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Soil Water Dynamics in Subsurface DRIP Irrigation under Onion Crop

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Abstract

Micro-irrigation enhances productivity and empower cash crop as well as in some cases export oriented cultivation by using very less amount of water with better nutrient management. An experiment was conducted to study soil water dynamics under onion crop with irrigation frequencies (one, two, three and four days) and lateral spacing (45 cm and 60 cm) under subsurface drip irrigation during the spring summer season 2020 and 2021 in 2 m x 2 m micro plots, built in the field area of Department of Soil and Water Engineering, CCSHAU, Hisar, Haryana, India. At the middle of 45 cm and 60 cm lateral spacing with daily irrigation, available moisture in the root zone (0-60 cm) was 12.73 cm and 12.33 cm respectively, which was higher by 3.14% in 45 cm lateral spacing than 60 cm. Average highest (75.53 cm) and lowest (71.68 cm) plant height of two seasons was recorded in I_2L_{45} and I_4L_{60} treatments at 90 DAT. On the basis of soil water dynamics, superior quality and highest yield of onion in sandy loam soil, it is concluded that subsurface drip irrigation with two days irrigation interval with 45 cm lateral spacing gives better performance as compared to one, three and four days irrigation in 45 as well as 60 cm lateral spacing.

Keywords: Water scheduling, irrigation frequency, subsurface drip, irrigation interval.

Introduction

For a country like India, which has 17 percent of the world's population but only 2.4 and 4 percent of the land and the world's water resources, respectively, efficient use of available water resources is vital. In 1947, per capita water availability was 6008 m^3, but it has since dropped to 1250 m^3 and is expected to drop up to 760 m^3 by 2050. (Patel and Rajput, 2009). To meet the needs of an increasing population and rising living standards by 2050, India will need to increase production of all agricultural commodities by around 30 percent which requires food grain about 450 million tonnes of per year (Chand, 2012). Micro-irrigation enhances productivity and empower cash crop as well as in some cases export oriented cultivation by using very less amount of water with better nutrient management. Depending on various crop conditions and soil types, water use efficiency under drip irrigation can varied from 80 to 90% (Sivanappan, 1994). Subsurface drip irrigation is the supreme modern irrigation method, in which water is delivered at low pressure directly to the plant roots below the soil surface (Nalliah *et al*., 2009). In terms of area, India ranks first with an area of 1.285 million hectare with production of 23.2623 million ton (NHRDF, 2018). The average onion productivity in India is 17.33 ton per ha, which is low when compared to the global average (Bhaskar *et al.,* 2018). Maximum onion production takes place in Maharashtra (8.85409 m ton).The area, production and productivity of onion in Haryana is 0.02993 m ha, 0.70150 m ton and 23.44 ton ha^{-1}, respectively (NHRDF, 2018). In Haryana, onion has a prominent place and is the second among the other vegetable crops after potato with respect to area under different vegetables (Kumar *et al.,*2020). Utilization of drip irrigation system promotes many benefits such as uniform distribution of water, water saving, nutrient application and increase in water use efficiency. Performance of the drip system is much influenced by its design components like dripper discharge and its spacing, lateral spacing, size of main line, submain and lateral or drip tape. Based on evapo-transpiration needs, water is provided to the crop root zone by fixing different irrigation frequency. Irrigation based on evapo-transpiration deficit and after a specific interval generates scope for improving the water use. Thus the soil water dynamics in subsurface drip irrigation is important component to irrigation practice and schedules for better irrigation management.

Materials and Methods
Experimental Site
The experiment was conducted in micro plots (2 x 2 m) built in the field area of Department of Soil and Water Engineering, Chaudhary Charan Singh, Haryana Agricultural University, Hisar at $29^0 09'0.97''$N latitude and $75^0 42'20.12''$E longitude with an average elevation of 215.2 m above mean sea level (MSL) from 19 February to 06 June in 2020 and 20 February to 07 June in 2021. Study was conducted on "Soil water dynamics in subsurface drip irrigation under onion crop". The laterals of drip system were buried 5 cm below the soil surface. The climate is continental with very hot summers and relatively cool winters. Average annual rainfall and temperature of experimental area has 429 mm and 21.5 ^{0}C, respectively. The Indo-Gangetic plain runs through the district. The entire area is a nearly flat alluvial plain with sand hummocks and sand dunes strewn about.

Soil Properties of Experimental Site
The soil in micro plots was filled uniformly. Soil samples were taken at four depths (i.e. 0-15, 15-30, 30-45, 45-60 cm) from different plots randomly to study the different soil properties. Table 1. Lists the standard methods and references opted to determine various physio-chemical properties of soil. The proportion of sand, silt and clay in a soil mass determines its texture. The soil texture was determined by using the international pipette method (Gee and Bauder, 1986). The bulk density of soil was determined using the core sampler method (Rechards, 1954). The reciprocal of electrical resistance is electrical conductivity (EC), which is a material's ability to transmit the electric current. It was measured in a ratio of 1:2 soil and water (distilled) suspension by using an EC meter. Soil pH is a measure of the acidity or basicity of a soil and defined as the negative logarithm of the hydrogen ion concentration. The glass pH meter was used to determine the pH of soil samples. The bulk density of soil is the weight of soil mass per unit volume. It's also referred as apparent specific gravity and expressed as g per cubic cm. The bulk density of soil was determined using the core sampler method (Rechards, 1954). The reciprocal of electrical resistance is electrical conductivity (EC), which is a material's ability to transmit the electric current. It was measured in a ratio of 1:2 soil and water (distilled) suspension by using an EC meter. Infiltration rate was determined by cylinder infiltrometer (Haise *et al*., 1956). The available organic carbon, nitrogen, phosphorus and potassium was determined by different methods given in the following table, respectively.

Table 1: Method used at the experimental site to determine various physico-chemical properties of soil

Soil Property	Method used	Reference
Soil Texture	International pippete method	Gee and Bauder, 1986
Bulk density	Core sampler	Richards, 1954
$EC_{1:2}$	EC meter	Richards, 1954
pH	pH meter	Richards, 1954
Infiltration rate	Cylinder infiltrometer	Haise *et al*., 1956
Nitrogen	Alkaline potassium permanganate method	Subbiah and Asija, 1956
Phosphorus	Olsen's method	Olsen *et al*., 1954
Potassium	Flame photometric method	Hanway and Heidal, 1952
Organic Carbon	Wet digestion method	Walkley, 1935
Moisture content	Gravimetric method	Michael, 2008

Treatment Details
Irrigation was applied using a subsurface drip irrigation system with two lateral spacing (i.e. 45 and 60 cm) on daily, one-day, two-day and three-day irrigation interval. Table no. 2 provides an abbreviated summary of various treatments imposed during the study.

