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Research paper

Assessment of yield and water productivity of subsurface drip irrigated onion under varying lateral spacing and irrigation water quality, and in comparison with surface drip irrigation method

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Freshwater scarcity in arid and semi-arid regions has increased reliance on poor-quality irrigation water. Conjunctive use of saline water with freshwater is an effective long-term strategy to deal with water scarcity in such regions while maximizing irrigation water use efficiency (IWUE) and yield. Management of canal fresh water and saline water under subsurface drip irrigation (SSD) was studied to maximise onion yield and IWUE by selecting the optimal irrigation treatment (IT) and lateral spacing (LS) in the semi-arid region of northern India. Treatments comprised of 4 water qualities (canal fresh water – C; conjunctive use of canal fresh water and saline water in 1:1 ratio – C_1S_1; in 1:2 ratio – C_1S_2; and saline water – S) and 2 LS (45 and 60 cm) under SSD methods. The effects on soil water–salt dynamics, growth parameters, IWUE and yield of onion grown using SSD were evaluated under different treatments in the years 2018 and 2019. Additionally, yield and IWUE under surface drip (SD) and SSD were compared. In general, soil moisture decreased vertically downward and radially outward, whereas soil salinity increased and decreased with increase in radial distance and soil depth, respectively. Significant effects of irrigation treatments were observed on plant growth parameters, yield and IWUE under both LS. The highest yield (36.69 t·ha^{-1}) and IWUE (16.17 kg·m^{-3}) were recorded at 45 cm LS under Treatment C; the lowest yield (27.01 t·ha^{-1}) and IWUE (10.96 kg·ha^{-1}·m^{-3}) were observed under Treatment S. Differences in results between Treatment C and C_1S_1 were non-significant, suggesting that C_1S_1 can be adopted for onion cultivation in sandy loam soils without compromising yield and IWUE. No significant differences were observed between SD and SSD for yield or yield-related parameters during the experimental period. The results highlight the importance of IT and LS for maximum onion production under SSD.

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INTRODUCTION

Onion (*Allium cepa* L.), belonging to the Amaryllidaceae family, is one of the most important commercial vegetable cash crops, after potato and tomato, and is cultivated worldwide. Globally, it is grown over 5.48 million hectares, with a total production of approx. 10.4554 million tonnes across 140 countries. Area-wise, India ranks first in production (1.434 million ha), but in terms of productivity, the Republic of Korea is in first position (79.62 t·ha^{-1}). India ranked 83rd in productivity, with 18.64 t·ha^{-1} in 2020–21, while world average productivity was 23.06 t·ha^{-1} (FAOSTAT, 2021). In Haryana, a state in northern India, the area, production and productivity of onion are 0.2993 million ha, 0.7015 million tonnes and 23.44 t·ha^{-1}, respectively (NHRDF, 2018). The state ranks third in terms of per capita onion consumption per day (i.e. 51.34 g), while the national average is 45.63 grams.

In tropical and subtropical regions, including India, short-day onion cultivars are widely cultivated because they only require 10–12 h day lengths for bulb initiation. However, their productivity is often constrained by high sensitivity to soil salinity. Onion has excellent nutritional properties with 1.2 g of protein and 11 g of fat and carbohydrates per 100 g onion (Bhaskar et al., 2018). In India, the varieties grown most frequently are red and white. Onion is a sparsely and shallow rooted (up to 30.0 cm) salt-sensitive crop, having an electrical conductivity (EC) threshold of 1.2 dS·m^{-1} (Mass and Hofman, 1977). Onion requires well-drained, fertile soil, with a pH of 6.5–8.0. The physiological stress in plants due to salinity can substantially affect plant growth (Joshi and Sawant, 2012; Allakhverdiev et al., 2000). Salinity reduces plant productivity due to reduced growth during the osmotic stress phase and senescence of leaves during the toxicity phase, when excessive salt accumulates in transpiring leaves (Munns, 2002). High salinity causes changes in the osmotic pressure of the soil. This diminishes growth rate, leaf colour, root/shoot ratio, maturity rate and germination rates. Due to continuously declining availability of good quality water resources worldwide, saline water must be utilized appropriately, without significantly decreasing the yield of crops or causing a negative impact on the environment. Thus, there is an urgent need for sustainable use of saline water using optimal management practices (Crescimanno, 2002).

In the state of Haryana, about 62% of the total area has poor quality water, which increases soil salinity levels leading to poor soil health and crop productivity (Ankush et al., 2021). In the west-central part of Haryana (Hisar District), groundwater quality ranges from fresh to highly saline, and availability of good-quality water is a major constraint. To overcome the problem of water scarcity, many countries are using poor-quality water for irrigation purposes. The most effective long-term strategy to deal with the problem of water scarcity is safe use of poor-quality water, i.e., conjunctive

use of saline groundwater with fresh water (Datta and Jong, 2002; Crescimanno et al., 2002; Kaur et al., 2007; Yadav et al., 2004), combined with more efficient on-farm irrigation practices (e.g. drip irrigation) to enhance the productivity of existing water resources, particularly in regions underlain with poor quality groundwater.

Various studies have been carried out worldwide on the effect of drip lateral spacing (LS), irrigation water quality (salinity levels) and conjunctive use on soil water–salt dynamics, crop growth parameters, yield and irrigation water use efficiency (IWUE), for different vegetable crops, such as potato (Patell et al., 2001; Chauhan et al., 2007; Sekhon et al., 2020; Garg et al., 2022; Jha et al., 2017), tomato (Malash et al., 2011; Li et al., 2023), onion (Chauhan et al., 2007; Dudhat and Asodaria, 2011; Chauhan, 2015; Shoaib et al., 2018; Yohannes et al., 2020; Regessa et al., 2022; Sanwal et al., 2022; Venancio et al., 2022, Kumar et al., 2024), okra (Kumar et al., 2023), broccoli (Singh et al., 2024), cabbage (Kim et al., 2016) and radish (Wan and Kang, 2006). Conjunctive use strategies, i.e., blending and cyclic modes, have been successfully implemented in saline water areas. In the blending method, crops are irrigated by mixing fresh water with saline water, whereas alternate irrigation with saline and fresh water is provided in the cyclic mode. Yohannes et al. (2020) found non-significant differences in onion yield between canal-only, 1 canal and 1 seepage, 2 canal and 1 seepage and seepage-only treatments. However, under the seepage treatment, onion yield was significantly reduced compared to other treatments in the clay soil of the semi-arid area of northern Ethiopia. Garg et al. (2022) found a reduction in potato yield by 54.2% and 29.0% by applying saline groundwater (EC of 3.65 $dS{\cdot}m^{-1}$) and blended water (canal and ground water, EC of 2.0 $dS{\cdot}m^{-1}$), respectively, as compared with canal water irrigation (EC of 0.35 $dS{\cdot}m^{-1}$).

