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Effect of varying irrigation frequency and lateral spacing under surface and subsurface drip irrigation

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Abstract
Agriculture is the largest consumer of fresh water resources, thus the scope of enhancing water productivity in agriculture is taken to be the priority area of research. The right amount and frequency of irrigation is essential for optimum use of limited water resources for crop production as well as management. The lower lateral spacing gave higher net return and benefit-cost ratio as compared to higher lateral spacing. The proper irrigation frequency gives better production. The surface drip irrigation gave lower production as compared to sub surface drip irrigation. The seasonal water applied and marketable flower yield, gross return, net return and benefit-cost ratio exhibited quadratic relationship which can be used for optimising economic return of broccoli under variable irrigation and lateral spacing. The findings of different study revealed that drip irrigation system is profitable for broccoli production inspite of high initial investment.

Keywords: varying irrigation frequency, lateral spacing under surface, subsurface drip irrigation

Introduction
Water is a vital resource used for food production. About 70% of the total fresh water resource is consumed by agriculture and its shortage is causing a severe impact in arid and semiarid areas of the world. The demand for water is continuously rising for various purposes viz., agriculture, domestic use, industry, power etc. and at the same time the share of available water for agriculture is decreasing day by day. Therefore, it is important that we should use water more efficiently. Various irrigation methods are being practiced for successful crop production but farmers generally go after the conventional irrigation methods like flood irrigation, basin irrigation, furrow irrigation, etc. Due to these methods of irrigation, about 27.42% of irrigation water is lost by deep percolation, which is beyond the reach of the crop root zone (Kumar *et al*., 2013). Surface irrigations such as furrow, check basin and border are the most frequently used method of irrigation in India.

The surface irrigation overall efficiency is considerably poor about 33% and 67% of the water is wasted and useless (Kumar *et al*. 2007) [17]. The low efficiency of surface irrigation can be partly responsible for by convenience loss due to seepage, water absorption, evaporation and non-beneficial use due to insufficient preparation of land and poor application of water. Drip irrigation not only saves water but also improve fertilizer use efficiency by allowing water soluble fertilizer to drip slowly on the surface of soil near to the plant roots or directly to the root zone, through a network of valves, pipes, tubing and emitters. This system maintains the moisture throughout the planting area for a longer period as compared to conventional method of irrigation. It is eco-friendly irrigation system which not only saves precious irrigation water but also increases productivity to the tune of 30-40 per cent over traditional methods of irrigation. In this system the maximum amount of water is stored in the root zone and deep percolation losses are minimized. Drip irrigation system will play 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 was found to be superior.

High frequency water management by drip irrigation provides daily water requirement for a portion of each plant's rootzone and sometimes retains high soil matrix potential in the rhizosphere to reduce the stress of plant water.

This lowers water losses by means of deep percolation, evaporation, and runoff. Irrigation contributes substantially in the agricultural production. The surface irrigation is conventional method for crop cultivation. The surface irrigation method covers major part and remaining is covered by micro irrigation in the crop cultivation (Postal *et al*., 2001).

A number of efforts have been made to in crease overall water use efficiency, but they have not made any significant impact on it. The water sources are limited and also decreasing day by day due to other uses like urbanization and industrialization (Himanshu *et al*., 2013). Therefore, it is essential to use efficient and economically feasible irrigation management practices that irrigate more land area with limited water resources. Irrigation water use efficiency in Indian agriculture can be increased by micro irrigation system which includes both drip and sprinkler irrigation system. In drip irrigation, water is delivered directly to the root zone of the crops using pipe network and emitters. The drip irrigation system typically improves crop yield by 25 to 30% and save irrigation water upto 50 to 60% relative to traditional irrigation methods (Priya *et al* 2017) [23].

Broccoli can be grown on a wide range of soil types, ranging from light sand to heavy loam or, even clay that are well supplied with organic matter. Successful production of broccoli depends on various factors. Fertilizer and moisture management are the most important factors, which assured crop production. Broccoli is a rich source of Vitamin- A, E, C along with fibres. The availability of β-carotene in brocooli is 22-24 per cent higher in comparison to fatty foods, thereby, enhancing the carotenoid uptake by the human body. Carotenoides are powerful antioxidants that may reduce the incidence of age related diseases such as cancer and coronary heart diseases (Ravikumar., 2015) [24].

