' is the profile water depletion. ER was calculated by the Evapotranspiration/precipitation method (Reddy and Reddi, 2008). The Relative Leaf Water Content (RLWC) was determined at 50 and 100 Days After Transplanting (DAT) during crop growth at 0700 h and 1400 h. RLWC was computed from the fresh weight, turgid weight and oven dry weight of leaves according to the method given as:

$$RLWC = \frac{\text{Fresh weight - Oven dry weight}}{\text{Fully turgid - Oven dry weight}} \times 100$$

Quality parameters like TSS, ascorbic acid and chlorophyll a, b and total chlorophyll was determined to find out the effect on these parameters with different irrigation levels and different methods of fertilizer application. TSS was determined by means of hand refractrometer which is based on the principle of total refraction. For determining the TSS, a drop of sample juice was placed on the prism and the percentage of dry substance in it was read directly (A.O.A.C., 1990). The ascorbic acid (vitamin C) content was determined by the titration method. In this method 10 gram of the sample was blended with 3% HPO_3 and the volume was made 100 ml. After filtration 10 ml of the filtrate was taken into conical flask and titrated with a standard dye to a pink end point. The ascorbic acid content was calculated by the following formula (A.O.A.C., 1990).

$$\text{Ascorbic Acid (mg/100 g)} = \frac{\text{Titre x Dye factor x Volume made x 100}}{\text{Volume of filtrate taken x Weight of sample}}$$

For estimation of chlorophyll content one gram of fresh sample was taken and 5 ml of water added to it and homogenized in a blender. Volume of homogenate was made 10 ml with water from which 0.5 ml aliquot was taken, to which 4.5 ml of 80% acetone was added to extract pigments. After centrifugation and removal of supernatant, its optical density (O.D) was recorded at 480, 645 and 663 nm using 80% acetone as a blank. Total chlorophyll content, chlorophyll a and chlorophyll b were calculated by the following formula (Rangana, 2007).

Total chlorophyll (g lit^{-1}) = (0.0202 (O.D at 645) + (0.00802) (O.D at 663) ; Chlorophyll a (g lit^{-1}) = (0.0127 (O.D at 663) - (0.00269) (O.D at 645) ; Chlorophyll b (g lit^{-1}) = (0.0229 (O.D at 645) - (0.00480) (O.D at 663).

The fertilizer expense efficiency was computed as described by (Veeranna *et al.,* 2001).

$$\text{FEE (kg ha}^{-1}) = \frac{\text{Oven dried fruit yield (kg ha}^{-1})}{\text{Toal quantity of nutrient applied (kg ha}^{-1})}$$

The fertilizer use efficiency with respect to N, P and K was calculated by the formula (Pomares Gracia and Pratt, 1987) given as:

$$\text{Percent efficiency} = \frac{A - B}{C} \times 100$$

Where, A = uptake with fertilizer; B = uptake without fertilizer; C = total amount of fertilizer that had been applied; where uptake = concentration × dry weight (kg).

The fresh marketable curd yield of broccoli was recorded at harvest expressed in Mg ha^{-1}. Water use efficiency (kg ha^{-1} mm^{-1}) was computed as curd yield per unit consumptive water use.

3. RESULTS AND DISCUSSION

Rainfall and Evaporation

The rainfall distribution and evaporation during growth period of broccoli for the year 2012-13 indicated that 4 mm rain (two rainy days) was received in the month of November 2012. During December 2012, 28.2 mm rainfall was received (three rainy days). There was a rainfall of 75.4 mm (four rainy days) during the month of January 2013. After that there was a subsequent rainfall of 165.2 mm during February 2013 with twelve rainy days. In the month of March 2013, no rainfall was received during first two weeks. The monthly evaporation values during November 2012, December 2012, January 2013 and February 2013 were 74.7, 58.9, 53.4 and 53.7 mm, respectively. The monthly evaporation rate during November 2012, December 2012, January 2013 and February 2013 were 2.5, 1.9, 1.7 and 1.9 mm d^{-1}, respectively total monthly evaporation exceeded the total monthly rainfall during November and December, 2012, whereas during the rest of the crop growth period, total monthly rainfall exceeded the total monthly evaporation.