The soil moisture content in narrow LS was found to be higher than for wider LS under surface drip (SD) and subsurface drip (SSD) irrigation in sandy, sandy-loam and clay-loam soil areas in India (Badr and Abuarab, 2013; Bajpai and Kaushal, 2020; Chouhan et al., 2014; Kumar et al., 2023; Singh et al., 2024). Further, higher crop yields can be obtained using close LS than wide LS (Kumar et al., 2023; Singh et al., 2024; Zhou et al., 2018). Dudhat and Asodaria (2011) found maximum onion yield under daily irrigation using a drip irrigation system. The highest potato IWUE and yield were attained with daily irrigation frequency in a silt-loam soil of China (Kang et al., 2004). Kumar et al. (2023) recorded the highest okra yield and IWUE at 45 cm LS when irrigated daily in a sandy-loam soil of Haryana, India. Bagli et al. (2012) observed significantly higher onion yield at irrigation intervals of 1 and 2 days using a drip irrigation system in deep black soil of India. Singh et al. (2024) concluded that daily irrigation at 45 cm LS produces higher IWUE and yield of broccoli in a sandy loam in India. Chauhan (2015) found the highest onion yield under canal freshwater (24.3 $t{\cdot}ha^{-1}$) followed by 2 $dS{\cdot}m^{-1}$ of water (23.4 $t{\cdot}ha^{-1}$); lowest yield was under 8 $dS{\cdot}m^{-1}$ of water (8.09 $t{\cdot}ha^{-1}$). Increasing salinity negatively impacts onion physiology, leading to a reduction in bulb yield and IWUE; maximum reduction was observed at 2.8 $dS{\cdot}m^{-1}$ among 0.65 $dS{\cdot}m^{-1}$, 1.7 $dS{\cdot}m^{-1}$ and 2.8 $dS{\cdot}m^{-1}$, in a semiarid region of Brazil (Venancio et al., 2022).

The effectiveness of drip irrigation systems to grow salt-sensitive crops (i.e. carrot, radish, onion, potato, cabbage) using saline water is due to preservation of optimum moisture in the root zone, which results in a relatively lower salt effect on plant growth as compared to conditions where plants are subjected to both moisture and salinity stress (Jha, 2016). But, it may result in accumulation of salt at the wetting front. In case of strip wetting (where several plant rows are irrigated with one lateral), salt deposited in the wetting front can affect the growth of marginal plant rows. In such situations, conjunctive use of fresh and saline water may be adopted for better crop yield and IWUE with minimum salinity built up in the crop root zone (Hassanli and Ebrahimian, 2016). Therefore, it is essential to investigate the effects of LS and saline irrigation water on soil water–salt dynamics, yield and efficiency of salt-sensitive crops like onion, because drip lateral placement and salinity levels affect the movement of soil moisture, which ultimately affects crop performance. The effect of LS, salinity levels of irrigation water and conjunctive use of good and poor quality water through drip irrigation on different crops and soil types has been studied previously by various researchers worldwide. However, the performance in terms of soil water–salt dynamics, crop parameters and IWUE of onion grown under SSD at different LS and salinity levels in the semiarid region of Haryana (Hisar District), where availability of good quality water is a major constraint and most of the population depend on agriculture, has not been reported in the literature to date. To solve the saline water problem in a semi-arid region while maximizing onion production and IWUE, it is necessary to choose the best irrigation treatment (IT) and LS under drip irrigation.

Therefore, various combinations of conjunctive use of canal fresh water and saline water were studied using SSD irrigation, with the aim to identify suitable strategies for onion growers of the semi-arid region to achieve maximum yield with limited water resources, by selecting the best IT and LS, with the following specific objectives: (i) to study the movement of soil water–salt dynamics under different LS and IT treatments applied using SSD irrigation system, (ii) to assess the effect of different treatments on onion growth parameters, yield and IWUE, and (iii) to compare SD with SSD in terms of yield and IWUE. The results of this study are expected to be beneficial for farmers exploring the conjunctive use of saline ground water and canal fresh water for onion production under drip irrigation in arid and semi-arid regions, from both an agricultural and environmental sustainability perspective.

MATERIALS AND METHODS

Study area

Micro-plots of 2 m × 2 m in a field at Soil and Water Engineering, Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar, situated in the west-central part of Haryana (India), were selected to conduct the experiment. The field is located at 29° 08' 36" N and 75° 42' 15" E at an altitude of 215.2 meters above sea level (Fig. 1). At the study site, the maximum temperature in hot summers is 45°C or more and minimum temperature in cold winters is below 1°C (Singh et al., 2010). The study area falls in the semi-arid region, which receives approximately 80% of its total rainfall (459 mm/year) in the monsoon season (Darshana and Pandey, 2012). The different weather parameters observed during the study period, i.e., from January 2018 to May 2018, and from January 2019 to May 2019, are shown in Table 1. The experimental site is susceptible to shallow and saline groundwater levels. Therefore, the present study was conducted in raised micro-plots, specifically constructed with bricks with an open bottom, filled with sandy loam soil (sand = 79.15%, silt = 5.70%, clay =15.15%). The bulk density and infiltration rate of soil are 1.55 $g{\cdot}cm^{-3}$ and 2.55 $cm{\cdot}h^{-1}$ (Table 2).

Experimental layout

The field experiment was carried out using a 3-factor split-plot design during the years of 2018 and 2019 (Table 3). Each treatment had 3 replicates. The treatments included 2 LS (45 cm and 60 cm) and 4 irrigation water qualities (canal fresh water, C; conjunctive use of canal fresh water and saline water in 1:1 ratio, C_1S_1; conjunctive use in 1:2 ratio, C_1S_2; and saline water, S).