Table 2: Combination of different irrigation frequency and lateral spacing treatments

S. No.	Treatment	Abbreviation
1.	Daily irrigation (one day interval) with 45 cm laterals spacing	I_1L_{45}
2.	Two days irrigation interval with 45 cm laterals spacing	I_2L_{45}
3.	Three days irrigation interval with 45 cm laterals spacing	I_3L_{45}
4.	Four days irrigation interval with 45 cm laterals spacing	I_4L_{45}
5.	Daily irrigation (one day interval) with 60 cm laterals spacing	I_1L_{60}
6.	Two days irrigation interval with 60 cm laterals spacing	I_2L_{60}
7.	Three days irrigation interval with 60 cm laterals spacing	I_3L_{60}
8.	Four days irrigation interval with 60 cm laterals spacing	I_4L_{60}

Experimental Layout
Figure 1. depicts the experiment's layout. With recommended spacing of 15 x 10 cm between row to row and plant to plant, the actual plant density is 666666 plants/ha. In the experiment plot, leaving some buffer zone near the brick lining, a total of 216 plants were transplanted in each micro plot of 4 m^2 area with 12 rows and 18 plants in each row. Layout of single microplot for 45 and 60 cm lateral spacing depicted by Figure 2.

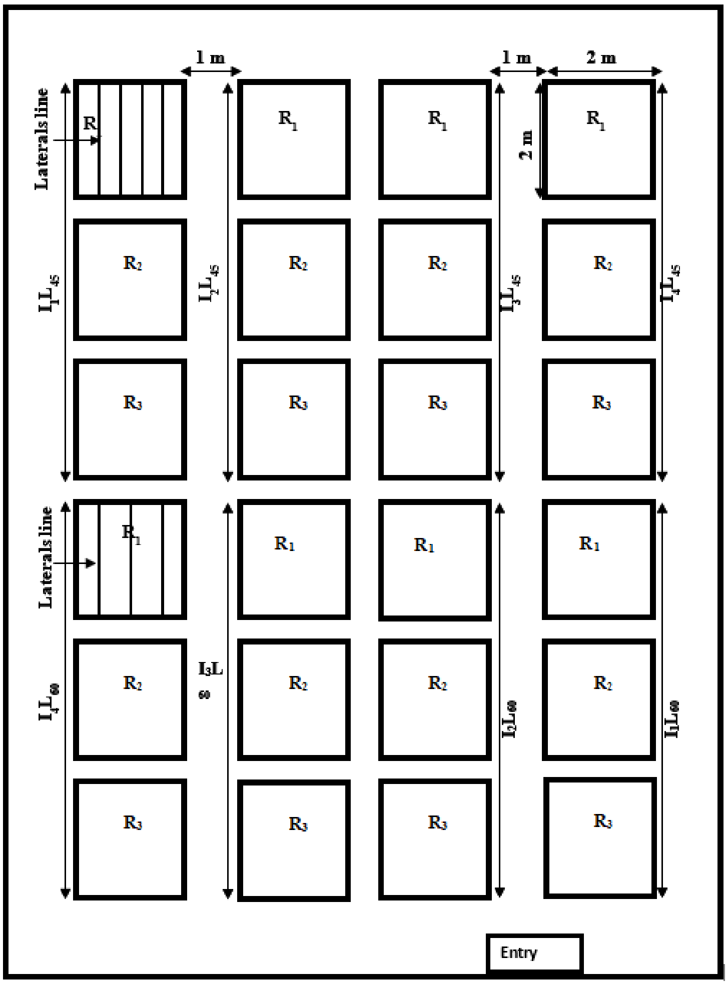

Fig 1: Experimental layout showing different treatments with replications

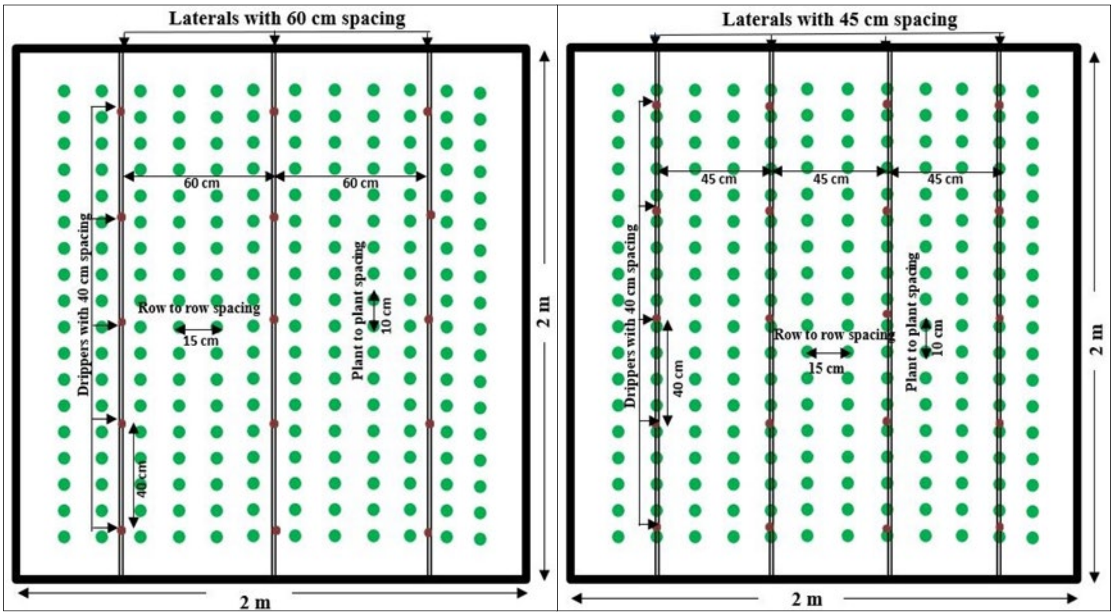

Fig 2: Layout of single microplot for 45 and 60 cm lateral spacing

Irrigation Scheduling

The crop was transplanted during the spring summer season but irrigation water spread by subsurface drip (at 5 cm depth) was beyond the reach of onion transplanted in the middle of the lateral spacing during the initial growing period due to sandy loam texture of soil. First Irrigation was applied through flood method of a depth of 6 cm to prevent crop mortality due to deficit in the moisture content between the two lateral lines. Irrigation was applied based on 100 percent pan evaporation (PE).