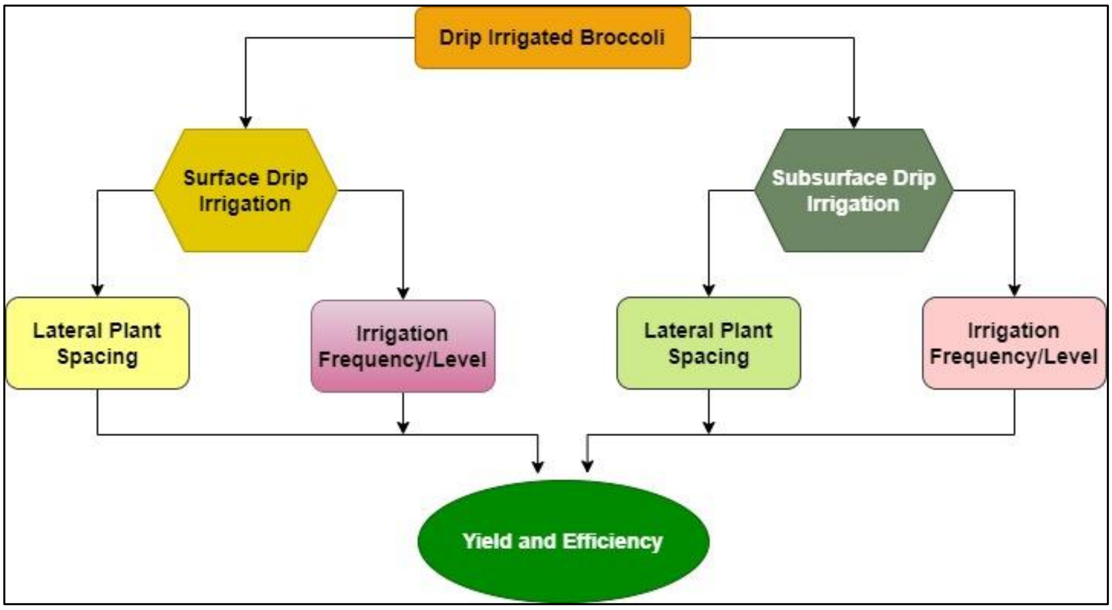

Fig 1: Flow diagram of study

Effect of irrigation frequency/level and lateral spacing under surface drip irrigation

The effect of different irrigation levels (50, 100, 150 and 200% of pan evaporation replenishment) and lateral spacing (0.5 and 1.0 m) on yield and irrigation production efficiency of broccoli was determined by Kumar and Imtiyaz (2007) who found higher irrigation production efficiency at 50% of pan evaporation replenishment and 0.5 m lateral spacing. They also observed an increase in yield with the increase in amount of irrigation water (up to 150% of pan evaporation replenishment) and decreasewith the increase in lateral spacing. Lordwin and Tayal (2008) [19] conducted similar type of experiment and observed identical results (irrigation replenishment at 150% pan evaporation resulted in higher flower weight, marketable flower yield and efficiency of irrigation production). Drip irrigation methods resulted in marginally higher marketable primary flower yield and efficiency in irrigation production as compared to micro-sprinkler methods, whereas, the surface irrigation methods produced substantially lower primary and secondary flowers yield and efficiency in irrigation production. Lordwin *et al.* (2007) [20] conducted the similar type of experiment on clay loam soil at Research Farm of the Allahabad Agricultural Institute, U.P., India during winter season and obtained similar results, i.e., higher flower weight, marketable flower yield and irrigation production efficiency with irrigation replenishment at 150% pan evaporation. The drip irrigation methods resulted in a marginally higher marketable yield as compared to micro-sprinkler methods, while surface irrigation methods produced substantially lower yield and irrigation production efficiency. The overall results of these studies clearly indicate that the micro irrigation (drip) system is highly economical for broccoli in these types of regions.