Soil Water Content

The soil water content (θ) determined during crop growth period of winter 2012-13 is shown in Fig. 1. The 'θ' determined at early crop growth stages *i.e.* at 30 DAT was 0.27, 0.32, 0.27 and 0.30 m^3 m^{-3} in $I_{0.4}$; 0.29, 0.33, 0.28 and 0.31 m^3 m^{-3} in $I_{0.6}$; 0.30, 0.33, 0.31 and 0.31 m^3 m^{-3} in $I_{0.8}$ and 0.37, 0.38, 0.37 and 0.36 m^3 m^{-3} in I_{Rec} at 0-0.15, 0.15-0.30, 0.30-0.45 and 0.45-0.60 m soil depths, respectively. The soil water content showed an increasing trend from $I_{0.4}$ to $I_{0.8}$ in 0-0.15, 0.15-0.30 and 0.30-0.45 m depths. The higher soil water content in $I_{0.8}$ may be attributed to higher amount of drip irrigation compensating evaporation and drainage losses. Similar findings have also been observed by Kumar *et al.* (2012). However, the soil water content was almost similar in $I_{0.4}$, $I_{0.6}$ and $I_{0.8}$ in 0.45-0.60 m deep layer. The soil water content was higher both in surface (0-0.15 and 0.15-0.30 m) as well as subsurface (0.30-0.45 and 0.45-0.60 m) layers in I_{rec}.

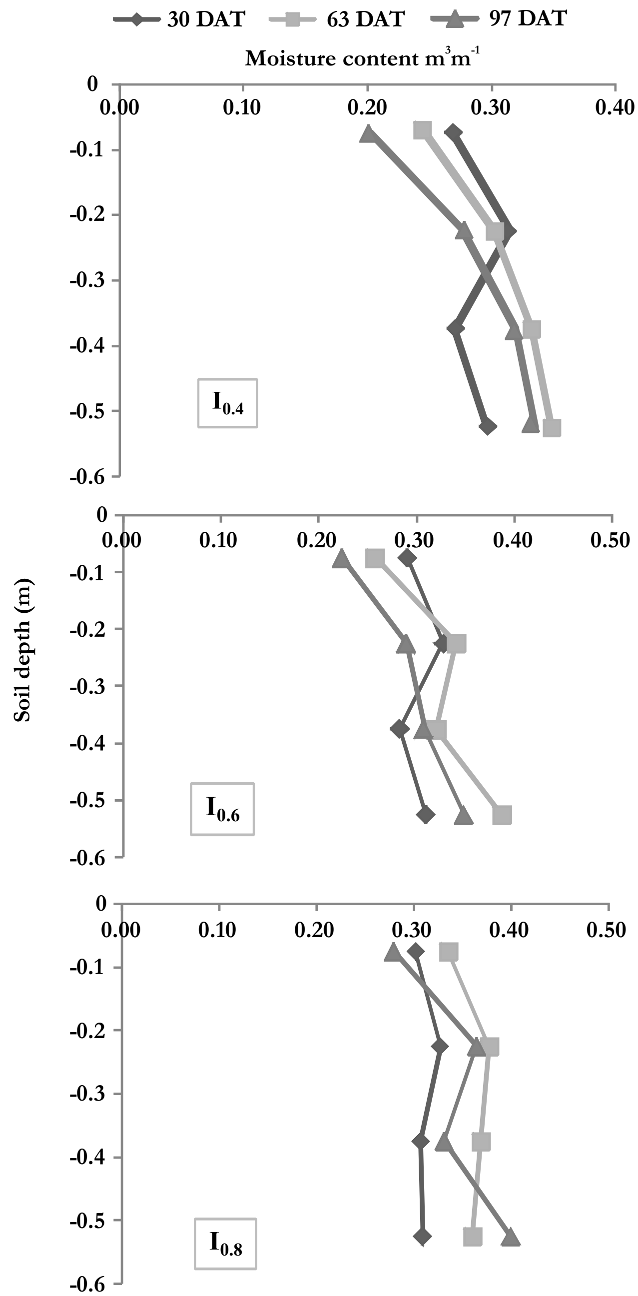

Fig.1. Depth wise soil water content on selected days of crop growth (2012-13)