Crop evapotranspiration (ET_c, mm) was estimated as:

$$ET_c = K_c \times K_p \times CPE \qquad \ldots (1)$$

Where,

K_c = Crop coefficient values as Table 3.3 (Allen *et al.*, 1998)

K_p = Pan coefficient (0.7)

CPE = Cumulative pan evaporation (mm)

The depth of irrigation for various irrigation treatments was calculated using CPE up to that day from the previous irrigation day. As a result, the volume of irrigation was based solely on the PE of that day for daily irrigation frequency. CPE was calculated in the same way for one, two, and three days irrigation frequency by adding PE from the previous one, two, and three days, respectively. The volume of water applied was determined using the following formula for water requirement (Kaulage, 2017):

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

Where,
V = Water requirement per plot (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)

Table 3: Crop coefficient for spring summer onion crop (Allen *et al*. 1998)

Growth stage	Crop coefficient value	Crop duration (days)	Crop period	
			2020	**2021**
Initial stage	0.7	0-20	19 Feb –10 March	20 Feb –11 March
Development stage	0.7	21-45	11 March-03 April	12 March-04 April
Mid-season stage	1.05	46-80	04 April-07 May	05 April-18 May
End stage	0.75	81-93	8 May- 22 May	9 May- 23 May

Time of irrigation was determined by using the following formula:

$$\text{Irrigation time (h)} = \frac{V}{q \times No.of\ drippers} \quad \ldots(3)$$

Where;
V = Water requirement per plot (l)
q = Dripper discharge rate ($l\ h^{-1}$)

Automatic Irrigation System
In the field lab of the Department of Soil and Water Engineering, College of Agricultural Engineering and Technology, an automatic irrigation system was installed in the micro plots. The time of irrigation for different plots can be controlled by controller box which operates the valves according to the running time feed into the system. Figure depicts the various components of automatic irrigation system and its controller.

(a) **(b)**

Fig 3: Components of the automatic irrigation system (a) and controller box (b)

Discharge Measurement
The drippers discharge was checked randomly in different plots to maintain the uniform distribution of water through the drip irrigation system, and the system's emission uniformity (Kruse, 1978) was calculated using the equation:

$$EU = \left[\frac{q_n}{q_a}\right] \times 100 \quad \ldots(4)$$

Where,
EU = System's emission uniformity
q_n = Average discharge of drippers lying in bottom quarter of discharge range ($l\ h^{-1}$)
q_a = Average dripper discharge ($l\ h^{-1}$)

Moisture Content of Soil
Soil samples were taken at 0-15, 15-30, 30-45, and 45-60 cm depth from the soil surface in a vertical direction using a tube auger hole in the field. The samples were collected at three radial distances from the dripper which was 0, 11.25, 22.5 cm and 0, 15, and 30 cm distance away from the dripper in the 45 and 60 cm lateral spacing, respectively. The gravimetric method was used to determine soil moisture, which involved drying of samples in an oven for 24 hours at 105°C. Before and after drying the samples, the weight of the soil was recorded, and the moisture content was calculated using equation 5. Equation 6 was also used to calculate the depth of water available in the root zone.

$$\text{Moisture Content (\%)} = \frac{W_1 - W_2}{W_2} \times 100 \quad \ldots(5)$$

Where,
W_1 = weight wet of a soil sample (g)
W_2 = weight of dry soil sample (g)

$$d_w = \frac{\rho_s \times \text{percent moisture content} \times d_s}{\rho_w \times 100} \quad ...(6)$$

Where,
d_w = depth of water available in the root zone (cm)
ρ_s = density of soil (g cm^{-3})
ρ_w = density of water (g cm^{-3})
d_s = depth of soil (cm)

Yield and Yield Attributes

Field observations of randomly selected samples were taken at various intervals and parameters related to yield attributes and yield were recorded for various plots by using standard procedures.

Results and Discussion

Physio-chemical Properties of Soil

The physical and chemical properties of the initial soil samples were calculated as per the procedure in Table 1 and their values are listed in Table 4.

Table 4: Physio-chemical properties of experimental site

Parameters/Properties	Soil depth (cm)			
	0-15	15-30	30-45	45-60
Sand (%)	82.18	82.18	82.18	82.18
Silt (%)	4.32	4.32	4.32	4.32
Clay (%)	13.5	13.5	13.5	13.5
Texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Bulk density (gm cm^{-3})	1.57	1.55	1.56	1.55
Ph	7.97	7.69	7.20	7.72
$EC_{1:2}$ (dS m^{-1})	0.25	0.24	0.22	0.22
N (kg ha^{-1})	119.3	117.7	115.2	114.4
P (kg ha^{-1})	25.2	23.5	22.8	22.3
K (kg ha^{-1})	180.5	176.7	152.4	147.6
Organic carbon (%)	0.29	0.27	0.25	0.24
Basic infiltration rate	2.63 cm h^{-1}			

The Volume of Water Used in Various Treatments

The average dripper discharge was estimated as 2.28 l h^{-1} with 90% system's emission uniformity. The volume of water applied for irrigation was calculated by using equation 2. Total depth of water applied in each plot and rainfall received during the experiment was 30.7 cm (1228 l) and 12.62 cm in 2020, and 36.61 cm (1464 l) and 3.43 cm in 2021, respectively. Figure 5 and 6 shows photographs of experiment under 45 and 60 cm lateral spacing with different irrigation frequency.

Moisture Content in Relation to Irrigation Frequency and Lateral Spacing

During the experiment period, radial and horizontal variations in soil moisture were analysed in different treatments after 30, 60, and 90 days of transplantation (DAT). Table 5 shows the moisture content in the root zone at 30, 60 and 90 DAT. The depth of water available in the root zone (0-60 cm) was determined by using equation 6 at different distances from the dripper and DAT (Table 6).

