



Soil water dynamics and yield response of broccoli (*Brassica oleracea*) under drip irrigation with different irrigation frequency

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ABSTRACT

Semi-arid region can benefit greatly from surface and subsurface drip irrigation techniques in overcoming the problem of water scarcity. Therefore, a field study was carried out at the research farm of CCS Haryana Agricultural University, Hisar, Haryana during winter (*rabi*) season 2019–20 and 2020–21 to investigate the effectiveness of surface and subsurface drip irrigation on growth and yield of broccoli (*Brassica oleracea* L.). Subsurface drip irrigation shows higher moisture content than surface drip irrigation at vertical as well as radial distance. The growth parameters were found highest in the treatment irrigation after one day under subsurface drip irrigation. The average highest (14610 kg/ha in 2019–20 and 14740 kg/ha in 2020–21) and lowest (12920 kg/ha in 2019–20 and 13030 kg/ha in 2020–21) total yield was recorded under irrigation after one day in subsurface drip irrigation and irrigation after three days in surface drip irrigation treatments, respectively. It is concluded that alternate days irrigation with subsurface drip irrigation gives better performance to obtain the maximum yield of broccoli grown in the semi-arid region of India.

Keywords: Irrigation water use efficiency, Irrigation scheduling, Soil water dynamics, Yield response

Due to ever increasing population, India's per capita water availability decreased from 3450 m³ in 1951 to 1250 m³ in 1999, which is further expected to decline to 662 m³ per person in 2050, (Gangwar 2013) and demanding around 450 million tonnes of food grain per year (Patel and Rajput 2008). Groundwater exploitation in India is 25% of the total groundwater extracted all over the world. Therefore, in the near future, water availability for irrigation will be a big constraint in agriculture production (Dhaloiya *et al.* 2022). Surface irrigation such as furrow, check basin and border are the most frequently used methods of irrigation in India. The low efficiency of surface irrigation can partly be responsible for conveyance loss due to the seepage, water absorption, evaporation and non-beneficial use due to insufficient preparation of land and poor application of water. The drip irrigation system plays a crucial role in this scenario, saving this scarce natural resource. In terms of water economy, yield and irrigation efficiency, drip irrigation system has ability to use limited but frequent water near the root zone of the plant through a network of tubing (Arvind *et al.* 2018).

The drip irrigation system typically improves crop

yield by 25–30% and saves irrigation water up to 50% relative to traditional irrigation methods (Priya *et al.* 2017, Singh *et al.* 2022). Drip systems not only save irrigation water, but also provide the best management of nutrients applied to the crop (Singh *et al.* 2018). Earlier studies have shown that drip irrigation is the most appropriate method of irrigation, particularly in vegetable crops, which increases the production and enhances the water use efficiency (Thompson *et al.* 2002). Many studies for different crops and locations have been reported that water use efficiency, fertilizer use efficiency and total yield of crop could be increased under drip irrigation systems (Kumari *et al.* 2018, Kapoor and Sandal 2021). Broccoli (*Brassica oleracea* L.) rich in minerals, especially in iron and calcium is also a good source of vitamins, thus, called as the *Crown of Jewel Nutrition* (Jeelani *et al.* 2017). It can prevent Alzheimer's disease, diabetes, calcium deficiency, cancer, heart disease and arthritis. In India, there is a lack of information on irrigation scheduling techniques and economic viability of the system. Therefore, an experiment were conducted to investigate the effect of variable irrigation regimes of drip irrigation on marketable yield, irrigation production efficiency and economic return of broccoli.

