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Standardization of lateral placement depths for subsurface drip irrigation with varying discharge rates of emitters in vertisols

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Abstract
A study was conducted to optimize lateral placement depth of subsurface drip irrigation (SDI) in vertisols at ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India. SDI laterals consisting of in-built emitter of discharge rates 1.3, 2, 2.3 and 3 Liter per hour (Lph) at 0.20, 0.30, 0.40, and 0.50 m spacing on lateral were placed at 0.05, 0.10, 0.15, 0.20 and 0.25 m depths below soil surface. Soil water content distribution in wetted zone was examined one day after water application for 0.5, 1, 2, and 3 hours through SDI. Placement depths were standardized based on higher availability and uniformity of soil water in wetted zone. Soil water content at 0.10-0.20 m depth close to emitter was found higher and uniform as compared to other depths. Similar trends in soil water content was observed at 0.15-0.25 m, and 0.15-0.20 m depth, respectively for 0.15 m and 0.30 m horizontal distance from emitter. Therefore, lateral placed at 0.10-0.15 m below soil surface might be recommended for SDI with emitter discharge rate 1.3 lph, and 0.15-0.20m depth for remaining laterals. SDI lateral placement depths for cultivating tomato revealed 7.47-12.64% significant increase in yield.

Keywords: Subsurface drip irrigation, emitter discharge, emitter spacing, lateral placement depths

1. Introduction
Surface irrigation methods are utilized in about 90% irrigated area in India. These have low field level application efficiency of 35 to 40% because of huge conveyance and distribution losses [1, 2]. On the other hand drip irrigation used in horticultural and vegetable crops may achieve field level water application efficiency of 80-90%, as surface runoff and deep percolation losses are minimized and also fertilizer saving [3-6]. Area under drip irrigation is increasing to realize enhanced water use efficiency and crop yield as well as sustainable management of irrigation water [7, 8]. It is suitable for areas that are presently under cultivation, and can also be used efficiently in undulating terrain, rolling topography, hilly areas, barren land and areas which have shallow soils [9]. It has vast potential of application in 27 million-hectare land in India [10, 11]. Drip irrigation with laterals placed at soil surface is most popular application in India.

Drip irrigation can be made more applicable for irrigating a wide range of agronomic, horticultural and fruit crops by installing the laterals below the soil surface, called subsurface drip irrigation. Subsurface drip irrigation (SDI) is defined as application of water below the soil surface through the emitters, with discharge rates generally in the same range as surface drip irrigation [12]. Worldwide studies reveal advantages of SDI of many crops over surface drip and other irrigation methods in terms of reduced evaporation loss and precise placement and management of water, nutrient and pesticides leading to more efficient water and nutrient use, enhanced plant growth, crop yield and quality [13-21]. Few studies conducted in India also indicate great potential of SDI in horticultural and vegetable crops [22-31]. However, lack of appropriate design of SDI system affect uniformity of application of water and nutrients in the soil required for proper plant growth and crop yield. Depth of placement of laterals is one of the important considerations in design of SDI [32, 33].

Lateral placement depth of SDI should be sufficient to avoid damage from tillage implements but shallow enough to wet the crop root zone. In general, depths of placement of laterals range from 0.02-0.70 m for lateral spacing of 0.25-5.0m. However, more specific information will be required to determine lateral depths for specific soil and crop combinations [13, 14]. In India, no significant research is reported on above aspect; and recommendations regarding placement depths of SDI laterals are lacking. Therefore, a study was conducted to optimize lateral placement depths of SDI in vertisols with respect to different emitter discharge rates and emitter spacing on the laterals. The standardized lateral placement depths were validated for cultivation of tomato.

2. Materials and Methods

2.1 Soil of Study Area

The study was conducted in black vertisols at ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India during 2005-08. The soil has high clay content and low infiltration rate (Table 1).

Table 1: Physical properties of soil at experiment site

Sl. No.	Properties	
	Soil texture	
1.	Clay	49.7-53.7%
	Silt	27.9-29.6%
	Sand	8.2-20.8%
	Gravel	2.9-3.8%
2.	Soil structure	Sub angular blocky
3.	Bulk density	1.39 -1.75 Mega gram /m^3
4.	Porosity	38.0-40.0%
5.	Max. water holding capacity	33.0-36.0%
6.	Field capacity	28.5-31.0%
7.	Permanent wilting point	19.0-19.5%
8.	Infiltration rate	0.011 m/h

2.2 Details of Experiment

The main components of designed SDI consisted of a pump, main and sub main pipe lines (63 X 10^{-3} m diameter), laterals (16 X 10^{-3} m diameter) with in–built, clog resistant emitters (discharge rate 1.3, 2, 2.3 and 3 liter per hour (lph) at various spacing on laterals as given in Table 2), pressure gauges, water meter, control valves, filtration unit, flush valve, air/vacuum release valves, flush line, and accessories required for connections and installation.