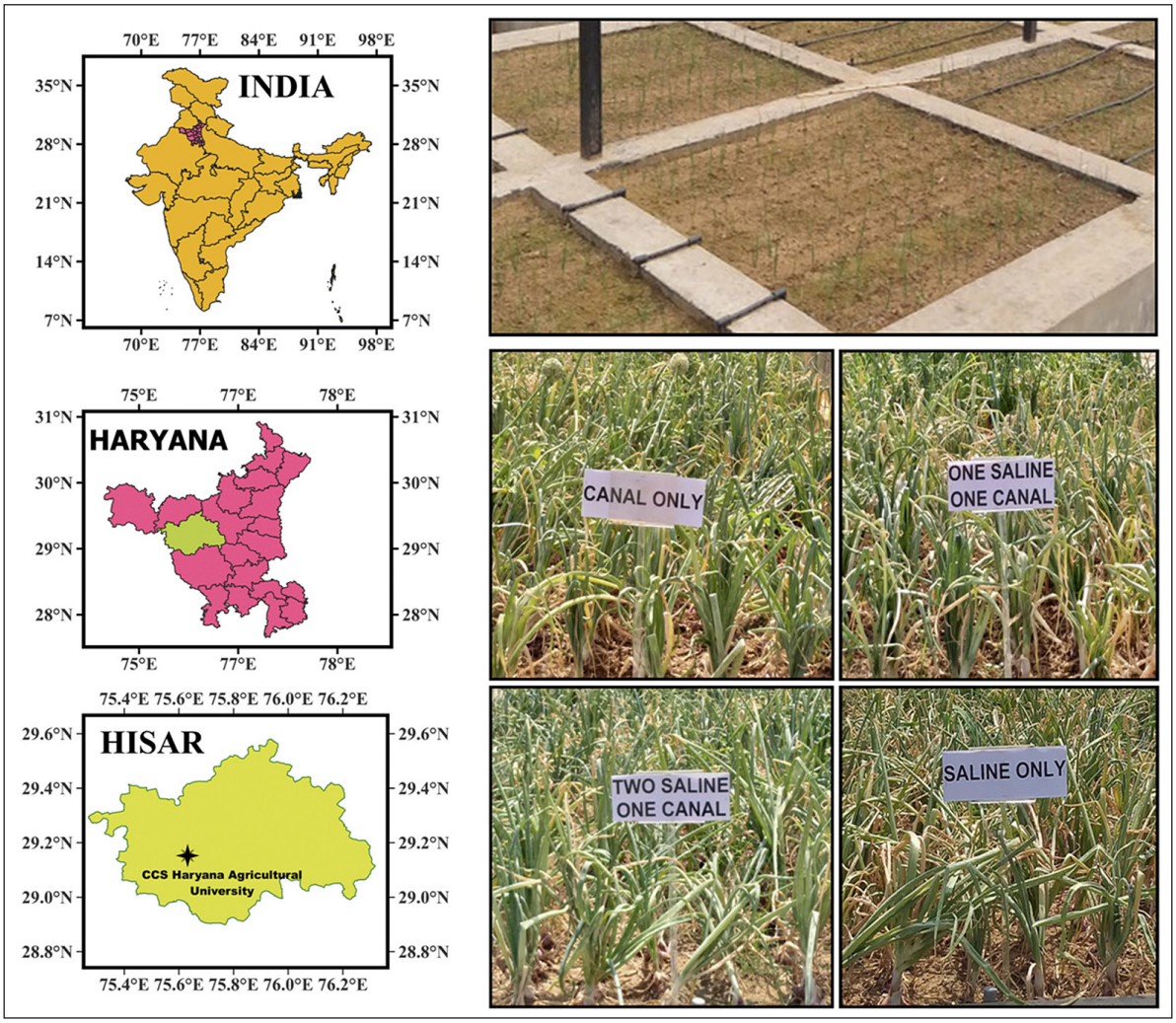

Figure 1. Location map of study area

Table 1. Meteorological parameters and volume of water applied during the study periods

Meteorological variables	Season	Month			
		January	February	March	April
Maximum air temperature (°C)	2018	21.0	23.9	30.7	36.6
	2019	19.3	20.1	26.3	36.6
Minimum air temperature (°C)	2018	4.9	7.3	12.3	19.5
	2019	5.1	7.7	10.2	18.5
Morning relative humidity (%)	2018	95	92	81	60.5
	2019	94	93	87	70
Evening relative humidity (%)	2018	55	56	37	33
	2019	59	59	42	28
Wind speed ($km \cdot h^{-1}$)	2018	2.5	2.3	2.8	5.6
	2019	2.6	4.1	4.0	5.0
Sunshine hours (h)	2018	5.9	6.5	7.0	7.3
	2019	4.6	4.7	6.9	7.7
Total rainfall (mm)	2018	10.9	1.2	0	14
	2019	6.5	8.8	6	15.5
Pan evaporation (mm)	2018	34.4	56.8	113	192.2
	2019	27.3	45.3	92	194.3
Volume of water applied per month per plot (L)	2018	93.14	106	299	356.69
	2019	72.92	73.64	223.07	361.44
Total volume of water applied per season per plot (mm)/(L)	2018	213.71 mm (854.83 L)			
	2019	182.76 mm (731.07 L)			

Table 2. Physical and chemical properties of soil at experimental site

Parameters/properties	Soil depth (cm)			
	0–15	15–30	30–45	45–60
Sand (%)	79.15	79.15	79.15	79.15
Silt (%)	5.70	5.70	5.70	5.70
Clay (%)	15.15	15.15	15.15	15.15
Texture	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Bulk density ($g \cdot cm^{-3}$)	1.55	1.55	1.56	1.56
pH	7.97	7.85	7.93	7.89
$EC_{1:2}$ ($dS \cdot m^{-1}$)	0.22	0.22	0.21	0.20
N ($kg \cdot ha^{-1}$)	119.7	117.2	110.4	99.8
P ($kg \cdot ha^{-1}$)	15.1	15.5	14.2	12.5
K ($kg \cdot ha^{-1}$)	168.2	153.5	138.3	139.5
Organic carbon (%)	0.29	0.28	0.25	0.24
Basic infiltration rate	2.55 $cm \cdot h^{-1}$			

Table 3. Details of the different treatments used in the present study

Lateral spacing	Irrigation treatment	Abbreviation
45 cm	Canal fresh water	45C
	Conjunctive use of canal and saline water in 1:1 ratio	$45C_1S_1$
	Conjunctive use of canal and saline water in 1:2 ratio	$45C_1S_2$
	Saline water with EC_{iw} ~ 2.5 $dS \cdot m^{-1}$	45S
60 cm	Canal fresh water	60C
	Conjunctive use of canal and saline water in 1:1 ratio	$60C_1S_1$
	Conjunctive use of canal and saline water in 1:2 ratio	$60C_1S_2$
	Saline water with EC_{iw} ~ 2.5 $dS \cdot m^{-1}$	60S

A total of 24 micro-plots (gross area per plot of 4 m^2 and net area per plot of 3.24 m^2) were used for the experiment (Fig. 2). The already installed fully automatic SSD irrigation system with fertigation facility was used. The drip laterals (diameter of 16 mm) were buried at 10 cm under the soil surface, with pressure-compensating in-line drippers spaced 30 cm along the line. The rated discharge of the dripper is 2.4 $L \cdot h^{-1}$ at an operating pressure of 147.1 kPa. Drip laterals were laid at 45 and 60 cm LS in different micro-plots, as per the experimental layout (Fig. 2). Three tanks, each of 2 000 L capacity, were installed at the experimental site, marked as Tank-1, Tank-2 and Tank-3, for preparation and application of irrigation water of required electrical conductivity (EC_{iw}). Tank-1 was filled with natural groundwater from an existing tube well (EC_{iw} ~ 25 $dS \cdot m^{-1}$). Tank-2 was filled with canal fresh water (EC_{iw} ~ 0.25 $dS \cdot m^{-1}$) and Tank-3 was filled with saline water of the required salinity (EC_{iw} ~ 2.5 $dS \cdot m^{-1}$), by mixing water from the other two tanks in the required specific ratio using the following expression:

$$V = \frac{EC_3 - EC_2}{EC_1 - EC_3} \quad \text{provided } EC_1 < EC_3 < EC_2 \qquad (1)$$

where: V is the volume of groundwater of electrical conductivity EC_1, to be added per litre of canal fresh water of electric conductivity EC_2, to obtain water of desired electrical conductivity EC_3. EC_{iw} of Tank-1 and Tank-2 were always calculated prior to mixing of water in Tank-3, to avoid any error in EC_{iw} of the resulting water. Tank-2 and Tank-3 were connected to the drip irrigation system in such a way that water from either tank could be supplied to the desired plots using solenoid valves.