Table 5: Observed moisture content (%) in the effective root zone after 30, 60 and 90 days of transplanting

Treatments	Depth (cm)	30 DAT			60 DAT			90 DAT		
		Radial distance (cm)			Radial distance (cm)			Radial distance (cm)		
		0	11.25	22.5	0	11.25	22.5	0	11.25	22.5
I_1L_{45}	0-15	16.32	15.9	15.22	15.95	15.51	14.87	14.82	14.18	13.9
	15-30	15.37	15.12	14.46	15.1	14.85	13.9	14.55	13.41	13.0
	30-45	15.01	14.08	13.87	14.7	13.87	13.21	13.68	12.32	12.2
	45-60	14.52	14.01	13.51	14.22	13.63	12.5	13.02	12.19	12.0
I_2L_{45}	0-15	15.55	14.9	14.67	15	14.28	13.76	14.35	13.9	13.42
	15-30	14.76	14.4	14.21	14.04	13.69	13.1	13.88	13.2	12.66
	30-45	14.2	13.6	13.32	13.68	13.2	12.54	13.42	12.3	11.7
	45-60	13.84	13.1	13.01	13.19	12.55	12.28	12.75	11.9	11.52
I_3L_{45}	0-15	15.21	14.56	14.24	14.3	13.96	13.56	14	13.2	12.7
	15-30	14.55	14.18	14.01	13.84	13.51	12.77	13.68	12.8	12.3
	30-45	13.98	13.32	12.98	13.6	13.02	12.1	13.13	11.9	11.6
	45-60	13.66	12.86	12.64	12.88	12.42	11.99	12.46	11.5	11.1
I_4L_{45}	0-15	14.9	14.28	13.82	14.1	13.68	12.88	13.6	12.8	12.3
	15-30	14.4	13.84	13.66	13.71	13.2	12.44	13.3	12.5	12.0
	30-45	13.62	12.88	12.72	13.22	12.76	11.82	12.6	11.4	11.2
	45-60	13.42	12.76	12.29	12.76	11.84	11.51	12.0	11.1	10.7

	Depth (cm)	Radial distance (cm)			Radial distance (cm)			Radial distance (cm)		
		0	15	30	0	15	30	0	15	30
I_1L_{60}	0-15	15.66	14.89	13.43	15.47	14.56	13.78	14.54	13.63	12.2
	15-30	15.28	14.67	13	15.06	14.09	13.6	14.1	12.98	11.77
	30-45	14.62	13.81	12.39	14.4	13.52	13.05	13.44	12.58	11.14
	45-60	13.86	13.2	12.21	13.66	13.06	12.35	12.7	11.96	11
I_2L_{60}	0-15	14.89	14.7	12.88	14.7	13.78	13.22	14.17	12.96	11.82
	15-30	14.67	14.48	12.56	14.45	13.6	13.15	13.89	12.51	11.7
	30-45	13.81	13.45	12.06	13.59	13.05	12.76	13.09	12.32	10.74
	45-60	13.2	12.8	11.91	12.89	12.35	11.91	12.35	11.23	10.87
I_3L_{60}	0-15	14.55	14.26	12.2	14.36	13.22	13.01	13.83	12.59	11.32
	15-30	14.46	13.8	12.34	14.24	13.15	12.74	13.68	12.13	11.13
	30-45	13.59	13.2	11.9	13.37	12.76	12.23	12.87	12.02	10.54
	45-60	13	12.58	11.26	12.75	11.91	11.75	12.22	10.95	10.45
I_4L_{60}	0-15	14.24	13.85	12.0	13.85	12.94	12.65	13.32	12.31	11.07
	15-30	13.89	12.98	12.02	13.67	12.81	12.02	13.11	11.79	10.91
	30-45	13.23	12.72	11.24	13.01	12.32	11.9	12.51	11.58	10.24
	45-60	12.76	12.31	10.99	12.45	11.81	11.15	11.98	10.85	10.02

The Impact of Lateral Spacing and Irrigation Frequency on Soil Water Dynamics

Analysis of spatial and temporal movement of moisture was done by plotting contour maps according to moisture content data taken at 30, 60 and 90 days after transplanting as indicated in Table 5. Depth from soil surface was taken on y-axis (downward) and radial distance from dripper was taken on x-axis. Wetting patterns were investigated as a function of depth from the soil surface as well as radial distance from the dripper or plant. Figures from 5 to 12 depicts the wetting pattern of 30, 60 and 90 days after transplanting under various irrigation frequencies and lateral spacing as mentioned by I_1L_{45}, I_2L_{45}, I_3L_{45}, I_4L_{45}, I_1L_{60}, I_2L_{60}, I_3L_{60} and I_4L_{60} treatments.

Moisture Variation With Respect to Radial Distance from Dripper and Vertical Distance from Soil Surface

Under 45 cm lateral spacing and different irrigation frequencies, observed average moisture content at radial distance of 0 cm from dripper (*i.e.* below dripper or near plant) was higher as compared to 11.25 cm and at 11.25 cm, it is higher than at 22.5 cm. Moisture content distribution with respect to depth, it was observed that as the depth (*i.e.* 0 to 60 cm) from soil surface increases the moisture content decreases. Similarly, under 60 cm lateral spacing and different irrigation frequencies, observed average moisture content at radial distance of 0 cm from dripper (*i.e.* below dripper or near plant) was more as compared to 15 cm and at 15 cm, it is higher than at 30 cm. Moisture content distribution with respect to depth was similar as in case of 45 cm lateral spacing. In all the treatments, the moisture content trended in the same manner.

Moisture Distribution with Respect to Different DAT

At the upper layer, the observed moisture content was more than the respective lower layer and it gets decrease with respect to depth from soil surface. With crop growth, minute depletion in moisture content was observed for corresponding same radial distance and depth. As depicted by Figure 5, for treatment of daily irrigation with 45 cm lateral spacing (i.e. I_1L_{45}), the contour map of 30 DAT shows that the contour of 14.6% moisture content was at 47.5 cm of depth. Contour of same value (14.6%) assented with time and reached to 39.5 cm depth in contour map of 60 DAT and 17 cm depth in contour map of 90 DAT respectively. Drippers buried at 5 cm depth from soil surface in subsurface drip system maintained better soil moisture between 0-15 cm depth. As the crop grown with time, more effective root zone was developed up to 35 cm depth, the applied water which reached in this zone, extracted by the roots and resulted into the less observed moisture content with further increases in depth. Similar result was reported by Anisuzzaman *et al*. (2009) for onion crop on comparing the contour maps of 30, 60, and 90 DAT under different treatments.

Moisture Content in Relation to Irrigation Frequencies with Respect to Depth from Soil Surface

On comparing the contours of moisture content in the root zone under different irrigation frequency, it is observed that the pattern of moisture content varied with irrigation frequency. In 45 cm lateral spacing at 30 DAT in I_1L_{45}, I_2L_{45}, I_3L_{45}, and I_4L_{45} treatments, contours of 14.6% moisture content was recorded at a depth of 47.5, 26, 21 and 16 cm from the soil surface just below the dripper, respectively. In 60 cm lateral spacing at 30 DAT in I_1L_{60}, I_2L_{60}, I_3L_{60}, and I_4L_{60} treatments, contours of 14.0% moisture content was recorded at a depth of 49, 34, 30.5 and 17 cm from the soil surface just below the dripper, respectively. This implies that increase in irrigation interval decreases the moisture content at a particular depth in the root zone.