The impact of various spacing of drip irrigation laterals (60 x 30 cm, 60 x 40 cm and 60 x 50 cm) and different irrigation levels (120, 100, 80 and 60% of crop water requirement) in sprouting broccoli at the Vegetable Research Centre, G.B. Pant Agriculture and Technology University, Pantnagar (Uttarakhand) during winter season was analyzed by Gariya *et al*. (2016) and the datareveal that increased spacing and drip irrigation levels supported plant growth, while lower crop spacing with increased irrigation levels substantially improved yield of heads. From 15 different treatments, the crops spaced at 60 × 30 cm with 100% crop water demand (I2S1) gave the maximum head yield (181.75 q ha^{-1}), net return and benefit to cost ratio of Rs. 197767.80 ha^{-1} and 3.64, respectively. Similarly, the broccoli (Kumari *et al*.,2018) with same irrigation frequencies (once every day, once every 2 days and once every 3 days) under drip irrigation system gave maximum yield (24.46±0.18 t ha-1) with 80% of ETc and irrigation once in 2 days followed by 100% of ETc with once in 2 days. Lowest yield (16.53±0.1 t ha-1) was obtained with irrigation once in 3 days at 60% of ETc.

The broccoli field had higher soil water content, soil water stock and profile water recharge under the treatment I0.8 as compared to I0.4 and I0.6 and higher water use efficiency (44.68% to 54.88%) along with water saving of 43.25 to 48.90% under drip irrigation as compared to conventional method of irrigationin wet temperate zone of Himachal Pradesh (Jeelani *et al*., 2017) [15]. Similarly, in sprouting broccoli, Chand *et al*. (2017) conducted a field experiment on drip irrigationat Horticulture Farm of Rajasthan Agricultural Research Institute, Durgapuraand observed that the application of irrigation regime I0.8 dramatically improved growth attributes (plant height, leaf number, crop area, etc.) and yield attributes (head length, head width, head weight, total head yield per hectare, etc.). Also, Kapoor and Sandal (2021) conducted a field experiment on broccoli at the farm of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur observed that higher water use efficiency and fertilizer use efficiency found in the treatment I0.8 with 50% recommended dose of fertilizer.

The effectiveness of drip and conventional surface irrigation with and without mulch on growth and yield of broccoli in West Bengal was compared by Thentu *et al*. (2016) [28] who analyzed that broccoli produced significantly higher marketable curd yield under drip irrigation at 0.8 ETc along with black polythene mulch over other treatments. Himanshu *et al*. (2013) compared different methods of irrigation, i.e., drip, micro-sprinkler and surface irrigation at Allahabad and obtained higher yield as well as irrigation production efficiency under drip irrigation as compared to micro-sprinkler method and considerably lower irrigation production efficiency undersurface irrigation method.

A field experiment was conducted by Bozkurt *et al*. (2011) [5] to investigate the effects of different irrigation (based on adjustment coefficients 0, 0.75, 1.0 and 1.25 of pan evaporation) and nitrogen levels (0, 75, 150 and 225 kg ha^{-1}) on yield, growth components and water use characteristics of cauliflower cultivated in a field for three consecutive years in the Eastern Mediterranean region of Turkey and they obtained highest yield under irrigation based on pan evaporation coefficients 1.0 and nitrogen application 225 kg ha^{-1}. They also observed that the water use efficiency and irrigation water use efficiency increased with decreasing irrigation rate. Similarly, Erdem *et al*. (2010) [9] obtained maximum yield and water use when the irrigation was applied at 50% of the evaporation of Class A pan for both the seasons.

Reduction in water use due to drip irrigation over the surface irrigation system varied from 30 to 70%, increase in productivity for various vegetable crops ranged from 20 to 80% and the yield potential of vegetable crops increased by three folds with the same volume of water under drip fertigation (Priya *et al*., 2017) [23]. The impact of different soil water tensions (15, 30, 45, 60, 75 and 90 kPa) on the development of broccoli grown in a protected environment under drip irrigation in order to develop criteria for adequate irrigation management was assessed by Tangune *et al*. (2016) who obtained higher total and marketable yield (26.5 and 23.7 t ha^{-1}, respectively) at a soil water tension15 kPa at 0.2 m depth. The effect of irrigation and the organic nitrogen fertilizers on organic broccoli production was measured by in two (Harris farm and UCSC farm). Irrigation treatment had great impact on yield, leaves, florets and stems at both sites of California regions with greater water use efficiency with 80 or 100% ETc at UCSC farm and with 100% ETc at Harris farm (Pasakdee *et al*., 2006).