The soil water content (θ) determined at 63 DAT was 0.25, 0.30, 0.33 and 0.35 m^3 m^{-3}in $I_{0.4}$; 0.26, 0.34, 0.32 and 0.39m^3 m^{-3} in $I_{0.6}$; 0.34, 0.38, 0.37 and 0.36 m^3 m^{-3} in $I_{0.8}$;0.32, 0.35,0.33 and 0.36m^3 m^{-3} in I_{Rec} at 0-0.15, 0.15-0.30, 0.30-0.45 and 0.45-0.60 m soil depths. This showed that there was less moisture content in surface layers of 0-0.15 and 0.15-0.30 m depth in $I_{0.4}$ and $I_{0.6}$ as compared to the surface layers of $1_{0.8}$ and I_{Rec}. There was an increase in soil water content with increase in depth of soil with highest subsurface-moisture content in $I_{0.8}$. The soil water content (θ) determined at 97 DAT also showed the similar trend. The soil moisture content (θ) determined during the growth stages of broccoli showed higher values for $I_{0.8}$ in comparison to $I_{0.4}$ and $I_{0.6}$. This might be due to the application of more quantity of water in $I_{0.8}$ than other treatments. Similar results were also reported by Ponnuswamy and Santhi (1998) and Ueta *et al.* (2009).

Soil Water Content and Aeration Porosity Distribution Studies Around Dripper

The soil water content and aeration porosity distribution values have been given in Table 1. The soil water content (θ) determined at 86 DAT indicated that soil moisture content at dripper point was at par in comparison to other four observation points A, B, C and D 22.5 cm away from the dripper in all drip irrigation levels. Since the drippers as well as laterals were separated by an equal spacing of 45 cm, there was an overlap of moisture distribution circles formed around the dripper at points A, B, C and D which made the moisture content at the dripper at par with the moisture content around the dripper at these points. For example in $I_{0.6}$ at 0.15-0.30 m depth moisture content at dripper was 0.32 $m^3m^{-3}$and at four points around the dripper were 0.32, 0.30, 0.30 and 0.29 m^3m^{-3} around the dripper. Among drip treatments, 'θ' was determined at 86 DAT indicated that soil moisture content was higher in $I_{0.8}$ (at dripper and other four observation points) in comparison to other drip irrigation levels due to the application of more quantity of water. The soil moisture content varied from 0.22 to 0.41 $m^3 m^{-3}$ at 86 DAT among all the soil depths and drip treatments.

The aeration porosity determined at 86 DAT, indicated that aeration porosity at the dripper point was at par to other four observation points A, B, C and D 22.5 cm away from the dripper in all drip irrigation levels. This was primarily due to the uniform moisture content at dripper point in and the other four observation points. For example, the aeration porosity at dipper (27.64%) and at other four observation points A, B, C and D were 25.40, 28.76, 29.88 and 27.64%, respectively. Among drip irrigation treatments, aeration porosity determined at 86 DAT indicated that aeration porosity was higher in $I_{0.4}$ (at dripper and other four observation points) in comparison to other drip irrigation levels due to the application of less quantity of water. The aeration porosity varied from 10.04-34.36% at 86 DAT among all the soil depths and drip treatments.

Relative Leaf Water Content (RLWC)

The RLWC determined at 50 and 100 DAT, during broccoli growth period at 0700 h and 1400 h are shown in Table 2. A significant increase in RLWC was recorded with increasing quantity of irrigation. The RLWC at 50 DAT was significantly higher under $I_{0.8}$ (90.68 and 84.95%) and $I_{0.6}$ (88.48 and 85.58%) compared to $I_{0.4}$ (83.58 and 77.77%) at 0700 h and 1400 h, respectively. Similar pattern was recorded at 100 DAT where RLWC was higher under $I_{0.8}$ (89.32 and 82.01%) and $I_{0.6}$ (88.93 and 82.47%) compared to $I_{0.4}$ (86.11 and 78.53%) at 0700 h and 1400 h, respectively (Table 2). The RLWC decreased with decrease in irrigation amount from $I_{0.8}$ to $I_{0.4}$ leading to proportional decrease in quantity of available water in soil.