Moisture Content in Relation to Irrigation Frequencies with Respect to Middle of Two Adjoining Laterals

While comparing moisture content contours at radial distance of 22.5 cm for 60 DAT in 45 cm lateral spacing it was observed that for I_1L_{45}, I_2L_{45}, I_3L_{45}, and I_4L_{45} treatments, moisture content on ground surface was 14.9, 13.7, 13.5 and 12.9%, respectively. Similarly, while comparing moisture content contours at radial distance of 30 cm for 60 DAT in 60 cm lateral spacing it was observed that for I_1L_{60}, I_2L_{60}, I_3L_{60}, and I_4L_{60} treatments, moisture content on ground surface was 13.8, 13.2, 13 and 12.6%, respectively. This implies that at the middle of two adjoining laterals, moisture content on the surface decreases with increasing irrigation frequency. It was also implies that more variation was observed in moisture content on ground surface in case of 45 cm lateral spacing than 60 cm lateral spacing for 60 DAT with respect to irrigation frequency.

Table 6: Depth of water available in the root zone (0-60 cm) at different DAT

Treatments	30 DAT			60 DAT			90 DAT		
	Radial distance (cm)			Radial distance (cm)			Radial distance (cm)		
	0	11.25	22.5	0	11.25	22.5	0	11.25	22.5
I_1L_{45}	14.30	13.81	13.33	14.01	13.52	12.73	13.10	12.17	11.91
I_2L_{45}	13.63	13.09	12.90	13.06	12.55	12.07	12.71	11.98	11.52
I_3L_{45}	13.41	12.83	12.59	12.76	12.36	11.78	12.45	11.55	11.12
I_4L_{45}	13.16	12.56	12.26	12.57	12.03	11.37	12.01	11.18	10.78
	Radial distance (cm)			Radial distance (cm)			Radial distance (cm)		
	0	15	30	0	15	30	0	15	30
I_1L_{60}	13.88	13.22	11.92	13.69	12.90	12.33	12.80	11.95	10.77
I_2L_{60}	13.22	12.95	11.54	13.00	12.33	11.92	12.50	11.45	10.54
I_3L_{60}	12.99	12.58	11.14	12.78	11.92	11.62	12.29	11.14	10.15
I_4L_{60}	12.64	12.12	10.81	12.38	11.65	11.15	11.90	10.87	9.87

Depth of Available Water in the Root Zone (0-60 cm) in Relation to Irrigation Frequencies at Different DAT

Table 6. shows the depth of water available in the root zone (0-60 cm) in 45 and 60 cm lateral spacing at distance 0, 11.25 and 22.5 cm, and 0, 15 and 30 cm distances from the dripper, respectively. Under 45 cm lateral spacing with 0, 11.25 and 22.5 cm distance from dripper, available moisture content in daily irrigation was higher than 4 days irrigation interval by 7.97, 9.05 and 8.03% at 30 DAT, 10.28, 11.02 and 10.68% at 60 DAT and 8.32, 8.13 and 9.49% at 90 DAT, respectively. This implies that in case of 45 cm lateral spacing, the maximum variation of available moisture was observed at 60 DAT. Similarly, under 60 cm lateral spacing with 0, 15 and 30 cm distance from dripper, available moisture content in daily irrigation was higher than 4 days irrigation interval by 8.93, 8.32 and 9.31% at 30 DAT, 9.57, 9.70 and 9.57% at 60 DAT and 7.03, 9.04 and 8.36 at 90 DAT, respectively. This also implies that in case of 60 cm lateral spacing, the maximum variation of available moisture was observed at 60 DAT.