The experiment was designed and laid out with six treatments (T_1, T_2, T_3, T_4, T_5, and T_6) as depths of lateral placement for each combination of emitter discharge rate and emitter spacing on lateral. Treatment T_1 consisted of lateral placed at soil surface. Treatments T_2, T_3, T_4, T_5, and T_6 consisted of laterals placed at depths of 0.05, 0.10, 0.15, 0.20 and 0.25 m below soil surface, respectively. The treatments were replicated for three times randomly. Each combination of lateral placement depths, emitter spacing and emitter discharge rate of SDI was operated at pressure of 1 kg/ cm^2 (100 kilo Pascal) for 0.5, 1, 2, and 3 hours. Selection of various placement depths of laterals and durations of water application were based on quantity of water required for wide range of crops during their different growth stages.

Table 2: Emitter discharge and spacing on lateral

Emitter discharge, lph (meter^3/second)	Emitter spacing on lateral, m
1.3 (3.61 X 10^{-07})	0.20
2 (5.55 X 10^{-07})	0.30, 0.40 and 0.50
2.3 (6.38 X 10^{-07}	0.50
3 (8.33 X 10^{-07})	0.60, 0.75 and 0.90

2.3 Standardization of lateral placement depths

The experiments were conducted to determine dimensions of wetted soil volume, after given duration of water application through SDI and soil water content at different locations in wetted profile i.e. wetted depths and widths of soil. The soil wetted profile and water content in both horizontal and vertical directions of wetted zone of soil was observed after one day to allow soil water content to reach at field capacity. Observations and soil samplings for determination of soil water content was accomplished by digging a soil pit across wetted zone [23, 34]. The placement depths of SDI laterals below soil surface were standardized based on higher availability and uniformity of water content in wetted zone of soil [28]. Because of desired higher availability and uniformity of soil water in plant root zone, values with higher availability and less variation in soil water content along wetted depth as well as wetted horizontal distance from lateral line are best suited to field condition for various crops.

2.4 Field Validation

Tomato (*Lycopersicon esculentum*) being one of the important vegetable crops, standardized lateral placement depths was validated for growing tomato under SDI. Tomato was transplanted at 0.50 m plant to plant spacing under irrigation treatments of SDI lateral placed at 0.05 m, 0.10 m, 0.15 m, 0.20 m and 0.25 m below soil surface (treatments, T_2 to T_6, respectively) and at soil surface (Treatment, T_1). Each lateral length was 20 m with emitter spacing of 0.50 m having discharge rate 2lph. Irrigation water was applied to tomato as per crop water requirement based on evapotranspiration on alternate day. Observations on crop growth attributes and yield of tomato were recorded periodically. The results under SDI were compared with those under surface drip irrigation system. Statistical test (t-test) was used to establish the statistical significance of increase in yield.

3. Results and Discussion

3.1 Soil water content distribution

The distribution of mean soil water content across soil wetted profile upto 0.30 m distance from lateral emitter location along soil surface and 0.60 m below soil surface one day after water application for 2 hours with emitter discharge rate of 2 lph for laterals placed at surface, 0.05 m, 0.10 m, 0.15 m, 0.20 m and 0.25 m depth below soil surface have been depicted in Figure 1 and 2. Soil water content distribution has been presented using Kriging gridding method of Surfer software. It may be observed that soil water content with SDI in upper soil layer, above emitter was more than that in lower soil layer of same thickness below the emitter. It may be attributed to dominance of capillary action over gravity for the soil in study.

The depth of soil wetting below emitter under SDI was lower than that under surface drip, because, part of applied water moved to wet soil above position of lateral placement, which reduced net volume of water availability to wet soil below lateral. The width of wetted soil zone was found to decrease with increasing depth of placement of laterals of SDI system. Greater depth of placement of lateral requires larger volume of water for upward movement upto the soil surface that results in decreasing availability of water for lateral movement. Soil water movement in horizontal direction was found less as compared to that in vertical direction. More uniform soil water distribution may be observed with laterals placed at 0.15 –0.20 m depths as compared to other placement depths.