The RLWC values at 50 DAT under methods of fertilizer application were, 89.57% in F_{100} followed by 87.07% in $F_{C25+F75}$ both of them however, were statistically at par with each other. The RLWC value in F_{100} was significantly higher over F_{CF} (86.10%) primarily due to better root growth

Table: 1
Effect of drip based irrigation scheduling on variation in soil water content (m^3 m^{-3}) and aeration porosity (%) around the dripper at 86 days after transplanting during 2012-13

Drip based irrigation	Soil depth (m)	Soil moisture content					Aeration porosity				
		O	A	B	C	D	O	A	B	C	D
$I_{0.4}$	0-0.15	0.29	0.31	0.28	0.27	0.29	27.64	25.40	28.76	29.88	27.64
	0.15-0.30	0.34	0.38	0.32	0.38	0.38	18.07	14.29	20.59	14.29	14.29
	0.30-0.45	0.31	0.34	0.34	0.37	0.36	23.85	20.16	20.16	17.70	18.93
	0.45-0.60	0.36	0.37	0.36	0.40	0.39	15.20	13.91	15.20	11.33	12.62
$I_{0.6}$	0.0-0.15	0.29	0.25	0.24	0.27	0.22	27.64	32.12	33.24	29.88	34.36
	0.15-0.30	0.32	0.32	0.30	0.30	0.29	20.59	20.59	21.85	21.85	23.11
	0.30-0.45	0.33	0.33	0.27	0.32	0.27	21.39	21.60	27.54	22.62	27.54
	0.45-0.60	0.39	0.34	0.35	0.35	0.36	12.62	17.78	16.49	16.49	15.20
$I_{0.8}$	0.0-0.15	0.31	0.28	0.29	0.27	0.27	25.40	28.76	27.64	29.88	29.88
	0.15-0.30	0.33	0.35	0.33	0.35	0.33	19.33	16.81	19.33	16.81	19.33
	0.30-0.45	0.37	0.33	0.34	0.37	0.36	17.70	21.39	20.16	17.70	18.93
	0.45-0.60	0.39	0.41	0.37	0.40	0.37	12.62	10.04	13.91	11.33	13.91

O = At dripper, A, B, C, D = Observation points at 22.5 cm away from dripper in four directions (A = ↓, B = →, C = ↑, D = ←)

Table: 2
Effect of drip based irrigation and method of fertilizer application on relative leaf water content during crop growth

Treatment	Relative leaf water content (%)			
	50 DAT		100 DAT	
	0700 h	1400 h	0700 h	1400 h
Drip irrigation levels				
$I_{0.4}$	83.58	77.77	86.11	78.53
$I_{0.6}$	88.48	85.58	88.93	82.47
$I_{0.8}$	90.68	84.95	89.32	82.01
CD (P=0.05)	2.462	4.422	2.210	2.666
Different methods of fertilizer application				
F_{100}	89.57	84.14	87.92	80.32
$F_{C25+F75}$	87.07	80.97	90.37	83.35
F_{CF}	86.10	83.19	86.07	79.35
CD (P=0.05)	2.462	NS	2.210	2.666
Control vs. Others				
Control	78.64	87.33	84.34	74.57
Others	87.58	82.77	88.12	81.00
CD (P=0.05)	3.178	NS	2.854	3.441

(Table 2). The RLWC values at 100 DAT were higher in $F_{C25+F75}$ (90.37 and 83.35%) followed by F_{100} (87.92 and 80.32%) and F_{CF} (86.07 and 79.35%), during 0700h and 1400 h, respectively. The RLWC under 'others' treatment (88.12 and 81.00%) was significantly higher over 'control' (84.34 and 74.57%) during 0700 h and 1400 h at 100 DAT (Table 2). The higher RLWC in 'others' treatments may be due to frequent application of irrigation water at 2-3 days interval, maintaining higher root zone moisture in comparison to 'control' where irrigation was applied at 8-10 days interval.

Quality Parameters in Broccoli

The effect of drip irrigation and different methods of fertilizer application on total soluble solids, ascorbic acid, chlorophyll a, chlorophyll b, and total chlorophyll in the curd of broccoli have been given in Table 3.