MATERIALS AND METHODS

An experiment was conducted at the research farm of CCS Haryana Agricultural University, Hisar, (29°9'0.97"N,

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longitude 75°42'20.12"E and 215.2 m amsl), Haryana during winter (*rabi*) season 2019–20 and 2020–21. In this experiment, the Fantasy variety of broccoli was grown in micro-plots (2 m × 2 m) filled with loamy sand. The treatments comprised of 4 irrigation frequencies (daily, after one, two and three days) under the surface and subsurface drip irrigation system with 45 cm lateral spacing. Different treatment combinations under surface drip represented as daily irrigation (I₁S), Irrigation after one day (I₂S), Irrigation after two days (I₃S), Irrigation after three days (I₄S). Under subsurface drip daily irrigation represented as (I₁SS), Irrigation after one day (I₂SS), Irrigation after two days (I₃SS), Irrigation after three days (I₄SS). The plants were transplanted with row to row and plant to plant spacing of 45 and 40 cm, respectively, with a total of 20 plants in each micro-plot. Drip lines of 16 mm diameter with 40 cm dripper spacing and 2 litre/h discharge rate were placed on soil surface in surface drip and at 10 cm below the soil surface in subsurface drip before planting under different irrigation levels.

Estimation of irrigation water requirements: Irrigation was applied based on crop evapotranspiration (ET_c, mm). ET_c was estimated as:

$$ET_c = K_c \times K_p \times CPE$$

Where, K_c, crop coefficient values (Allen *et al.* 1998); CPE, cumulative pan evaporation (mm) and K_p, pan coefficient of US Class A pan (0.7). For broccoli crops, Allen *et al.* (1998) showed crop coefficients ranged from 0.7 (initial growth stage) to 1.05 (mid-season growth stage) and then to 0.95 (late-season growth stage).

For different irrigation treatments, depth of irrigation was calculated by CPE from the day of previous irrigation. The volume of water applied (V) was calculated as (Kaulage 2017):

$$V = \frac{ET_c \times \text{Area of plot (m}^2\text{)} \times W_a}{EU}$$

where, (L), W_a, wetted area factor (0.8 up to 30 DAT and 1.0 after 30 DAT); EU, emission uniformity of the system (0.90). The duration of irrigation was determined as:

$$\text{Irrigation time (h)} = \frac{V}{q \times \text{No. of drippers per slot}}$$

where, q, dripper discharge in L/h.

Soil water dynamics: The soil samples were collected randomly from the field with the help of tube auger at 0–15, 15–30, 30–45 and 45–60 cm depth from the soil surface in vertical direction. The samples were collected at three radial distances from the dripper which was 0, 11.25 and 22.5 cm distance away from the dripper in the 45 cm lateral spacing, respectively. Soil moisture was determined by using the gravimetric method in which, the samples were dried in oven for 24 h at 105°C (Michael 2008). To study the radial and downward movement of water in the root zone, the soil samples were taken just before the next irrigation.

Analysis of spatial and temporal movement of moisture was done by plotting contour maps (Surfer software) according to moisture content data taken at 30, 60 and 90 days after transplanting.

Growth and yield parameters: Plant height and leaf length of broccoli were measured manually and expressed in centimeter (cm). Number of leaves per plant were counted on the basis of true leaves present. Weight of curd was expressed in gram (g), and total yield of main head plus auxiliary sprouts from all plots were taken in kilogram and then converted to yield in kg/ha. Irrigation water use efficiency (IWUE) was calculated as total broccoli yield divided by irrigation water applied (Howell *et al.* 1990). Fertilizer use efficiency (FUE) was calculated as total broccoli yield divided by the total fertilizer applied (Hebbbar *et al.* 2004).

Statistical analysis: Results for different observation were statistically analyzed using two factor split plot design by using the OPSTAT software (Sheoran 2010) at 5% level of significance.

RESULTS AND DISCUSSION

Soil water dynamics: Same amount of water was applied in each plot of all treatments. The average drip discharge was 2.25 litre/h and 2.20 litre/h during 2019–20 and 2020–21, respectively and accordingly amount and time of irrigation was calculated. Total depth of water applied in each plot and rainfall received during the experiment was 14.72 cm (588.8 litre) and 2.72 cm in 2019–20, and 16.54 cm (661.6 litre) and 3.75 cm in 2020–21, respectively.