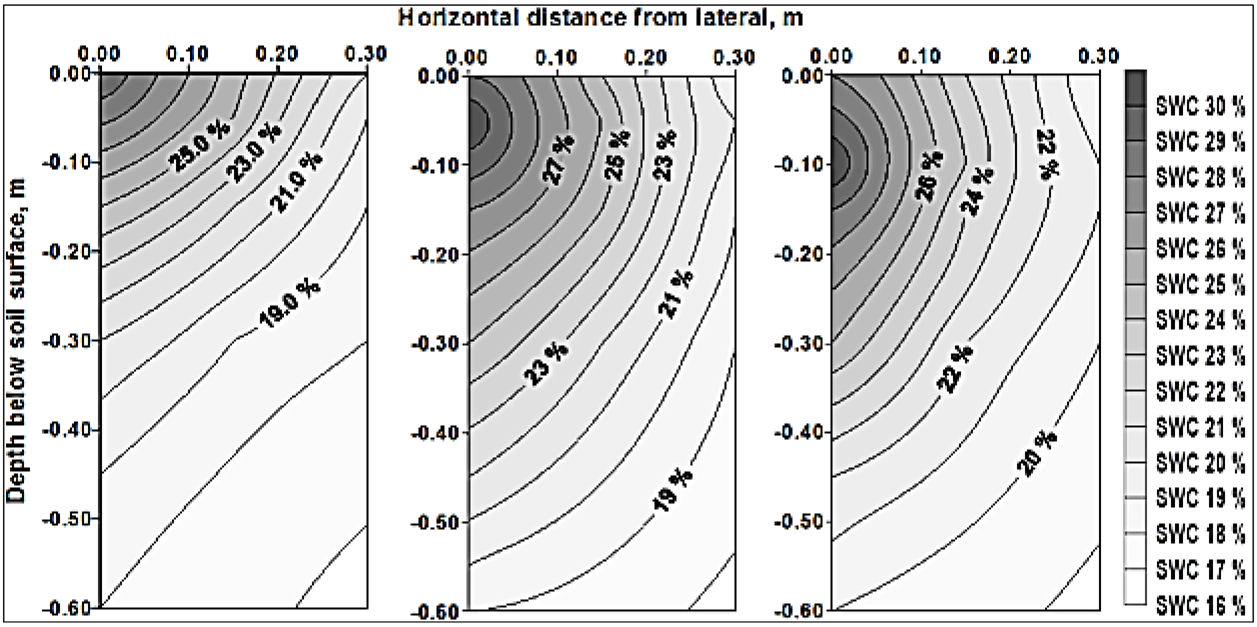

Fig 1: Soil water content (SWC) distribution for SDI placed at surface and at 0.05 and 0.10 m depth below soil surface