The effect of deficit irrigation on yield of broccoli grown under unheated greenhouse conditions with sandy loam soil was determined by Ayas *et al*. (2011) [4] at the Agricultural Research Station, Bursa (Turkey). They applied water as 1.00, 0.75,0.50, 0.25 and 0.00 (as control) of evaporation from a Class A Pan corresponding at 2 days irrigation frequency and found the maximum value of WUE (6.71 kg m^{-3}) and IWUE (6.50 kg m^{-3}) when water was applied as 0.75 of evaporation. The marketable curd yield of broccoli from the field applied irrigation through drip at 0.8 CPE was higher with higher soil water content, soil water storage, profile water recharge, NPK uptake and water use efficiency as compared to other irrigation treatments. The study also showed that drip-based irrigation scheduling resulted in higher water usage efficiency (44.68 to 54.88%) and a savings of irrigation water 43.25 to 48.90% as compared to conventional irrigation methods (Jeelani *et al*., 2017) [15].

The highest mean marketable yield of cabbage (90.51 t ha-1) was recorded by Himanshu *et al*. (2012) when irrigation was applied at 175% of pan evaporation replenishment with 1.0 m lateral spacing due to the higher mean head weight (2.26 kg), however, irrigation at 25% of pan evaporation replenishment resulted in higher irrigation efficiency (61.59 kg m-3) with a lateral spacing of 1.0 m and substantially decreased with an increase in irrigation level, though, the irrigation application at 175% of pan evaporation replenishment and 1.0m lateral spacing resulted in higher gross return (271530 Rs ha^{-1}), net return (210972 Rs ha-1) and benefit to cost ratio (4.48). The irrigation strategy on loessal loam in spring and on alluvial loam in autumn greatly influenced the overall plant biomass and the total yield was lowest when water was supplied at 75% of available soil water in both spring and autumn season (Gutezeit, 2004) [12]. An experiment was conducted by Suthar *et al*. (2017) [26] with three plant spacing (30 x 30, 30 x 45 and 45 x 45 cm) on Broccoli at College of Horticulture and Forestry, Jhalawar and highest yield (221.73 t ha^{-1}) was recorded under closing spacing (30 x 30 cm), whereas, lowest (12.72 t ha^{-1}) yield was observed wide spacing of 45 x 45 cm. Hossain *et al*. (2011) [14] also conducted similar type of study with different spacing (60 x 40, 60 x 50 and 60 x 60 cm) at Agricultural Research Station, BARI, Thakurga on and recorded the highest yield (18.8 t ha^{-1}) under the spacing of 60 x 40 cm.

Effect of irrigation frequency/level and lateral spacing with subsurface drip irrigation

The okra plant height, yield and water use increased due to the subsurface placement of lateral and soil moisture content under subsurface drip irrigation and the maximum increased okra yield was recorded 5.22, 13.48 and 11.56% below lateral placement depths of 0.05, 0.10 and 0.15 m, respectively as compared to surface drip, thus, the subsurface drip irrigation laterals could be installed between 0.10 and 0.15 m depth below soil surface for getting higher yield of okra (Singh and Rajput, 2007) [25].

The hot pepper root distribution was noticed best at 30 cm of emitter spacing and 20 cm lateral line width under subsurface drip irrigation and the highest values for water use efficiency (44.39 kg m^{-3}) and fertilizer use efficiency (104.5 kg fruit kg^{-1} NPK) was recorded when lateral lines placed at zero depth with 30 cm emitter spacing (Aboamera *et al*., 2008) [1]. The maximum yield (25.7 t ha^{-1}) with maximum irrigation water use efficiency (0.55 t ha^{-1} cm^{-1}) was registered at 10 cm lateral depth and 20% reduction in irrigation water lowered the onion yield by 2% (Patel and Rajput, 2008). Among the irrigation systems, Oliveira *et al*. (2016) [21] found the subsurface drip irrigation most feasible system for broccoli as compared to the other systems (surface drip, micro-sprinkler and conventional sprinkler). Similarly, Camp (1998) [7] compared the subsurface drip irrigation with other irrigation methods and found greater yield under subsurface drip system than other irrigation methods and achieved substantial reduction in irrigation amount with subsurface drip when the season was started with a large water volume stored in the soil profile and all water extracted was not replaced via irrigation.