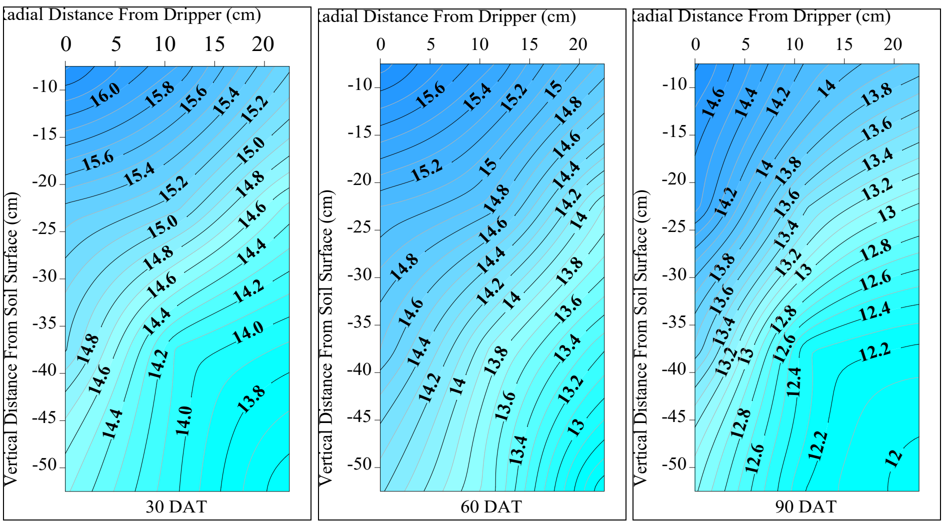

Fig 4: Spatial and temporal movement of moisture content in I_1L_{45}

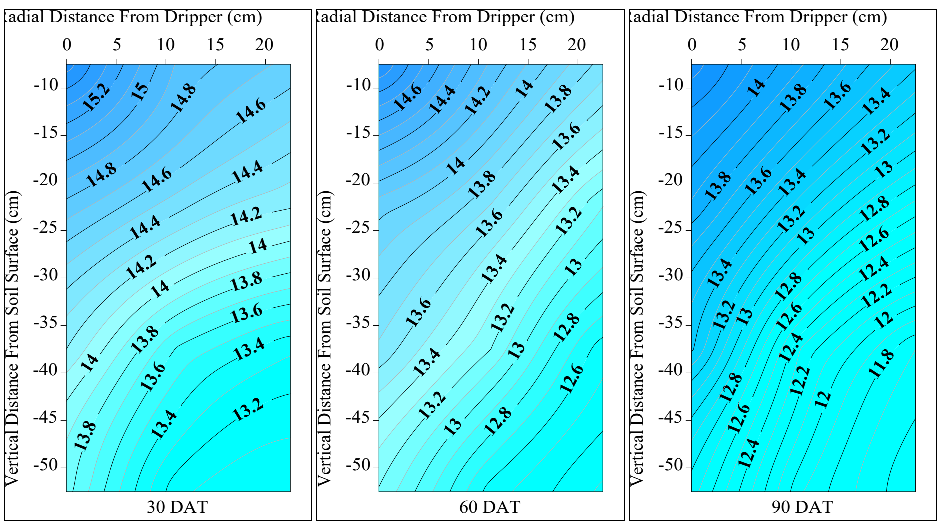

Fig 5: Spatial and temporal movement of moisture content in I_2L_{45}

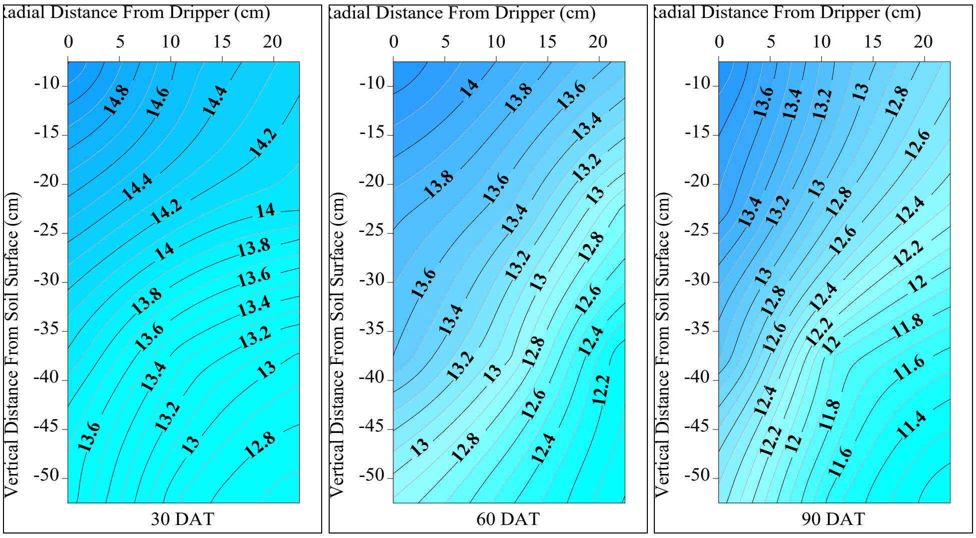

Fig 6: Spatial and temporal movement of moisture content in I_3L_{45}

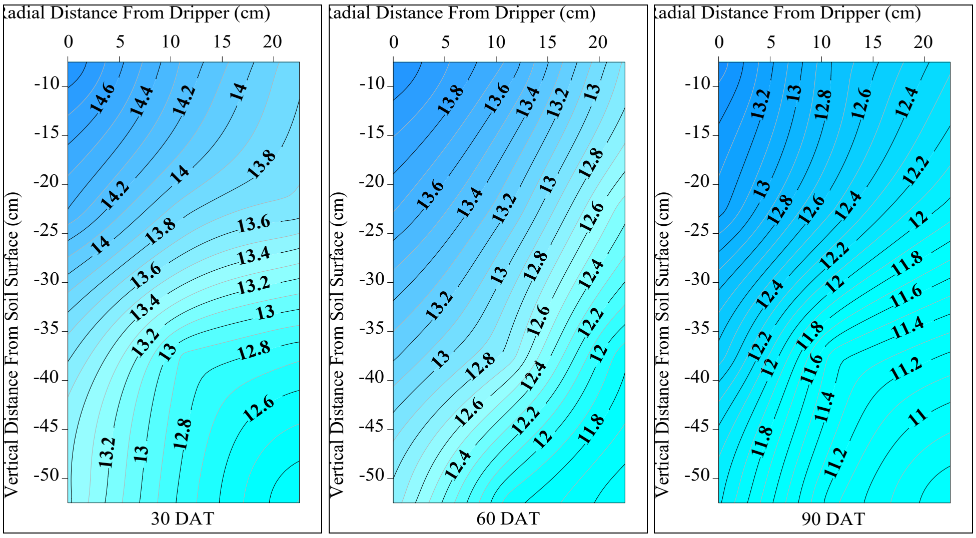

Fig 7: Spatial and temporal movement of moisture content in I_4L_{45}

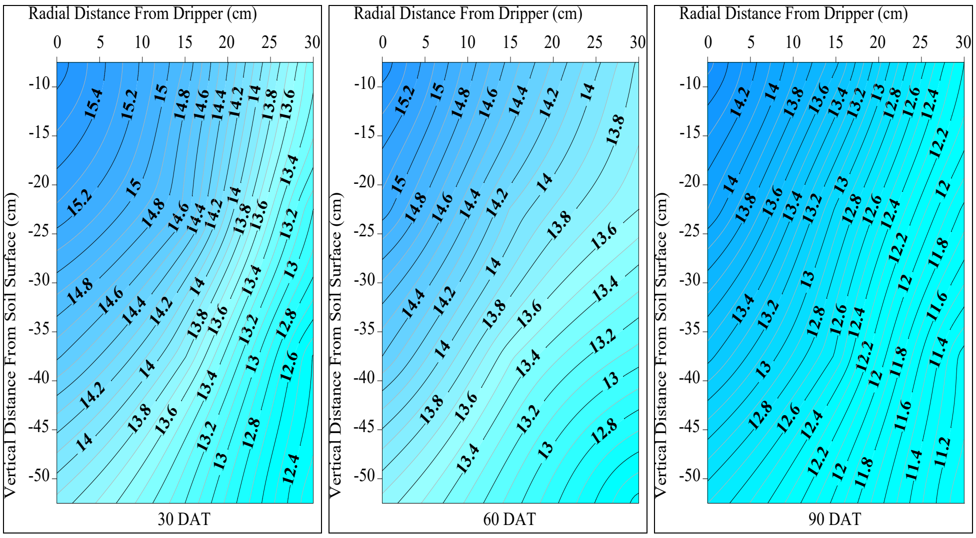

Fig 8: Spatial and temporal movement of moisture content in I_1L_{60}

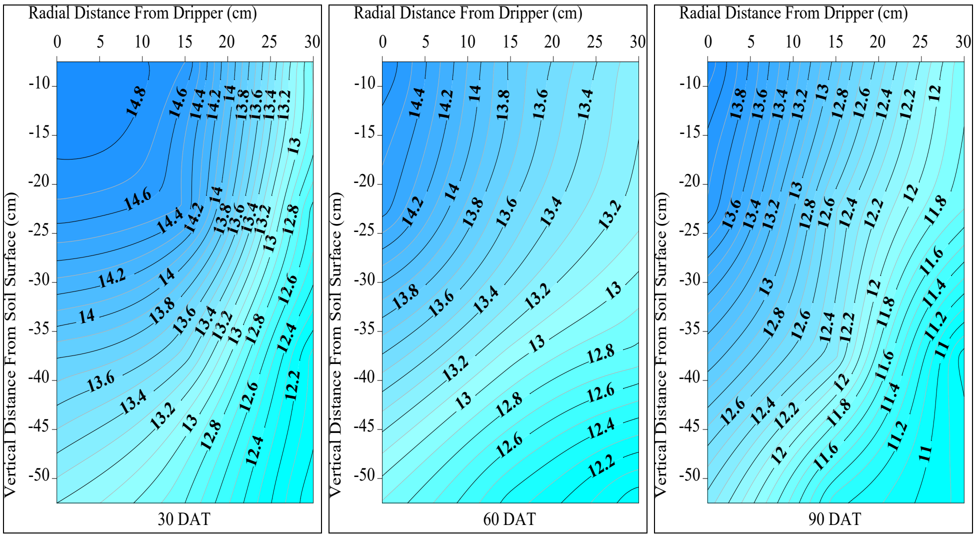

Fig 9: Spatial and temporal movement of moisture content in I_2L_{60}

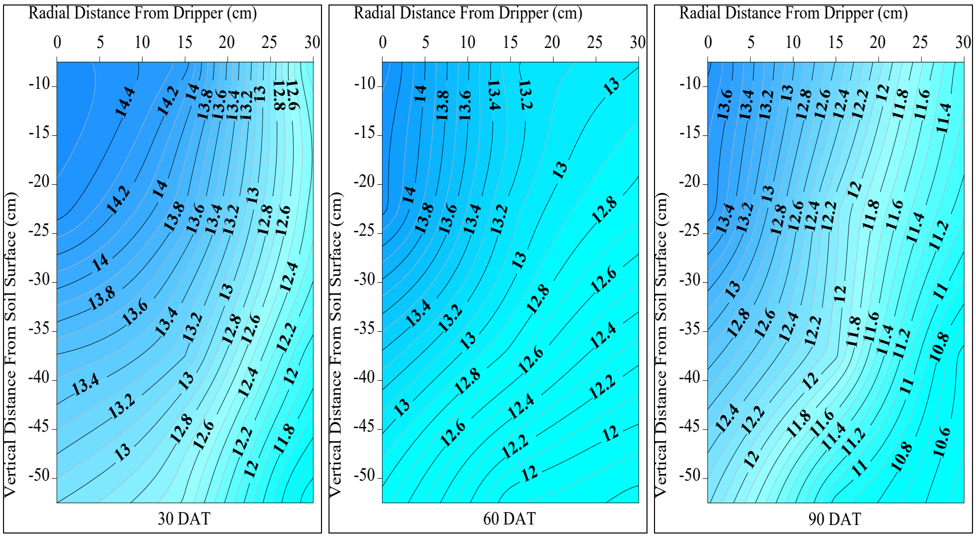

Fig 10: Spatial and temporal movement of moisture content in I_3L_{60}

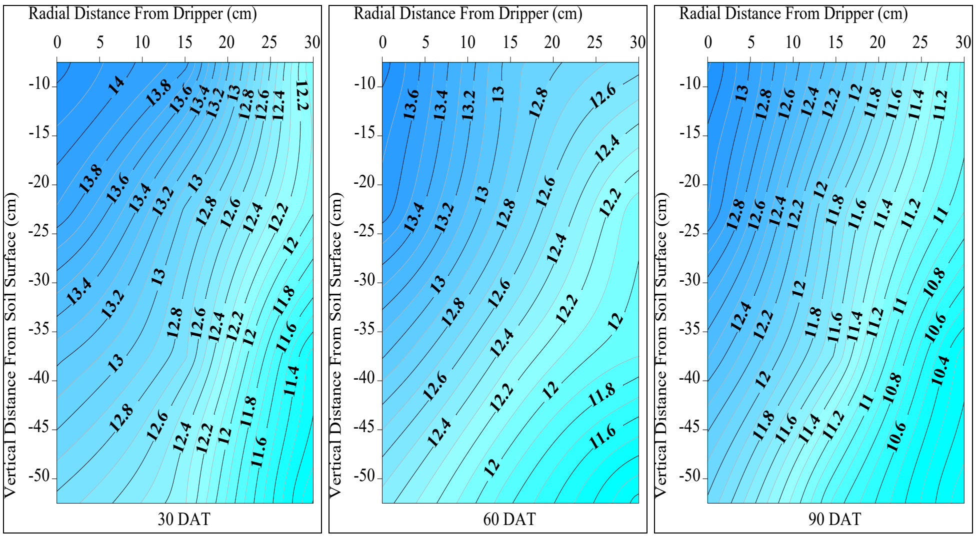

Fig 11: Spatial and temporal movement of moisture content in I_4L_{60}

Available Moisture Content Analysis According to Different Irrigation Frequencies

In daily irrigation, the water availability to the plants was more as compared to two, three and four day irrigation intervals at all the respective radial distances even the total quantity of water applied in all treatments was equal (Table 6). For I_1, I_2, I_3 and I_4 treatments, the amount of water applied was calculated on the basis of previous one day, two days, three days and four days pan evaporation, respectively. In case of moisture determination the soil samples were taken before the irrigation, hence in high irrigation frequency treatment more moisture was observed and hence it leaves less time for soil aerations.