In daily irrigation, less water was applied per irrigation which maintained more moisture content in the top layer with minimum percolation losses, whereas in irrigation after three days, more amount of water was applied per irrigation and less moisture content was observed in the top layer before the next irrigation in comparison to lower layer due to more percolation losses from top to lower layers. It reflects that moisture content was higher in the upper layer of the root zone from which a plant extracts maximum water under higher irrigation frequency treatment, whereas, moisture content decreased relatively with the increase in irrigation interval, i.e. after one, two and three days irrigation interval. But in lower layers, moisture content was lowest in daily irrigation treatment and it increased relatively with the increase in irrigation interval, i.e. after one, two and three days. When the field is irrigated less frequently, water can permeate deeper levels, whereas more frequent irrigations keep water in the upper layers (Chaharmahali *et al.* 2022). On the basis of maximum yield of broccoli, Kumari *et al.* (2018) also predicted the optimum moisture content under once in two days irrigation frequency with 80% of ET_c. The soil water content is one of the most important factors which has direct impact on fruit yield (Ismail *et al.* 2007).

With crop growth, decrease in moisture content was observed for corresponding same radial distance and depth due to uptake of water by plants, thus, due to increase in irrigation interval from daily to after one, two and three days,

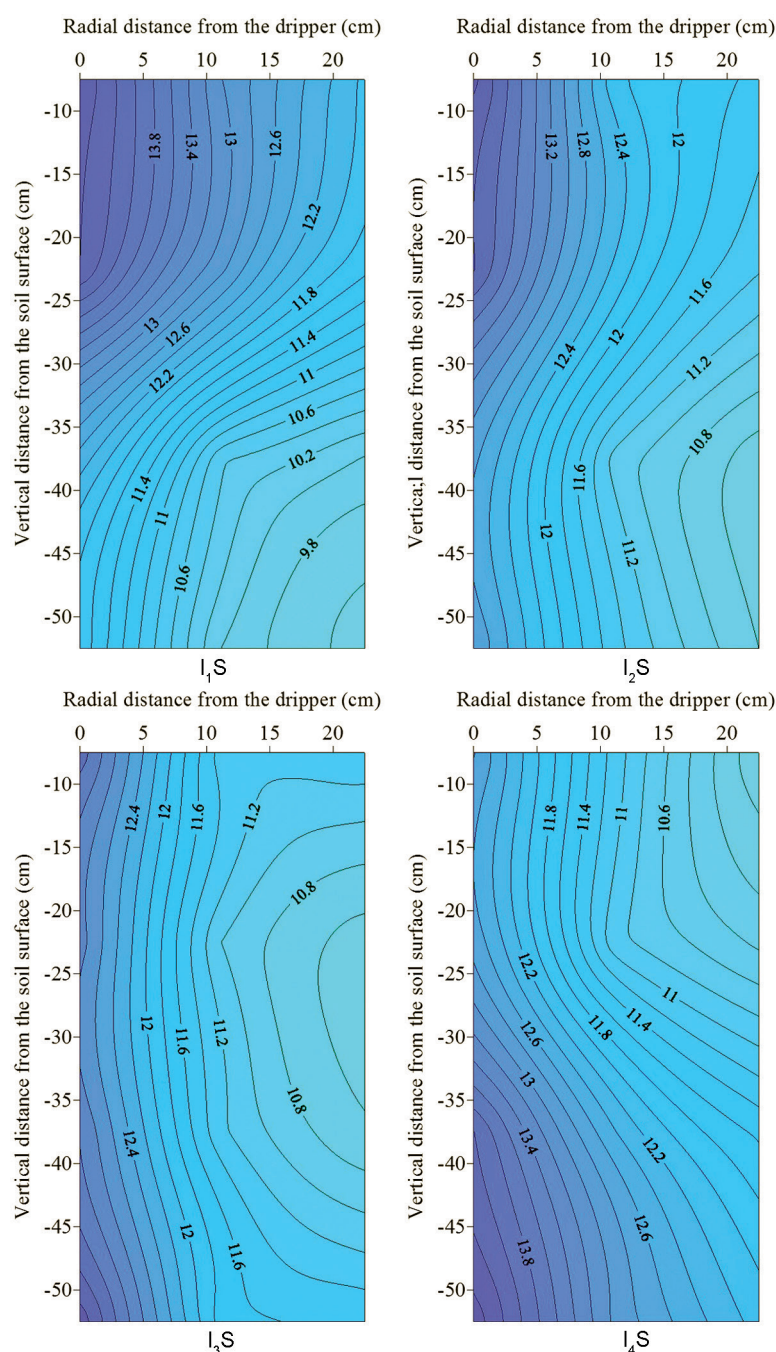


Fig 1 Spatial and temporal movement of moisture content in soil with different irrigation frequency (I_1 , I_2 , I_3 and I_4) under surface drip.

the water availability to the plants was decreased accordingly even quantity of water applied in all treatments was equal.

The wetting pattern of 60 DAT under various irrigation frequencies in surface and subsurface drip irrigation treatments is depicted in Fig 1 and Fig 2. These figures are also indicating that the moisture variation in the root zone is also a function of irrigation frequency. Wan *et al.* (2022) observed that the distribution efficiency of irrigation water is more in less lateral spacing than higher lateral spacing. In surface and subsurface drip irrigation with different irrigation frequency, observed average moisture content at radial distance of 0 cm from dripper (i.e. below the dripper or

near plant) was higher as compared to 11.25 cm, and at 11.25 cm, it was higher than at 22.5 cm.