The highest value of TSS, ascorbic acid and chlorophyll a, b and total chlorophyll was recorded in $I_{0.8}$ and lowest in $I_{0.4}$. This showed that the quality parameters in broccoli increased with increase in the amount of water applied resulting in better root and shoot growth (Table 6) due to increased nutrient availability. Similar results were reported by (Shirgure *et al.,* 2004). Under different methods of fertilizer application, values for TSS, ascorbic acid and chlorophyll a, b and total chlorophyll were found to be superior in $F_{C25+F75}$ and F_{100} in comparison to F_{CF} (Table 3). The values for 'others' treatments was also found to be significantly higher than 'control'. The 100% fertilizer application through drip in equal splits improved the quality parameters of broccoli due to 25% RDF as a basal dose followed by fertigation in 7 splits than conventional method of fertilizer application. Similar results were reported by Patel *et al.* (2011).

Table: 3
Effect of drip irrigation and method of fertilizer application on TSS, ascorbic acid, chlorophyll a, chlorophyll b and total chlorophyll content in broccoli

Treatments	TSS	Ascorbic acid mg $100g^{-1}$	Chlorophyll a mg l^{-1}	Chlorophyll b mg l^{-1}	Total chlorophyll mg l^{-1}
Irrigation levels					
$I_{0.4}$	7.88	61.85	0.89	0.73	1.58
$I_{0.6}$	8.24	69.87	1.09	0.87	1.68
$I_{0.8}$	8.97	74.34	1.27	0.97	1.98
CD (P=0.05)	0.627	4.029	0.131	0.081	0.250
Method of fertilizer application					
F_{100}	8.49	70.22	1.13	0.81	1.83
$F_{C25+F75}$	8.70	72.53	1.34	0.97	1.99
F_{CF}	7.90	63.32	0.78	0.78	1.42
CD (P=0.05)	0.627	4.029	0.131	0.081	0.250
Control vs. Others					
Control	7.33	54.67	0.63	0.41	0.89
Others	8.36	68.69	1.08	0.86	1.74
CD (P=0.05)	0.809	5.201	0.170	0.105	0.322

Marketable Yield and Water Use Efficiency

The effect of drip irrigation and different methods of fertigation on biological yield of broccoli is given in Table 4. The highest curd yield was recorded with $I_{0.8}F_{C25+F75}$ (6.59 Mg ha^{-1}) and lowest under $I_{0.4}F_{CF}$ (5.46 Mg ha^{-1}). The highest curd yield was due to more quantity of irrigation applied with a fertilizer method in which 25% was applied as basal dose and 75% through fertigation, resulting in better root and shoot growth due to increased nutrient availability Table 6. Also, the treatment combinations $I_{0.4}F_{100}$ and $I_{0.6}F_{100}$ were statistically at par with each other resulting in saving of 20% irrigation water (Table 7). Similar findings were also reported by Sathya, *et al.* (2008).

By producing broccoli curd yield of 6.35 Mg ha^{-1}, $I_{0.4}F_{C25+F75}$ was found to be the best treatment as it produced yield at par with the $I_{0.6}F_{C25+F75}$ and $I_{0.8}F_{C25+F75}$ and superior to all other treatment combinations, thereby saving water as well as fertilizer (Table 4).

The highest Water Use Efficiency (WUE) was recorded under $I_{0.4}F_{C25+F75}$ (21.21 kg ha^{-1} mm^{-1}) and $I_{0.6}F_{C25+F75}$

Table: 4
Effect of drip irrigation and fertigation on curd yield (Mg ha^{-1})

Drip Irrigation Levels	Fertigation Levels				
	F_{100}	$F_{C25+F75}$		F_{CF}	Mean
$I_{0.4}$	5.87	6.35		5.46	5.89
$I_{0.6}$	6.06	6.44		5.66	6.05
$I_{0.8}$	6.46	6.59		5.75	6.25
Mean	6.13	6.46		5.62	
CD I (P=0.05)			0.178		
CD F (P=0.05)			0.178		
CD I*F (P=0.05)			0.309		