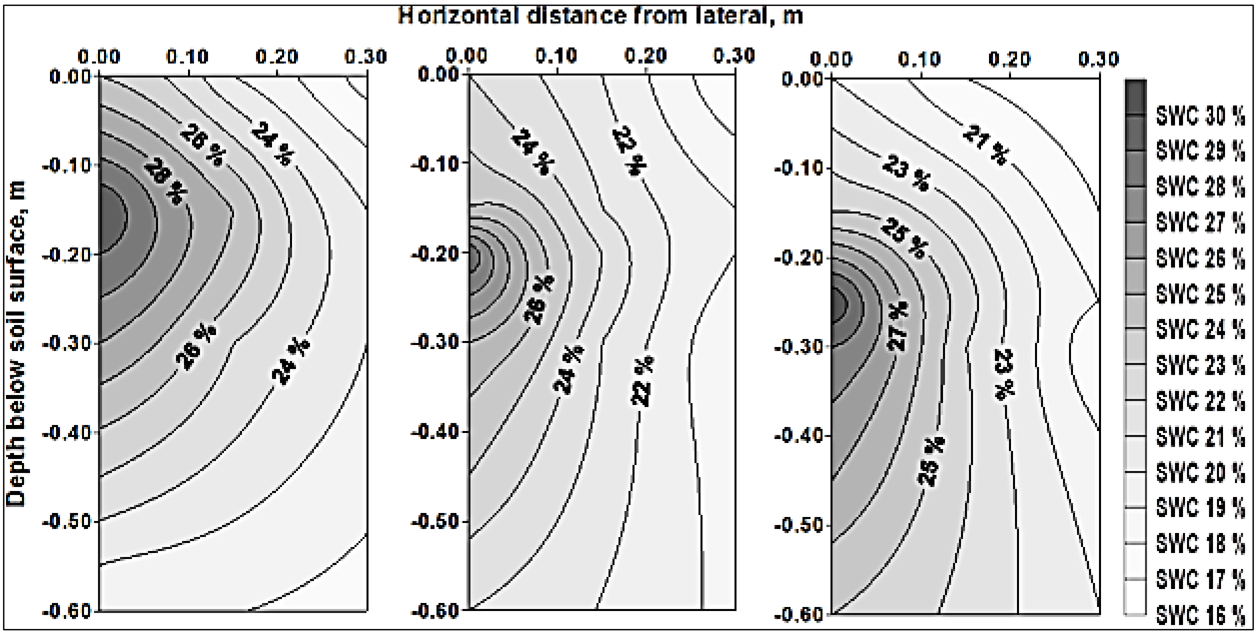

Fig 2: Soil water content (SWC) distribution for SDI placed at 0.15, 0.20 and 0.25 m depth below soil surface

3.2 Variation in Soil Water Content

The availability of soil water content due to emitter discharge rate 2 lph at position of lateral emitter location at a depth of 0.10-0.20m was found higher and near to field capacity with more uniform as compared to other depth increments. However, at 0.15m distance from emitter location water content at a depth of 0.15-0.25m was higher and more uniform than other depth increments. Availability of soil water at depth of 0.15-0.25m at 0.30m distance from emitter location was higher and uniform as compared to other depth increments. Soil water content away from the source emitters reduced in both horizontal and vertical directions. It may be observed that variation in soil water content was less with SDI laterals placed at 15-20cm depths below soil surface. Therefore, lateral placement depth of 15-20cm could be recommended for SDI with emitter discharge rate of 2.0lph.

3.3 Standard Placement Depths of Lateral

Uniform and higher availability of soil water was found with SDI laterals having 2lph emitter discharge rate and 0.30, 0.40 and 0.50 m spacing on laterals placed at depths of 0.15– 0.20 m under study. Similar trends were observed for laterals with emitter of 2.3 and 3lph discharge rates. While, in case of SDI with emitter discharge rate 1.3lph and 0.20m spacing on lateral uniform soil water content was observed when laterals were placed at 0.10-0.15 m below soil surface. Therefore, depths of lateral placement for various SDI laterals could be recommended as given in Table 3.

Table 3: Recommended depths of placement of SDI laterals

Emitter discharge of lateral, lph (meter^3/second)	Emitter spacing on lateral, m	Placement depth of SDI laterals, m
1.3 (3.61 X 10^{-07})	0.20	0.10 – 0.15
2 (5.55 X 10^{-07})	0.30, 0.40 and 0.50	0.15 –0.20
2.3 (6.38 X 10^{-07}	0.50	0.15 –0.20
3 (8.33 X 10^{-07})	0.60, 0.75 and 0.90	0.15 –0.20

3.4 Field Validation of Optimized Lateral Placement Depths

It may be observed that upto 30 days offer transplanting, plant height increased little more in case of T_1, and T_2 as compared to other treatments (Figure 3). Beyond 90 days of transplanting, plant height reached to maximum under treatment T_4. Leaf area index increased during initial 70 days of crop development (Figure 4). Around 70 days after transplanting, leaf area index reched maximum from 2-5 under T_4 treatment. It increaded rapidaly during 50 -70 days and declined slowly during 90-115 days in late season of crop.