"Hisar Onion 4" variety of onion was selected and seeds were sown in the nursery at a seed rate of 4 to 5 $kg \cdot acre^{-1}$ (10–12.5 $kg \cdot ha^{-1}$), on 3 m x 1 m seed beds, by maintaining a row-to-row distance of 5 cm. Before sowing, to protect the plants from rot, seeds and soil in the nursery beds were treated with Thiram at a rate of 3 $g \cdot kg^{-1}$ seed and 5 $g \cdot m^{-2}$, respectively. After sowing, seeds were covered with compost and light irrigation with a micro-sprinkler was applied every day till germination. Further, Thiram was sprayed, at 2 $g \cdot L^{-1}$ at an interval of 15 days to prevent rotting of plants. The seedlings were ready at 45 days after sowing for transplantation. For the nutritional requirements of onion, farmyard manure (FYM) at 20 $t \cdot acre^{-1}$, 50% nitrogen (at 50 $kg \cdot acre^{-1}$), 100% phosphorus (at 20 $kg \cdot acre^{-1}$) and 100% potash (at 10 $kg \cdot acre^{-1}$), were applied before transplanting of the onion seedlings (following Anonymous, 2017). The remaining 50% of nitrogen was applied in 5 split doses at 14-day intervals through the fertigation unit of the drip irrigation system. The source used for NPK was urea, DAP (diammonium phosphate) and MoP (muriate of potash), respectively. Onion seedlings were transplanted at 15 cm (row-to-row) by 10 cm (plant-to-plant) spacing with plant density of 266 $plants \cdot plot^{-1}$, on 8 January 2018 and 7 January 2019, respectively.

Experimental design

The experimental approach included: (i) assessment of soil moisture and salt distribution horizontally (radial distance) and vertically (depth) from the dripper; (ii) estimation of plant growth parameters (i.e. plant height, polar and equatorial bulb diameters and bulb weight), yield and IWUE for different treatments; (iii) determining the optimal IT and LS to achieve the maximum production and IWUE for onion; and (iv) comparing the yield and IWUE obtained under SD and SSD system under different treatments.

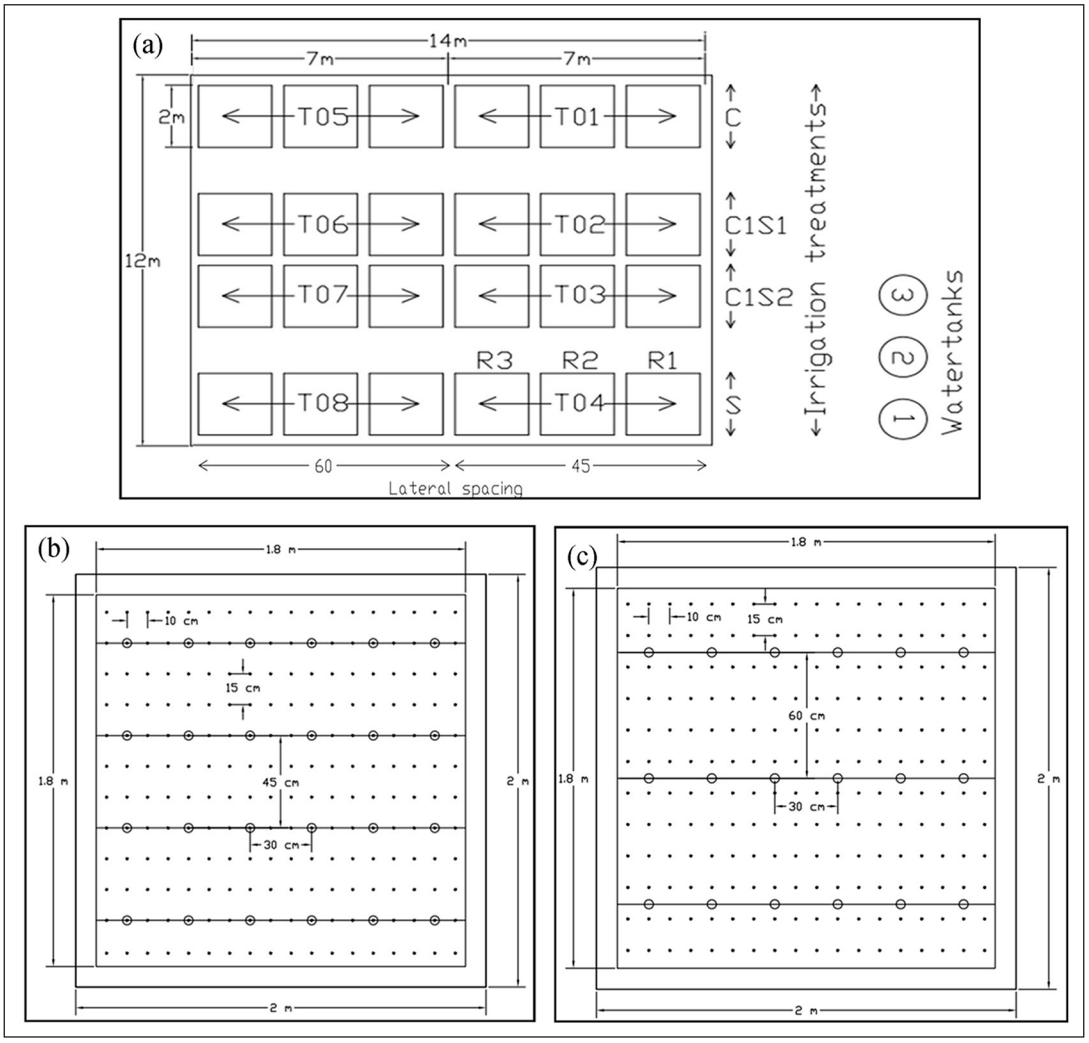

Figure 2. The experimental plot layout (a) and micro-plot layouts for 45 cm (b) and 60 cm (c) lateral spacing

Irrigation scheduling for onion

For proper establishment of the crop in all treatments, the first canal fresh water was applied on the day of transplantation, at sufficient duration to ensure proper moisture distribution. Irrigation was then applied based on 100% ET_C (crop evapotranspiration), which was calculated by multiplying observed cumulative pan evaporation (ET_{pan}), crop coefficient (K_c, Allen et al., 1998; Patil and Tiwari, 2018; Duhan et al., 2021, 2023) and pan coefficient (K_p = 0.7 for US pan evaporation). K_c values for onion during the initial (0–20 days), development (21–50 days), mid-stage (51–85 days), and late stage (86–115 days) were 0.7, 0.7 1.05 and 0.75, respectively. The same amount of water was given in all the treatments because the same K_c values were utilized.