(20.38 kg $ha^{-1}mm^{-1}$) followed by $I_{0.8}F_{C25+F75}$ (19.82 kg $ha^{-1}mm^{-1}$) in comparison to rest of the treatment combinations and lowest was recorded under control (9.57 kg $ha^{-1}mm^{-1}$) as shown in Table 7. The highest WUE in $I_{0.4}F_{C25+F75}$ was primarily due to higher curd yield produced with lesser quantity of water applied. The lowest WUE in control was primarily due to higher amount of water used which, however, produced lesser yield in comparison to other drip treatments. This shows that water application beyond 0.8 CPE was not utilized by the crop. Similar results were reported by Rathore *et al.* (2009). Similarly, Tanaskovik *et al.* (2011) reported that drip fertigation showed almost 87% more WUE in comparison with the treatment with furrow irrigation and conventional application of fertilizer. The total consumptive water use through drip and surface system was 299.30 and 585.80 mm, resulting in 49% water saving over control.

Table: 5
Effect of drip irrigation and method of fertilizer application on fertilizer expense efficiency (kg kg^{-1})

Treatments	Fertilizer expense efficiency (Oven dried yield kg per kg of total nutrient applied)
Irrigation levels	
$I_{0.4}$	3.44
$I_{0.6}$	3.40
$I_{0.8}$	3.30
CD (P=0.05)	0.102
Method of fertilizer application	
F_{100}	3.39
$F_{C25+F75}$	3.63
F_{CF}	3.12
CD (P=0.05)	0.102
Control vs. Others	
Control	3.47
Others	3.38
CD (P=0.05)	NS

Fertilizer Expense Efficiency

The data shows that fertilizer expense efficiency was significantly higher in $I_{0.4}$ (3.44 kg kg^{-1}) in comparison to $I_{0.6}$ (3.40 kg kg^{-1}) and $I_{0.8}$ (3.44 kg kg^{-1}) as given in Table 5. Among different methods of fertilizer application, highest fertilizer expense efficiency was recorded under $F_{C25+F75}$ (3.63 kg kg^{-1}) and lowest under F_{CF} (3.12 kg kg^{-1}). As the quantity of nutrient applied is same in all the treatments, the difference is attributed to the difference in oven dry yield. The fertilizer expense efficiency under 'control' vs. 'others' was found to be at par with each other.

Fertilizer Use Efficiency with Respect to N, P and K

The data presented in Table 8 indicates the significant effect of drip irrigation and fertigation levels on fertilizer use efficiency with respect to N, P and K. The highest N use efficiency was recorded with $I_{0.8}$ (71.70%) and lowest with $I_{0.4}$ (69.64%) among irrigation levels. Similarly, the highest P and K use efficiency was recorded with $I_{0.8}$ (26.46 and 75.31%) and lowest in $I_{0.4}$ (23.24 and 64.82%) among the irrigation levels. The reason for higher fertilizer use efficiency with respect to N, P and K in $I_{0.8}$ may be attributed to higher uptake of nutrients (Table 9) which, in turn, improved the yield and other growth parameters of the plants. Under different methods of fertilizer application, the highest N use efficiency found to be in $F_{C25+F75}$ (74.12%) followed by F_{100} (70.60%). Similarly, the highest P and K efficiency was found to be in $F_{C25+F75}$ (28.32 and 82.25%) followed by F_{100} (25.22 and 72.15%) which was again due to higher uptake of nutrients in $F_{C25+F75}$ in comparison to F_{100} (Table 9). There was significantly higher N, P and K use efficiency in 'others' (70.62, 25.05 and 69.44%) as compared to 'control' (65.86, 19.99 and 54.91%). This showed that treatments other than control (where conventional method of fertilizer was applied along with the flood irrigation method) resulted in better uptake of nutrients

Table: 6
Effect of drip irrigation and method of fertilizer application on root growth (0-0.30 m) and shoot growth of broccoli