At 60 DAT in I_1S , I_2S , I_3S and I_4S treatments (surface drip), just below the dripper at 15 cm depth, contours line of 14.4, 14.0, 12.8 and 12.6% moisture content, respectively were observed, whereas, at 45 cm depth, contours line of 11.8, 12.9, 13.2 and 14.2%, respectively were observed. It reflects that in the top layer just below the dripper, moisture content was highest in daily irrigation treatment and it decreased relatively with the increase in irrigation interval, i.e. after one, two and three days but in lower layers, moisture content was lowest in daily irrigation treatment and it increased relatively with the increase in irrigation interval, i.e. after one, two and three days. At 60 DAT in I_1SS , I_2SS , I_3SS and I_4SS treatments (subsurface drip), just below the dripper at 15 cm depth, contours line of 14.7, 14.3, 13.2 and 12.9% moisture content, respectively were observed, whereas, at 45 cm depth, contours line of 12.1, 13.1, 13.5 and 14.5%, respectively were observed.

Under I_1SS , I_2SS , I_3SS and I_4SS treatments at a radial distance of 20 cm from the dripper and 15 cm vertically downward, contours line of 12.4, 12.0, 11.2 and 10.3% moisture content, respectively were observed, whereas, at 45 cm depth, contours line of 10.0, 10.9, 11.4 and 12.2%, respectively were observed. Similar trend of soil moisture was observed under surface drip irrigation as in subsurface irrigation, but in subsurface drip, moisture content was found higher than surface irrigation. Badr *et al.* (2010) also reported that movement of water through the soil to the surface becomes limiting as the soil surface dries, which resulted in smaller soil evaporation loss there by repressing the upward movement of water.

Spatio-temporal water availability in the root zone under different treatments: Under surface as well as subsurface drip irrigation, available water in the root zone (0–60 cm) just below the dripper is almost remained same in all the irrigation frequency. But available moisture

has been decreased with the increase in distance from the dripper from daily irrigation to irrigation after three days. The soil of the experimental site was sandy loam with coarser particles with higher macro-porosity, which favours high gravitational water movement and poor water retention in the soil, so there is more vertical movement of water. Irrigation water applied daily easily replenished the water due to evapotranspiration from previous days and has very little water to move downward, but in case of irrigation after three days has more water to move downward after replenishing the water due to evapotranspiration.