The total volume of irrigation water applied was calculated based on ET_c under 4 different qualities of irrigation water. During the initial stage of crop establishment (20 days), irrigation was applied with an irrigation interval of 2, 3 or 4 days, based on cumulative ET_c values, and after 20 days the crop was irrigated on a daily basis based on the previous day's ET_c. The volume (V, L·day^{-1}·emitter^{-1}) was determined using Eq. 2 (Kaulage 2017).

$$V = \frac{ET_c \times L_s \times E_s \times W_a}{\eta} \quad (2)$$

where: L_s is LS (45 or 60 cm), E_s is the emitter spacing (30 cm), W_a is the wetted area factor and η is the system emission uniformity (0.9).

Then, irrigation time, which is the ratio of the volume of water applied to the emitter discharge rate (L·h^{-1}) was determined. Irrigation was stopped 15 days before harvesting. W_a was taken as 0.8 up to 30 days after transplanting (DAT) and 1.0 after 30 DAT (Mane and Magar, 2008).

Data collection

Physico-chemical properties of soil

Before transplanting the seedlings to the plots, soil samples were collected for the determination of various physico-chemical properties (i.e. soil texture, bulk density, infiltration rate, nitrogen, phosphorus, potassium, organic carbon, pH and electrical conductivity) at 4 depths (0–15, 15–30, 30–45 and 45–60 cm) in the vertical plane from each micro-plot. Table 4 shows the standard methods adopted for the determination of soil properties. Electrical conductivity (EC), measured by soluble bridge conductivity meter in 1:2 soil and water suspension (Richards, 1954), was converted into electrical conductivity of saturated soil extract (EC_e) by multiplying the observed EC values by 5.6 (Kumar, 1994). Infiltration rate was determined using a double-ring infiltrometer. Soil samples were collected using a tube auger (James and Wells, 1990) at 30, 60 and 90 DAT to detect the spatio-temporal distribution of soil moisture and salinity at 0–15, 15–30, 30–45 and 45–60 cm depths below the soil surface, in vertical planes located at a radial distance of 0, 11.25 and 22.50 cm and 0, 15 and 30 cm from the dripper, perpendicular to lateral, at 45 and 60 cm LS, respectively. The reason for selecting 3 radial distances (0, 11.25 and 22.5 cm or 0, 15 and 30 cm) was to capture the moisture and salinity gradient from near the dripper to the midpoint (22.5 cm or 30 cm) of 2 laterals and to assess wetting

Table 4. Standard method used for determining various physico-chemical properties of soil

Soil property	Method applied	Reference
Soil texture	International pipette 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)
Moisture content	Gravimetric method	Michael (2008), Reynolds, 1970
Nitrogen	Alkaline potassium permanganate method	Subbiah and Asija (1956)
Phosphorus	Olsen's method	Olsen et al. (1954)
Potassium	Flame photometric method	Jackson (1958)
Organic carbon	Wet digestion method	Walkley (1935)

pattern interference between adjacent drippers. The intermediate point (11.25 or 15 cm) helps in understanding the transition zone of wetting and salt movement.

Depth of stored water in the root zone (d_w, cm) was also estimated (Michael, 2008) using Eq.3.

$$d_w = \frac{\rho_s \times \text{moisturecontent} \times d_s}{\rho_w \times 100} \quad (3)$$

where: d_s represents the depth of soil (cm), ρ_s and ρ_w are the densities of soil (g·cm^{-3}) and water (g·cm^{-3}).

Measurement of plant growth parameters

At the end of the experimental period (at 90 DAT), a meter scale was used for the measurement of plant height from ground level to the tip of the longest leaf of a plant from each plot. The polar and equatorial bulb diameters were determined using digital Vernier calliper by measuring vertically and horizontally, respectively. Average bulb weight (g) was calculated from randomly selected plants by cutting leaves approximately 2–2.5 cm above the neck from each plot using an electronic weighing machine. Total bulb yield per plot (kg·ha^{-1}) was also determined from the whole plot. IWUE (kg·m^{-3}), which is the ratio of bulb yield per hectare (kg·ha^{-1}) and the amount of irrigation water applied for its production per hectare (m^3·ha^{-1}), was computed under different treatments (Kumar et al., 2023). The data for yield and IWUE under SD method for each treatment are taken from Kumar et al. (2024).

Analysis of results

For the determination of spatio-temporal distribution, contour maps of soil moisture content and salinity were prepared at 45 and 60 cm LS under different DAT by employing SURFER software. Further, Online Programme for Statistical Analysis of Agricultural Research Experiments (OPSTAT) software (Sheoran, 2010) was used to check the statistical significance of results between different treatments using Duncan's multiple range test at 5% significance level (Kumar et al., 2021).

RESULTS AND DISCUSSION

Characteristics of meteorological parameters and water applied in the study area

Table 1 shows meteorological parameters, i.e., maximum temperature (T_{max}), minimum temperature (T_{min}), rainfall, relative humidity (RH, %), sunshine hours, pan evaporation (ET_{pan}), and water applied during the study years of 2018 and 2019. The amount and time of irrigation were estimated according to drip discharge. T_{min} and T_{max} varied from 4.9 to 19.5°C and 19.3 to 36.6°C, respectively. The mean RH (%) ranged from 47 to 77% during the study periods. The maximum and minimum sunshine hours recorded were 4.7 and 7.7 in the month of January and April, respectively. Total rainfall and cumulative pan evaporation of 26.1 and 36.8 mm, and 396.4 and 358.9 mm, occurred during the study period of 2018 and 2019, respectively. Per plot total volume of water applied was 213.71 mm (854.83 L) and 182.76 mm (731.05 L) during the study periods of 2018 and 2019, respectively.