Treatment	Root length (m)		Total root volume (x 10^{-6} m^3)	Root weight (× 10^{-3} kg) (Primary)	Root diameter (× 10^{-2} m) (Primary)	Plant height (cm)	Leaf area index
	Primary	Secondary					
Drip irrigation levels							
$I_{0.4}$	0.09	1.21	36.11	15.08	1.90	36.28	0.84
$I_{0.6}$	0.09	2.33	51.11	17.49	2.32	41.39	1.02
$I_{0.8}$	0.08	2.69	50.56	16.10	2.37	44.60	0.95
CD (P=0.05)	NS	0.262	6.915	1.642	0.336	1.548	0.140
Method of fertilizer application							
F_{100}	0.09	1.91	43.33	16.22	2.21	43.17	0.92
$F_{C25+F75}$	0.09	2.23	53.33	16.99	2.36	40.70	1.01
F_{CF}	0.08	2.09	41.11	15.47	2.02	38.40	0.88
CD (P=0.05)	NS	0.262	6.915	NS	0.336	1.548	NS
Control vs. Others							
Control	0.10	1.62	25.00	12.81	1.50	37.00	0.65
Others	0.09	2.08	45.93	16.22	2.20	40.76	0.95
CD (P=0.05)	NS	0.338	8.928	2.120	0.434	1.998	0.180

(Table 9) which lead to improved root and shoot growth parameters (Table 6) and higher yield (Table 4). Similar results were also reported by Nilesh and Gulati (2004).

Economics

The gross return was highest under $I_{0.8}F_{C25+F75}$ (₹ 1,97,600) followed by $I_{0.8}F_{100}$ (₹ 1,93,790) and lowest under I_{rec} (₹ 1,68,110) Table 7. The higher gross return in $I_{0.8}F_{C25+F75}$ and $I_{0.8}F_{100}$ may be due to higher marketable yield. The B:C ratio was highest in control *i.e.* I_{Rec} (4.17) in comparison to drip-fertigation treatments and lowest under $I_{0.4}F_{100}$ (1.35). The higher B:C ratio in $I_{Rec}F_{100}$ was due to less cost of cultivation primarily due to less cost of conventional fertilizers in comparison to drip irrigation treatments where cost of soluble fertilizers was much higher (₹ 150 kg^{-1}). Also, the interest and depreciation values of drip system were included

Table: 8
Effect of drip irrigation and method of fertilizer application on fertilizer use efficiency (%) w.r.t N, P and K

Treatments	N use efficiency (NUE)	P use efficiency (PUE)	K use efficiency (KUE)
Irrigation levels			
$I_{0.4}$	69.64	23.24	64.82
$I_{0.6}$	70.52	25.46	68.20
$I_{0.8}$	71.70	26.46	75.31
CD (P=0.05)	0.855	1.117	9.243
Method of fertilizer application			
F_{100}	70.60	25.22	72.15
$F_{C25+F75}$	74.12	28.32	82.25
F_{CF}	67.15	21.62	53.93
CD (P=0.05)	0.855	1.117	9.243
Control vs. Others			
Control	65.86	19.99	54.91
Others	70.62	25.05	69.44
CD (P=0.05)	1.104	1.442	11.933

Table: 7
Effect of drip irrigation and method of fertilizer application on water use efficiency, returns and B:C ratio

Treatment	Curd yield (Mg ha^{-1})	Consumptive water use (mm)	Water use efficiency (kg ha^{-1} mm^{-1})	Gross return (₹)	Cost of cultivation (₹ ha^{-1})			Net Return (₹)	B:C ratio
					Seedlings+spray materials+labour cost +interest & depreciation on drip system	Fertilizer cost	Total cost		
$I_{0.4}F_{100}$	5.87	299.30	19.60	176000	28500	46,245	74745	101255	1.35
$I_{0.4}F_{C25+F75}$	6.35	299.30	21.21	190400	28500	36230	64730	125670	1.94
$I_{0.4}F_{CF}$	5.46	299.30	18.24	163800	28500	6233	34733	129067	3.72
$I_{0.6}F_{100}$	6.06	316.00	19.19	181900	28500	46,245	74745	107155	1.43
$I_{0.6}F_{C25+F75}$	6.44	316.00	20.38	193200	28500	36230	64730	128470	1.98
$I_{0.6}F_{CF}$	5.66	316.00	17.90	169720	28500	6233	34733	134987	3.89
$I_{0.8}F_{100}$	6.46	332.40	19.43	193790	28500	46,245	74745	119045	1.59
$I_{0.8}F_{C25+F75}$	6.59	332.40	19.82	197600	28500	36230	64730	132870	2.05
$I_{0.8}F_{CF}$	5.75	332.40	17.30	172480	28500	6233	34733	137747	3.97
I_{Rec}	5.60	585.80	9.57	168110	26300	6233	32533	135577	4.17
CD (P=0.05)	0.302		0.904						