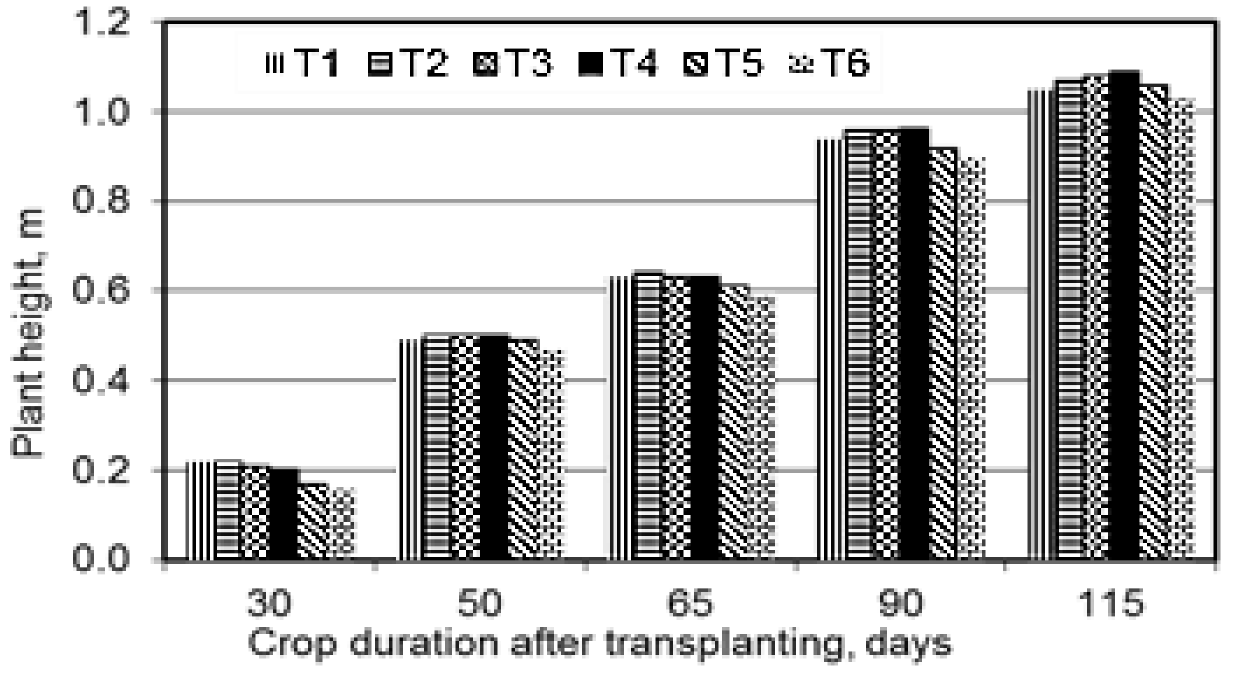

Fig 3: Plant height of tomato under various SDI after transplanting

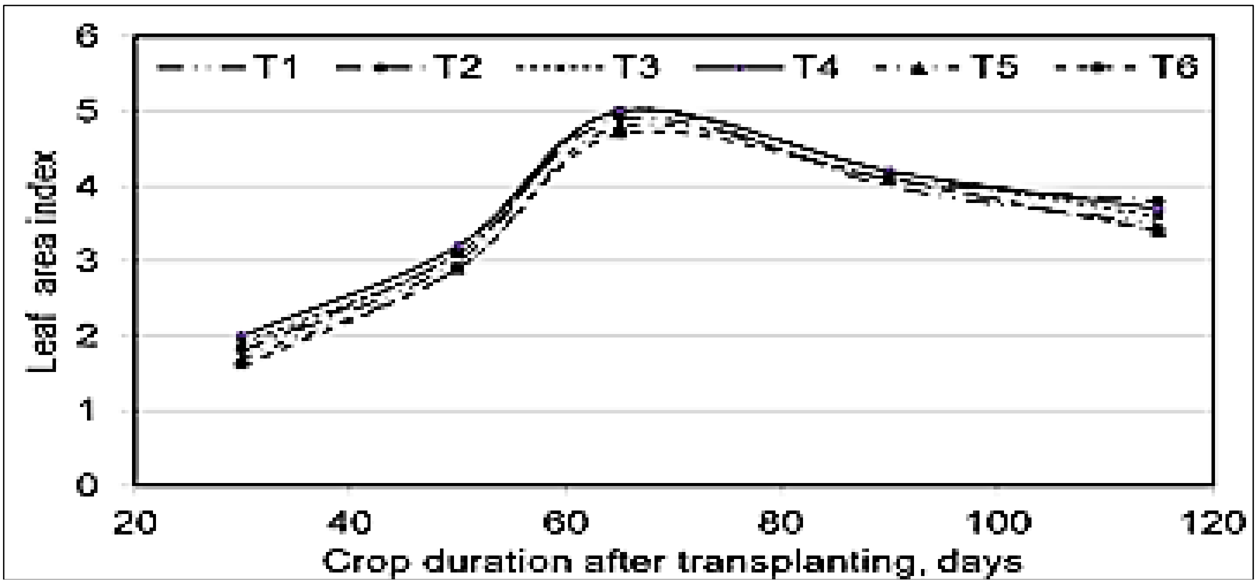

Fig 4: Leaf area index of tomato transplanted under various treatments

It was found that mean yield of tomato enhanced due to SDI (T_2–T_6) laterals placed at 0.05-0.25m depths as compared to surface drip irrigation (T_1) (Figure 5). Increase in mean yield of tomato as compared to T_1 was found maximum under T_4 followed by T_3, T_5, T_2 and T_6. Statistical analysis indicated that enhanced in yield due to SDI was significant under treatments, T_2, T_3, T_4 and T_5, but not under T_6. Mean yield of tomato under treatment T_4 significantly increased over other treatments (Table 4). The mean yield under treatment T_3, and T_4 were significantly higher than that under treatments T_1, T2, T_5 and T_6. The findings revealed that lateral placement depths, T_3 and T_4 could be preferred over other lateral placement depths of SDI.