Effect of different treatments on available soil moisture

Table 5 shows the observed depth of stored water (cm) at 45 cm LS under different treatments along vertical (i.e. 0–15, 15–30, 30–45 and 45–60 cm) and horizontal planes (i.e. 0, 11.25 and 22.5 cm from dripper) at 30, 60 and 90 DAT in the year of 2019. In general, stored water decreased vertically downward and radially outward in all the treatments under a given DAT. Irrespective of treatments, the minimum stored water (cm) was found under Treatment C at soil depth of 45–60 cm and maximum under Treatment S at soil depth of 0–15 cm for a given DAT and radial distance. Among the given DAT, the maximum stored water is available at 30 DAT at or near the dripper (0 cm) and at 0–15 cm depth vertically, followed by 60 and 90 DAT irrespective of given soil depths and radial distances. Further, results also depict the maximum stored water under Treatment S as compared to C_1S_2, followed by C_1S_1 and Treatments C for the respective DAT, radial distance and soil depth. The maximum stored water for Treatment S at radial distances of 0, 11.25 and 22.5 cm were observed as 3.81, 3.68, 3.46 cm, respectively, for 30 DAT, at 3.77, 3.65, 3.42 cm, respectively, for 60 DAT, and at 3.74, 3.61, 3.39 cm, respectively, for 90 DAT, at a soil depth of 0–15 cm. This may be due to increased salt concentration, which creates a hindrance for the plants for extraction of moisture from soil irrigated with salty water compared to soil irrigated with canal fresh water. Thus soil moisture content, in soils of higher salt concentration, remains on the higher side, as compared to moisture content in soils with relatively lower salt concentrations in the soil profile. Similar results were also obtained at 60 cm LS (Table 6), for which moisture content was found to be higher at 0 cm radial distance, then at 15 cm and even at 30 cm radial distance. However, by comparing the results for both the laterals, stored depth of soil moisture was found to be higher at 45 cm LS than 60 cm LS, irrespective of radial distances, DAT and irrigation treatments. The results confirmed the findings of Kumar et al. (2023) and Singh et al. (2023), who stated that the highest soil moisture is near the dripper, under closer LS and 30 DAT for different crops grown in sandy loam soil of India.

Table 5. Depth of water stored (cm) at 30, 60 and 90 DAT under 45 cm lateral spacing in year 2019

Treatments	Depth of soil (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
45C	0–15	3.70	3.57	3.36	3.66	3.54	3.32	3.62	3.50	3.29
	15–30	3.61	3.50	3.29	3.58	3.46	3.25	3.54	3.43	3.22
	30–45	3.53	3.42	3.22	3.49	3.39	3.19	3.46	3.36	3.15
	45–60	3.31	3.21	3.02	3.28	3.18	2.99	3.24	3.14	2.97
$45C_1S_1$	0–15	3.72	3.59	3.38	3.68	3.55	3.34	3.65	3.52	3.31
	15–30	3.63	3.51	3.30	3.59	3.48	3.27	3.56	3.44	3.24
	30–45	3.55	3.44	3.23	3.51	3.40	3.20	3.47	3.37	3.17
	45–60	3.32	3.22	3.04	3.29	3.19	3.01	3.26	3.16	2.98
$45C_1S_2$	0–15	3.76	3.63	3.41	3.72	3.59	3.37	3.68	3.55	3.34
	15–30	3.67	3.55	3.34	3.63	3.52	3.30	3.59	3.48	3.27
	30–45	3.58	3.48	3.26	3.54	3.44	3.23	3.51	3.40	3.20
	45–60	3.36	3.26	3.07	3.32	3.22	3.04	3.29	3.19	3.01
45S	0–15	3.81	3.68	3.46	3.77	3.65	3.42	3.74	3.61	3.39
	15–30	3.72	3.60	3.39	3.68	3.57	3.35	3.65	3.53	3.32
	30–45	3.63	3.52	3.31	3.60	3.49	3.28	3.56	3.45	3.25
	45–60	3.41	3.30	3.12	3.37	3.27	3.09	3.34	3.24	3.06

Table 6. Depth of water stored (cm) at 30, 60 and 90 DAT under 60 cm lateral spacing in year 2019

Treatments	Depth of soil (cm)	30 DAT			60 DAT			90 DAT		
		Radial distance (cm)			Radial distance (cm)			Radial distance (cm)		
		0	15	30	0	15	30	0	15	30
60C	0–15	3.73	3.58	3.13	3.69	3.54	3.10	3.65	3.50	3.07
	15–30	3.64	3.48	3.07	3.60	3.44	3.04	3.57	3.41	3.01
	30–45	3.54	3.41	2.99	3.51	3.38	2.95	3.47	3.35	2.93
	45–60	3.32	3.20	2.79	3.28	3.17	2.77	3.25	3.14	2.74
$60C_1S_1$	0–15	3.75	3.59	3.15	3.71	3.55	3.12	3.67	3.52	3.09
	15–30	3.66	3.50	3.08	3.62	3.46	3.05	3.58	3.43	3.02
	30–45	3.56	3.44	3.00	3.52	3.40	2.98	3.49	3.36	2.94
	45–60	3.33	3.22	2.81	3.30	3.19	2.78	3.27	3.15	2.75
$60C_1S_2$	0–15	3.78	3.63	3.18	3.74	3.59	3.15	3.71	3.56	3.12
	15–30	3.70	3.53	3.12	3.66	3.50	3.08	3.63	3.46	3.06
	30–45	3.59	3.46	3.03	3.56	3.43	3.01	3.52	3.40	2.97
	45–60	3.36	3.25	2.83	3.34	3.22	2.81	3.30	3.18	2.78
60S	0–15	3.84	3.69	3.23	3.80	3.64	3.19	3.76	3.60	3.16
	15–30	3.75	3.59	3.16	3.71	3.55	3.13	3.67	3.51	3.10
	30–45	3.65	3.52	3.08	3.62	3.49	3.05	3.58	3.45	3.02
	45–60	3.41	3.30	2.88	3.38	3.26	2.85	3.35	3.23	2.82

Spatio-temporal distribution of soil moisture content (%)

The spatio-temporal distribution of soil moisture, is shown in the form of contour maps in Figs 3 and 4, under different treatments and DAT. Figures depict that with increasing soil depth, soil moisture content decreased under all the radial distances. Further, the decrease in soil moisture content with increase in radial distance was found in all the treatments, irrespective of LS and IT. For a given DAT and soil depth, soil moisture was higher at 45 cm LS (Fig. 3), compared to 60 cm LS (Fig. 4) under the corresponding treatments. This may be due to adequate interference of moisture fronts between adjacent laterals at 45 cm LS, which is due to the smaller mid-point distance between adjacent laterals (i.e. 22.5 cm away from the dripper) as compared to 60 cm LS (i.e., 30 cm away from the dripper). These results are also in agreement with Badr and Abuarab (2013), who reported high moisture distribution efficiency with closer LS. Bajpai and Kaushal (2020) also reported similar results.

On the other hand, all the treatments with 60 cm LS have higher moisture content just below the dripper compared to the corresponding treatments with 45 cm LS for a given DAT and soil depth.