Cost of broccoli seed: @50/- ₹/100 seedlings ; Cost of labour : ₹ 3750/- (for 25 man days) for drip irrigation and ₹ 6300/- (for 42 man days @ ₹ 150/man day) for control; Cost on spray : ₹ 1500/-; Cost of fertilizers : Urea - @ 241.50/50 kg , SSP - @ 340/50 kg , MOP - @ 222.75/50 kg , 19:19:19 - @ 150/kg, 12:61:0-@ 150/kg; Interest on drip irrigation system @ 8% per annum - ₹ 2000/-, Depreciation cost on drip system - ₹ 1250/-

Table: 9
Effect of drip irrigation and method of fertilizer application on nutrient uptake of broccoli (kg ha^{-1})

Treatments	Nitrogen uptake			Phosphorous uptake			Potassium uptake		
	Curd	Haulm	Total	Curd	Haulm	Total	Curd	Haulm	Total
Drip irrigation levels									
$I_{0.4}$	37.91	137.39	175.29	10.69	19.82	30.50	29.51	29.54	59.05
$I_{0.6}$	38.51	138.10	176.61	12.14	20.58	32.72	31.85	29.05	60.91
$I_{0.8}$	39.72	138.65	178.37	12.30	21.43	33.72	31.25	33.57	64.82
CD (P=0.05)	1.065	1.058	1.283	0.447	1.009	1.117	1.243	NS	5.084
Method of fertilizer application									
F_{100}	38.62	138.10	176.73	12.10	20.39	32.48	31.10	31.98	63.08
$F_{C25+F75}$	41.44	140.56	182.00	13.00	22.58	35.58	34.72	33.92	68.74
F_{CF}	36.08	135.46	171.54	10.03	18.85	28.88	26.80	26.26	53.06
CD (P=0.05)	1.065	1.058	1.283	0.447	1.009	1.117	1.243	5.305	5.084
Control vs. Others									
Control	35.04	134.57	169.61	9.99	17.26	27.25	26.88	26.72	53.60
Others	38.71	138.04	176.76	11.71	20.61	32.32	30.87	30.72	61.59
CD (P=0.05)	1.375	1.366	1.657	0.578	1.303	1.442	1.604	NS	6.563

which resulted in higher cost of cultivation. The data also revealed that the labour requirement was higher under 'control' in comparison to drip irrigated treatments. Similar results were also reported by Woltering *et al.* (2011).

4. CONCLUSIONS

Increasing the drip irrigation quantity from 0.4 to 0.8 CPE and application of fertilizer 25% as basal and 75% through fertigation significantly increased the curd yield and NPK uptake. Curd yield obtained in $I_{0.4}F_{100}$ and $I_{0.6}F_{100}$ was statistically at par, which resulted in saving of 20% irrigation water. By producing broccoli curd yield of 6.35 Mg ha^{-1}, $I_{0.4}F_{C25+F75}$ was found to be the best treatment as it produced yield at par with the $I_{0.6}F_{C25+F75}$ and $I_{0.8}F_{C25+F75}$ and superior to all other treatment combinations, thereby saving water as well as fertilizer. Gravity fed drip based irrigation along with fertigation through water soluble fertilizers had comparatively lower net return and B:C ratio in comparison to flood irrigation and conventional fertilizer application. The quality parameters of broccoli increased with increase in IW/CPE from 0.4 to 0.8 and the fertilizer treatment in which 25% was applied through conventional method and 75% through drip showed superiority over other methods of fertilizer application. N, P and K use efficiency increased with increasing drip irrigation quantity from 0.4 to 0.8 and in different methods of fertilizer application, N, P and K use efficiency was highest in $F_{C25+F75}$ in comparison to other treatments. Drip based irrigation scheduling resulted in higher soil water content, water use efficiency and saving in irrigation water in comparison to conventional method of irrigation.

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