Available Moisture Content in the Root Zone (0-60 cm) at Middle of Two Adjoining Laterals

Available moisture in the root zone (0-60 cm) at 60 DAT under different irrigation frequency and the middle of two adjoining laterals, means at a distance of 22.5 cm from the dripper, was 12.73, 12.07, 11.78, and 11.37 cm and at a distance of 30.0 cm from the dripper, it was 12.33, 11.92, 11.62 and 11.15 cm, respectively. It implies that the moisture content at the middle of 45 cm lateral spacing was higher by 3.14, 1.24, 1.36 and 1.93% than at middle of 60 cm lateral spacing for daily, two, three and four day interval irrigation, which may also play an important role in yield reduction under higher lateral spacing (60 cm).

Variation in Plant Height with Respect to Different Irrigation Frequency and Lateral Spacing

Table 7 (a, b) displays the influence of lateral spacing and irrigation frequency on average plant height during the study year 2020 and 2021. From period of development stage to mid season stage (*i.e.*, 30 to 60 DAT) the crop grown more rapidly than period of mid season to maturity stage (*i.e.*, 60 to 90 DAT). In year 2020, at 30, 60 and 90 DAT, the plant height was impacted significantly by irrigation frequency but does not impacted by lateral spacing as well as interaction between lateral spacing and irrigation frequencies. In year 2021 at 60 DAT, average plant height was impacted significantly by irrigation frequency as well as interaction between lateral spacing and irrigation frequencies but not impacted by lateral spacing.