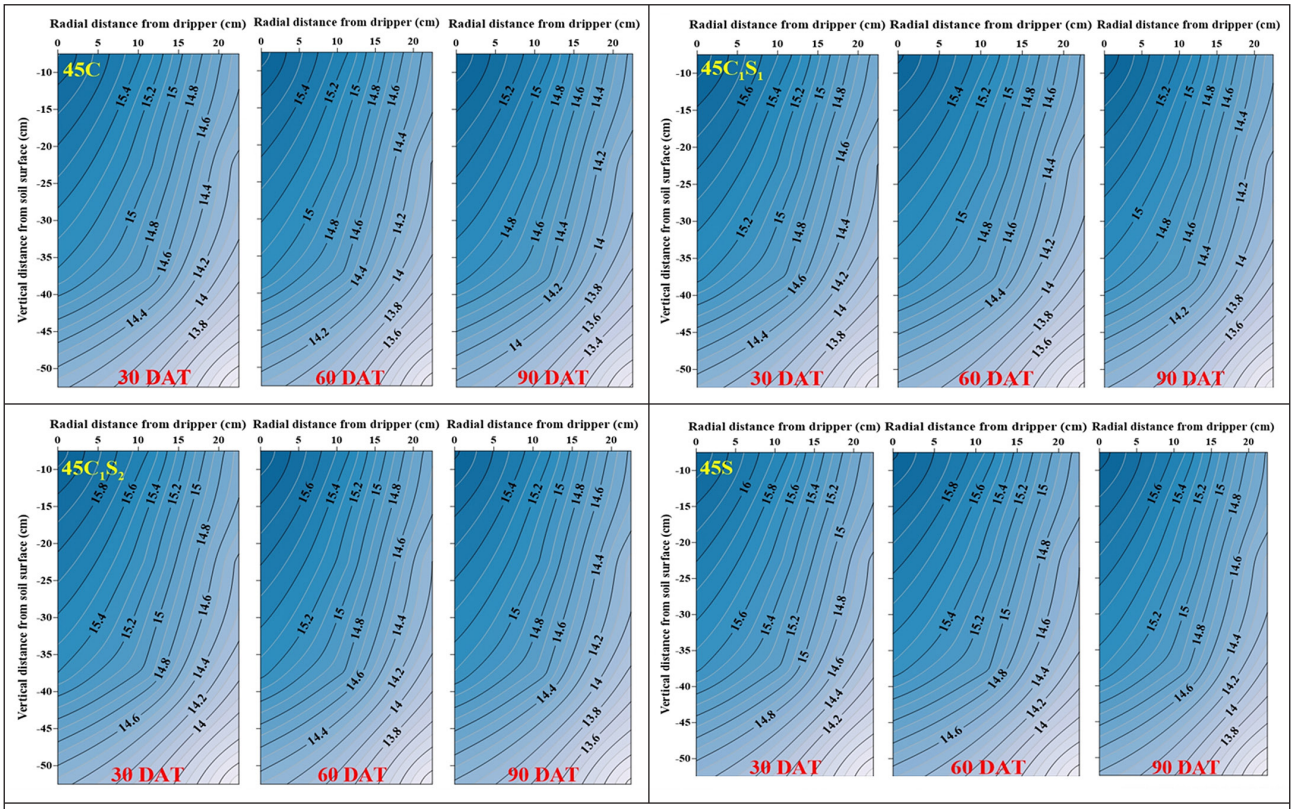

Figure 3. Spatial distribution of soil moisture (%) at 45 cm lateral spacing under different treatments at 30, 60, and 90 days after transplanting (DAT) in 2019

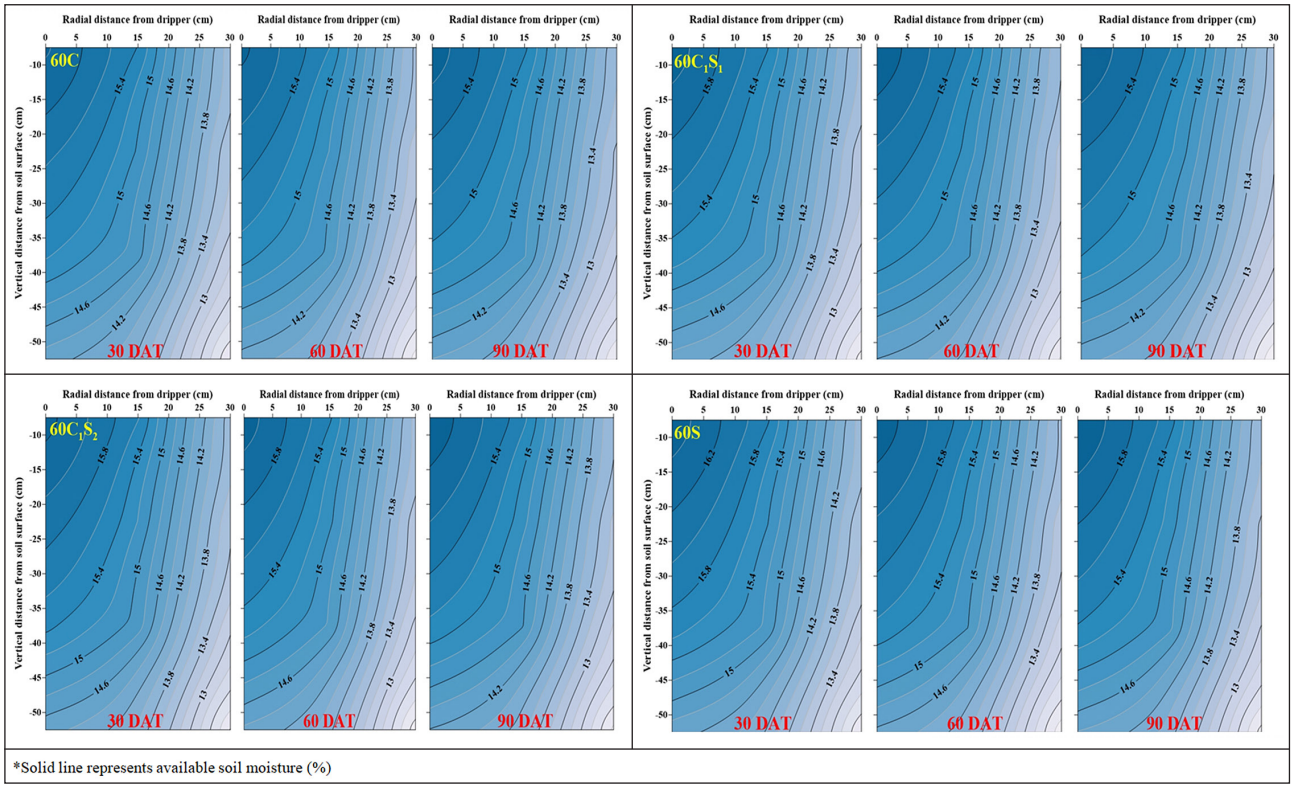

Figure 4. Spatial distribution of soil moisture (%) at 60 cm lateral spacing under different treatments at 30, 60, and 90 days after transplanting (DAT) in 2019

This might be due to longer irrigation application times in treatments with 60 cm LS (only 3 laterals per plot) compared to treatments with 45 cm LS (only 4 laterals per plot) to ensure an equal amount of water was delivered to each plot. This longer time of operation resulted in higher moisture content accumulated just below the dripper with 60 cm LS versus 45 cm LS (same dripper discharge). Both years of the study, i.e., 2018 and 2019 (here results are shown only for 2019), resulted in similar soil moisture distribution patterns with respect to change in LS. Kumar et al. (2023) also reported similar results.