The subsurface drip irrigation with factorial combinations of three irrigation regimes (low, medium and high) and four nitrogen rates from 60 to 500 kg ha^{-1} in Broccoli was studied by Thompson *et al*. (2002) [29] in the southwestern USA. The yield of Broccoli under all treatments ranged from 3 to 18 Mg ha-1. Application of nitrogen rate significantly affected the marketable yield during all three seasons and by soil water tension during two out of three seasons. Quality parameters (head weight and diameter) were more responsive to nitrogen rate than soil water tension. Thompson *et al*. (2002b) [30] obtained 95% of the overall net yield with the application of nitrogen 300 to 500 kg ha-1and soil water tension 7 to 25 kPa. The optimum soil water tension for maximum net return was similar to that for marketable yield, while excess quantity of irrigation water with nitrogen had only modest impacts on marketable and net yield but they had major effects on residual soil nitrogen. The highest residual NO_3-N was occurred under the conditions of high nitrogen and high stress on soil surface. Ayars *et al*. (1999) [3] conducted experiments in Laboratory of Water Management Research to observe the effect of subsurface drip irrigation on crops (tomato, cotton, sweet corn, alfalfa, and cantaloupe) grown in rows over a period of 15 years and found that the use of high frequency irrigation water resulted in reduced deep percolation and increased use of water from shallow ground water when the crops were grown in high water table areas. Uniformity studies found that subsurface drip irrigation uniformity was as strong as it was at deployment time after 9 years of service, if management protocols were followed to avoid root intrusion.

The effect of soil moisture depletion (30, 40 and 50%) on evapotranspiration, yield and quality parameters of subsurface drip irrigated broccoli in Turkey was observed by Oztekin *et al*. (2015) who found no significant difference in the yield and quality components among various irrigation treatments.

In coastal plain areas of North Carolina, the effect of lateral spacing (0.91 and 1.82 m) and water distribution in subsurface drip irrigation system on cotton yield and water use efficiency was evaluated by Grabow *et al*. (2006) [11]. The water moved laterally to midpoint of spaced lateral, which was due to the pan layer located at around 0.3 m just below the lateral depth of 0.23 m for both the spacing. The average cotton yield for 0.91 m lateral spacing was 3.44 t ha^{-1} and for the 1.82 m spacing, it was 3.22 t ha-1. Average water use efficiency of irrigation was higher for the spacing of 0.91 m drip line but not significantly different from the water use efficiency of irrigation at 1.82 m spacing.

An experimental design used randomized block split-split plot with four replications to investigate the effect of subsurface drip line placement, cutback amount of water, and cutoff time on yield and quality characteristics in California. The typical design solution is to bury 0.2-0.36 m deep drip lines in the center of the plant row, which place drip lines directly below the plant rows. Some design approaches are being explored to make the drip systems more versatile. Such approaches are the installation of drip lines in alternate furrows, and the installation of drip lines in each furrow, both of which place drip lines midway between plant rows.

Results showed the highest yield for the buried drip lines directly below the plant row sat 0.2-0.36 m depth and the lowest yield for the alternative placement of the furrow. Soil water content and root density were concentrated around the drip lines immediately below the plant rows for the buried placement, while high soil water content and root density zones did not coincide with the plant rows for the furrow placements (Hanson and May, 2007) [13]. The effects of subsurface drip irrigation emitter spacing (0.3, 0.6, 0.9 and 1.2 m) on soil water redistribution, corn yield and water productivity were observed by Arbat *et al*. (2010) [2] in silt loam soils of the US Great Plains. The findings suggest that the preferential water flow along the dripline (parallel) increased relative to the perpendicular to the dripline and this phenomenon partially compensated for wider emitter spacing in terms of soil water redistribution. Emitter spacing with the application of a full irrigation regime had no significant effect on corn yield and water productivity.