Table 7 (a): Average plant height (cm) at 30, 60 and 90 DAT in the year 2020

Plant height at 30 DAT					
Lateral spacing	**Irrigation frequency**				
	I_1	**I_2**	**I_3**	**I_4**	**Mean**
L_{45}	39.73	40.13	38.39	38.67	39.23
L_{60}	38.45	40.2	38.17	38.37	38.8
Mean	39.09	40.17	38.28	38.52	
Factor	L	I	I at same level of L		L at same level of I
C.D. (5%)	NS	1.371	NS		NS
Plant height at 60 DAT					
L_{45}	51.55	53.09	51.6	51.3	51.89
L_{60}	51.73	51.98	51.41	50.88	51.5
Mean	51.64	52.54	51.5	51.09	
Factor	L	I	I at same level of L		L at same level of I
C.D. (5%)	NS	0.503	NS		NS
Plant height at 90 DAT					
L_{45}	73.42	74.76	72.27	71	72.86
L_{60}	73.25	74	71.72	70.91	72.47
Mean	73.33	74.38	72	70.95	
Factor	L	I	I at same level of L		L at same level of I
C.D. (5%)	NS	0.39	NS		NS

Table 7 (b): Average plant height (cm) at 30, 60 and 90 DAT in the year 2021

Plant height at 30 DAT					
Lateral spacing	**Irrigation frequency**				
	I_1	**I_2**	**I_3**	**I_4**	**Mean**
L_{45}	42.08	42.48	40.74	41.02	41.58
L_{60}	40.80	42.55	40.52	40.72	41.15
Mean	41.44	42.52	40.63	40.87	
Factor	L	I	I at same level of L		L at same level of I
C.D. (5%)	NS	0.78	NS		NS
Plant height at 60 DAT					
L_{45}	53.86	55.8	53.74	53.54	54.235
L_{60}	54	54.5	53.72	53.327	53.887
Mean	53.93	55.15	53.73	53.433	
Factor	L	I	I at same level of L		L at same level of I
C.D. (5%)	NS	0.213	0.409		0.43
Plant height at 90 DAT					
L_{45}	74.95	76.29	73.81	72.53	74.4
L_{60}	74.78	75.53	73.25	72.45	74
Mean	74.87	75.91	73.53	72.49	
Factor	L	I	I at same level of L		L at same level of I
C.D. (5%)	NS	0.39	NS		NS

During 2020 year of at 90 DAT in 45 cm lateral spacing, plant height at two days irrigation interval was higher by 1.41, 3.20 and 4.61% than daily, three and four days irrigation interval. Similar results were reported by Satpute *et al.* (2013). During 2021 year, at 90 DAT in 45 cm lateral spacing, plant height at two days irrigation interval was higher by 1.37, 3.13 and 4.50% than daily, three and four days irrigation interval, respectively. At 90 DAT, maximum and minimum plant height was recorded in I_2L_{45} and I_4L_{60} treatments during both years, respectively (Figure 12 a, b). While comparing plant height in both lateral spacing, 45 cm lateral spacing shows higher plant height during both years in their respective irrigation frequencies. Similar result was reported by Kunapara *et al.* (2016) and Chen *et al.* (2015).

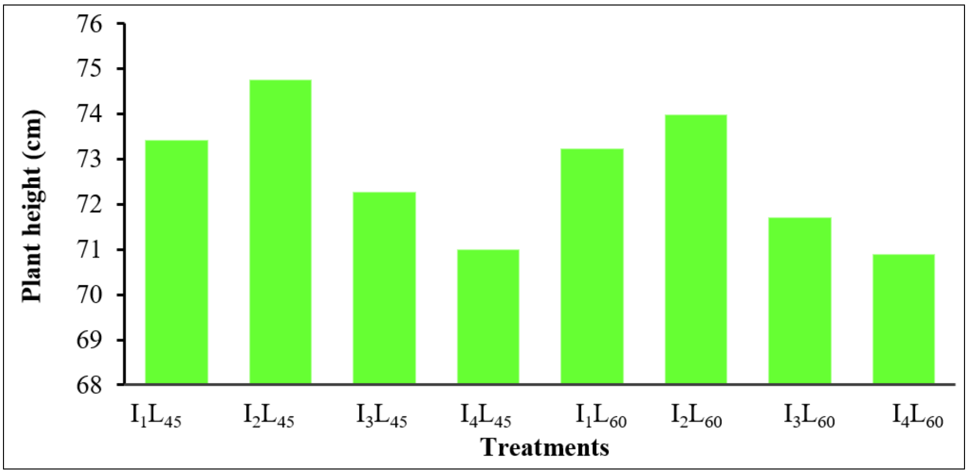

Fig 12 (a): Plant height of onion of different treatments at 90 DAT in 2020

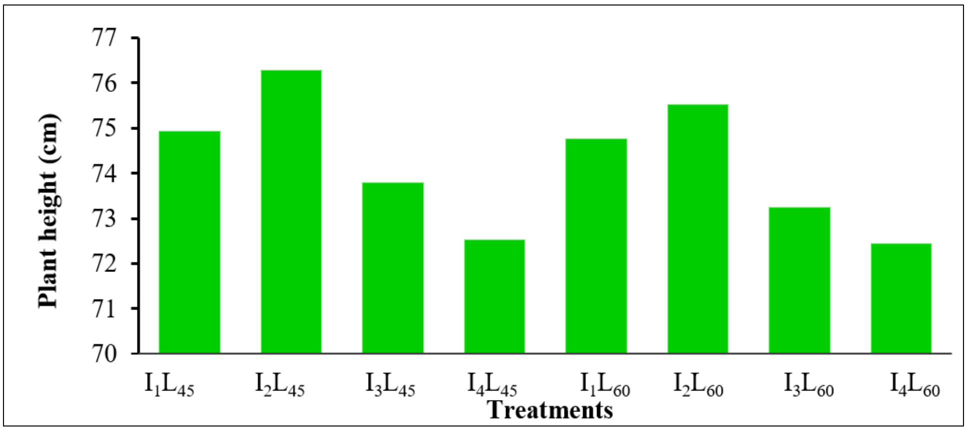

Fig 12 (b): Plant height of onion of different treatments at 90 DAT in 2021

Conclusion

At the middle of 45 cm and 60 cm lateral spacing with daily irrigation, available moisture in the root zone (0-60 cm) was 12.73 cm and 12.33 cm, respectively, which was higher by 3.14% in 45 cm lateral spacing than 60 cm. Average highest (75.53 cm) and lowest (71.68 cm) plant height of two seasons was recorded in I_2L_{45} and I_4L_{60} treatments at 90 DAT.

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