While comparing available depth of water in surface

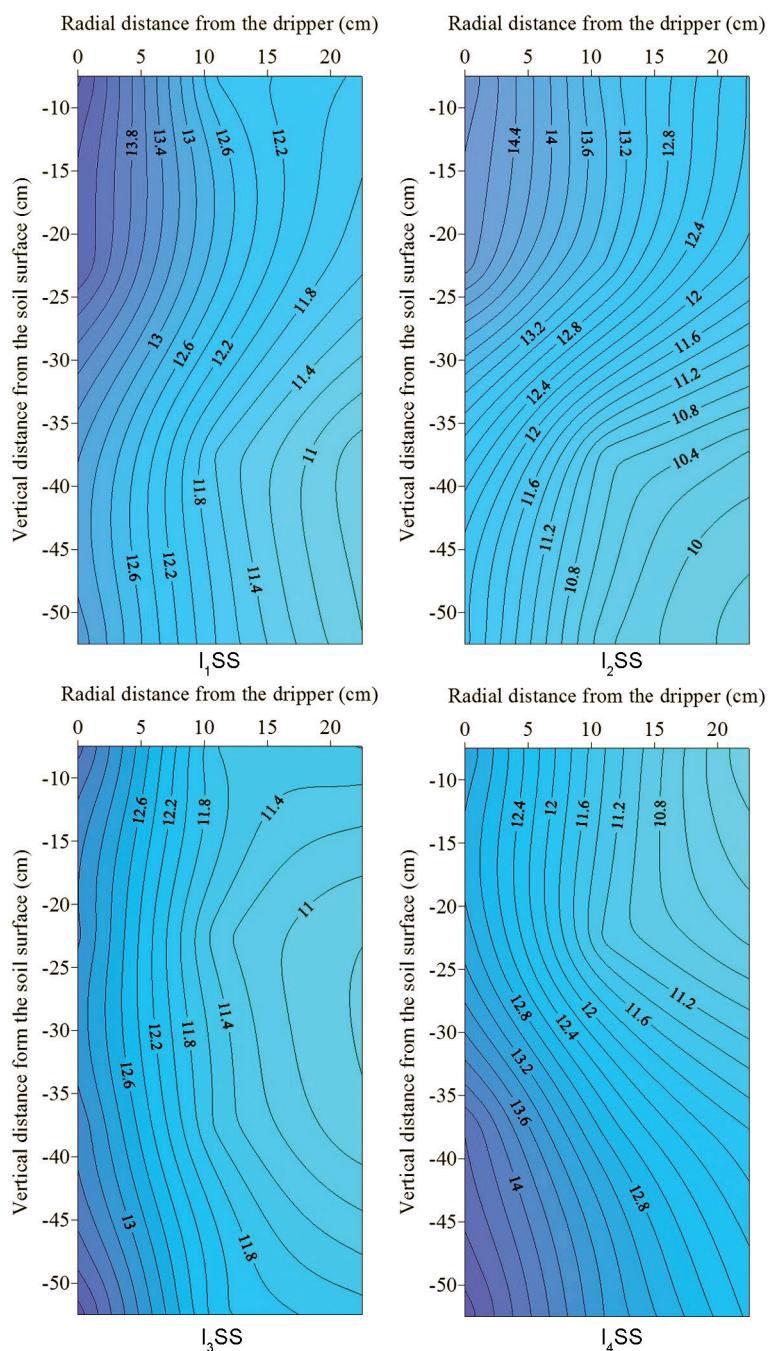


Fig 2 Spatial and temporal movement of moisture content in soil with different irrigation frequency (I_1 , I_2 , I_3 and I_4) under subsurface drip.

and subsurface drip irrigation, subsurface drip irrigation shows higher available depth of water in all treatments. At 30, 60, 90 under subsurface drip irrigation near dripper with I_2SS , available depth of water was higher by 2.28, 4.25 and 2.78% than surface drip irrigation in its respective treatment (I_2S). Similar results were also reported by Badr *et al.* (2013). Previous studies have been reported that subsurface drip system reduced evaporation from the soil and increased the wetted soil volume and surface area more than surface systems, allowing a deeper rooting pattern (Patel and Rajpat 2008, Montoya *et al.* 2022) Therefore, keeping the drip line within the crop root level below the

soil surface replenishes water and nutrients effectively, which have positive effects on yield, tuber size and water savings and thus increase the irrigation efficiency.