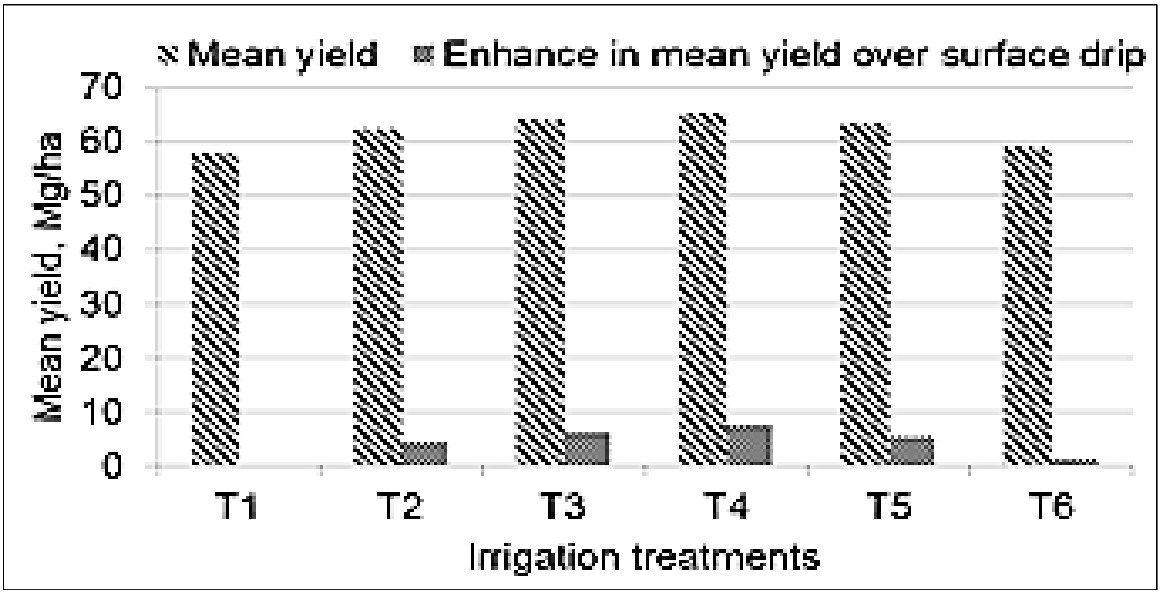

Fig 5: Mean yield of tomato under various irrigation treatments

Table 4: Increase in mean yield of tomato over various treatments of SDI

Treatments	Increase in mean yield (%) over following treatments					
	T1	T2	T3	T4	T5	T6
T1	0	-	-	-	-	-
T2	7.47*	0	-	-	-	5.6*
T3	10.34*	3.22*	0	-	-	8.5*
T4	12.64*	5.38*	2.08*	0	3.68*	10.7*
T5	9.2*	2.15	-	-	0	7.3*
T6	1.72	-	-	-	-	0

*: significant increase at t-critical ($t_{0.05,\ 4}$ =2.776445); –: Negative values

5. Conclusions

Placement depths of laterals were recommended based on higher availability and uniform soil water content through SDI placed at various depths below soil surface. Higher availability and uniform soil water content was found at 0.10-0.20 m depth below soil surface at location of emitter as compared to other depths. Soil water availability was higher and uniform at depth of 0.15-0.25 m at 0.15 m distance from emitter location. However, at 0.30 m distance from emitter location soil water availability was higher and uniform at depth of 0.15-0.20 m. Therefore, depth of lateral placement at 0.10-0.15 m below soil surface could be recommended for SDI with emitter discharge rate 1.3 lph with 0.20 m spacing on lateral. However, placement depth of 0.15 – 0.20 m could be preferred for SDI lateral with emitter discharge rate 2, 2.3 and 3lph spaced at 0.20, 0.30, 0.40, and 0.50 m on laterals. The optimized values of lateral placement depths of SDI were validated for cultivation of tomato under SDI having emitter spacing 0.50m and discharge rate 2 lph which revealed significant increase of 7.47 to 12.64% in yield of tomato.

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