The precise distribution of water around the emitters must be understood to better controlled subsurface drip irrigation, which improved the productivity of water usage, while reducing the water losses due to evaporation. Irrigation systems buried at 5 cm (T1), 20 cm (T2) and 35 cm (T3) were represented the soil moisture distribution as 9.25±2.72, 13.01±4.59 and 15.39±4.97, respectively. Soil water content under T1 and T2 ranged widely and had higher trends for the depth of 5 cm, varying from a minimum of 7% to a maximum of 17%, while the depth of 20 and 35 cm ranged from a minimum of 15% to a maximum of 26% (Douh *et al*. 2013). The potential contribution of subsurface drip irrigation to water-saving agriculture was investigated by Thompson *et al*. (2009) [31]. Subsurface drip irrigation decreased NO^3 leaching as compared to surface irrigation and increased yield, dry soil surface for better weed management, crop quality and versatility in harvesting of many field crops. The use of subsurface drip irrigation also allows the virtual removal of crop water tension, the ability to add water and nutrients to the most productive area of the root region, the protection of the drip lines from damage caused by cultivation and tillage and the ability to irrigate with waste water while avoiding human contact. The two major obstacles to subsurface drip irrigation survival in arid regions are climate, including high construction costs and salt deposition, including frequent leaching, advanced tillage techniques, or seedlings transplantation rather than direct seeding.

The effect of irrigation frequency on corn yield under subsurface drip-irrigation was analyzed by Caldwell *et al*. (1994) in silt loam soil. The experiment had four time-based treatments (irrigated at one day, three day, five day and seven day frequencies) and four depletion-based treatments (irrigated when 12.7, 25.4, 38.1 and 50.8 mm of water). The findings showed that the treatments with longer period between irrigations with 38.1 and 50.8 mm irrigation water had greater irrigation water use efficiency because rainfall was used more effectively. The one day and three day and 12.7 mm treatments had significantly lower irrigation water use efficiency. In addition, these treatments did not affect the crop yield and soil water content significantly.

The effects of subsurface drip tape emitters spacing (15, 20 and 30 cm) on yield and efficiency of onions grown at two sites in South Texas Weslaco and Los Ebanos was measured by Enciso *et al*. (2007) [8]. The results showed that emitter spacing did not affect the onion yield (58.5 to 70.3 t ha^{-1}), which might be due to the fact that irrigation was handled in all treatments to have relatively equal levels of irrigation and optimum soil moisture. The output of crop water use efficiency in Weslaco (13.7 kg m-3) was marginally higher than in Los Ebanos (11.7 kg m^{-3}) due to variations in overall water consumption due to differences in irrigation management. An experiment was conducted by Kumar (2019) to study the effect of lateral spacing (45 cm and 60 cm) and irrigation frequencies (daily, alternate, third and fourth day) on subsurface drip irrigated onion crop in micro plots (2 x 2 m) at CCS Haryana Agricultural University, Hisar, Haryana, India. The highest yield (17.56 t ha^{-1}) and irrigation water use efficiency (10.23 kg m-3) was obtained in alternate day irrigation frequency with lateral spacing of 45 cm.

Conclusions

From the foregoing review, it could be clearly seen that drip irrigation requires less irrigation water with increased irrigation efficiency and ensure uniform distribution of water and fertilizers as compared to conventional methods. It was observed that majority of research work on the application of drip irrigation had expressed the advantages like increase in yield, saving of water and labour, improving in produce quality, reducing weed growth, also extends self-life of produce and uniform application of water. Some studies were carried out on irrigation scheduling with drip irrigation without taking care of lateral spacing. It was also observed from the literature that surface and subsurface drip irrigation also plays important role regarding the moisture availability to plant. The effect of proper laterals spacing, irrigation frequency and type of drip irrigation (surface or subsurface) are available a few in literature. These problems can be overcome by adopting advanced methods of irrigation drip irrigation system.

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