Growth and yield parameters: Plant height, number of leaves, fruit diameter and fruit weight were obtained from each treatment at harvest for the both seasons (2019–20 and 2020–21). Average plant height, number of leaves, fruit diameter and fruit weight resulted from subsurface drip system was significantly higher over surface drip in their respective irrigation frequency treatments. The improved performance under subsurface drip can be attributed to the root zone maintaining a favourable soil water status, which allowed the plants to use moisture and nutrients more efficiently from the limited wetted area. Under surface drip irrigation, the value of these parameters at I_2S treatment was higher than I_1S , I_3S and I_4S , respectively in both years. Similarly, results were observed for subsurface drip irrigation.

It was observed that the maximum total yield (14220 kg/ha in 2019–20 and 14370 kg/ha in 2020–21) was obtained with treatment I_2SS followed by daily irrigation. Lowest yield (12680 kg/ha in 2019–20 and 12830 kg/ha in 2020–21) was obtained at I_4S . Similarly, the higher marketable yield (13960 kg/ha in 2019–20 and 14120 kg/ha in 2020–21) was found with I_2SS treatment and lowest marketable yield was found at I_4S (Table 1). These results are in close conformity with Kumari *et al.* (2018) who found that irrigation after one day at 0.8 ET_c showed a significantly higher total yield of broccoli. The significantly higher IWUE and FUE were recorded under I_2SS and lowest was obtained in the treatment I_4S during both seasons.

The study concluded that the soil moisture in the top layer just below the dripper was highest in daily irrigation treatment and it decreased relatively with the increase in irrigation interval, i.e. after one, two and three days, but in lower layers, moisture content was lowest in daily irrigation treatment and it increased relatively with the increase in irrigation interval, i.e. after one, two and three days. Overall soil moisture decreased laterally, but increased vertically downward with the increase in the irrigation interval. The available depth of water in the subsurface drip irrigation was higher than surface drip in all respective treatments. Growth and yield parameters of broccoli were higher in all the subsurface drip irrigation as compared to their respective treatment of irrigation frequency in the both seasons. While comparing irrigation frequency treatment, irrigation after one day had higher growth and yield parameters as compared to other

Table 1 Effect of different treatments on yield, irrigation water use efficiency and fertilizer use efficiency of broccoli

Treatment	Total yield		Marketable yield		IWUE		FUE	
	(kg/ha)		(kg/ha)		(kg/m ³)		(kg/kg)	
	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21
I ₁ S	13670	13820	13410	13570	9.3	8.4	28.5	28.8
I ₂ S	14030	14180	13770	13930	9.5	8.6	29.2	29.5
I ₃ S	13570	13720	13310	13470	9.2	8.3	28.2	28.6
I ₄ S	12680	12830	12420	12580	8.6	7.8	26.4	26.7
I ₁ SS	13870	14020	13610	13770	9.4	8.5	28.9	29.2
I ₂ SS	14220	14370	13960	14120	9.7	8.7	29.6	29.9
I ₃ SS	13770	13920	13510	13670	9.4	8.4	28.7	29.0
I ₄ SS	12880	13030	12620	12780	8.8	7.9	26.8	27.1
CD (P=0.05)	0.81	0.80	0.80	0.81	NS	NS	NS	NS

Treatment details are given under Materials and Methods.

treatments. Surface drip probably aids moisture losses predominantly in the upper soil layer, whereas subsurface drip produces beneficial soil moisture levels in the active crop root zone. The irrigation water use efficiency and fertilizer use efficiency were found maximum in treatment, irrigation after one day with subsurface drip irrigation during both seasons. On the basis of soil, water dynamics, yield and quality of broccoli in sandy loam soil, it is concluded that subsurface drip irrigation to irrigation after one day is the best treatment among the surface/subsurface drip system, and four different irrigation frequencies for the broccoli crop of *rabi* (winter) season.

In future, drip irrigation with mulching and fertigation can be checked on broccoli for getting more increased production. Irrigation level will be further prospects for water saving and checked the behaviour of broccoli plant.

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