Effect of different treatments on electrical conductivity of saturated soil extract

The effect of different treatments on electrical conductivity of saturated soil extract (EC_e) is shown in Tables 7 and 8 at 45 and 60 cm LS, respectively, for 2019. At 45 cm LS (Table 7), maximum EC_e was observed under Treatment S, followed by C_1S_2, C_1S_1 and Treatments C, for the respective DAT, radial distance and soil depth. The minimum EC_e was found at a soil depth of 45–60 cm under Treatment C at 30 DAT and observed as 0.90, 0.92, 0.93 dS·m^{-1} at radial distances of 0, 11.25 and 22.5 cm, respectively. However, maximum EC_e of 2.70, 2.78, and 2.89 dS·m^{-1} were found at radial distances of 0, 11.25 and 22.5 cm, respectively, under Treatment S at soil depth of 0–15 cm at 90 DAT. Similar results were also reported by Pessoa et al. (2019), who observed that soil EC was significantly increased when irrigating onion with highly saline water in sandy loam and silty clay loam soils of a semi-arid region of Brazil. Further, EC_e decreased vertically downward at all radial distances but increased radially outward at all soil depths. A similar pattern in EC_e was observed at 60 cm LS (Table 8). Yohannes et al. (2020) also reported high salt build-up under irrigation by seepage, as compared to irrigation with canal fresh water. By comparing the results for both LS, higher EC_e was found at 45 cm LS (Table 7) than 60 cm LS (Table 8), irrespective of radial distance and irrigation treatment.

Table 7. Observed EC_e (dS·m^{-1}) at 30, 60 and 90 DAT at 45 cm lateral spacing in year 2019

Treatments	Depth of soil (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
45C	0–15	1.17^{c}	1.20^{c}	1.25^{c}	1.19^{c}	1.22^{c}	1.27^{c}	1.29^{c}	1.33^{c}	1.38^{c}
	15–30	1.07^{c}	1.09^{c}	1.11^{c}	1.09^{c}	1.11^{c}	1.13^{c}	1.19^{c}	1.20^{c}	1.23^{c}
	30–45	1.02^{c}	1.04^{c}	1.07^{c}	1.04^{c}	1.06^{c}	1.09^{c}	1.13^{c}	1.15^{c}	1.19^{c}
	45–60	0.90^{c}	0.92^{c}	0.93^{c}	0.92^{c}	0.93^{c}	0.94^{c}	1.00^{c}	1.01^{c}	1.03^{c}
$45C_1S_1$	0–15	1.25^{bc}	1.29^{bc}	1.34^{bc}	1.35^{bc}	1.39^{bc}	1.45^{bc}	1.70^{bc}	1.75^{bc}	1.82^{bc}
	15–30	1.16^{b}	1.17^{b}	1.19^{b}	1.25^{b}	1.26^{b}	1.29^{b}	1.55^{b}	1.57^{b}	1.60^{b}
	30–45	1.10^{bc}	1.12^{bc}	1.16^{bc}	1.18^{bc}	1.21^{bc}	1.25^{bc}	1.36^{bc}	1.40^{bc}	1.48^{bc}
	45–60	0.97^{bc}	0.99^{bc}	1.00^{bc}	1.05^{bc}	1.06^{bc}	1.08^{bc}	1.25^{bc}	1.27^{bc}	1.29^{bc}
$45C_1S_2$	0–15	1.36^{ab}	1.40^{ab}	1.46^{ab}	1.61^{ab}	1.66^{ab}	1.72^{ab}	2.23^{ab}	2.30^{ab}	2.39^{ab}
	15–30	1.27^{b}	1.28^{b}	1.31^{b}	1.48^{b}	1.50^{b}	1.53^{b}	2.04^{b}	2.06^{b}	2.11^{b}
	30–45	1.20^{ab}	1.23^{ab}	1.27^{ab}	1.41^{ab}	1.44^{ab}	1.48^{ab}	1.76^{ab}	1.80^{ab}	1.92^{ab}
	45–60	1.07^{ab}	1.08^{ab}	1.09^{ab}	1.25^{ab}	1.27^{ab}	1.28^{ab}	1.63^{ab}	1.65^{ab}	1.68^{ab}
45S	0–15	1.46^{a}	1.51^{a}	1.57^{a}	1.82^{a}	1.88^{a}	1.95^{a}	2.70^{a}	2.78^{a}	2.89^{a}
	15–30	1.36^{a}	1.38^{a}	1.41^{a}	1.68^{a}	1.70^{a}	1.73^{a}	2.47^{a}	2.49^{a}	2.55^{a}
	30–45	1.29^{a}	1.32^{a}	1.36^{a}	1.59^{a}	1.63^{a}	1.68^{a}	2.08^{a}	2.13^{a}	2.29^{a}
	45–60	1.15^{a}	1.16^{a}	1.18^{a}	1.41^{a}	1.43^{a}	1.45^{a}	1.95^{a}	1.98^{a}	2.00^{a}

Note: Different letters in a row represent significant differences at $p \leq 0.05$

Table 8. Observed EC_e (dS·m^{-1}) at 30, 60 and 90 DAT at 60 cm lateral spacing in year 2019

Treatments	Depth of soil (cm)	30 DAT			60 DAT			90 DAT		
		Radial distance (cm)			Radial distance (cm)			Radial distance (cm)		
		0	15	30	0	15	30	0	15	30
60C	0–15	1.14^{c}	1.19^{c}	1.28^{c}	1.16^{c}	1.21^{c}	1.31^{c}	1.26^{c}	1.32^{c}	1.42^{c}
	15–30	1.05^{b}	1.07^{b}	1.14^{b}	1.07^{b}	1.09^{b}	1.16^{b}	1.17^{b}	1.19^{b}	1.26^{b}
	30–45	1.00^{b}	1.03^{b}	1.11^{b}	1.02^{b}	1.05^{b}	1.13^{b}	1.10^{b}	1.14^{b}	1.23^{b}
	45–60	0.89^{b}	0.91^{b}	0.96^{b}	0.90^{b}	0.92^{b}	0.97^{b}	0.98^{b}	1.00^{b}	1.06^{b}
$60C_1S_1$	0–15	1.22^{b}	1.27^{b}	1.38^{b}	1.33^{b}	1.38^{b}	1.49^{b}	1.66^{b}	1.73^{b}	1.87^{b}
	15–30	1.13^{ab}	1.16^{ab}	1.23^{ab}	1.22^{ab}	1.25^{ab}	1.33^{ab}	1.52^{ab}	1.56^{ab}	1.65^{ab}
	30–45	1.07^{ab}	1.11^{ab}	1.19^{ab}	1.16^{ab}	1.20^{ab}	1.29^{ab}	1.34^{ab}	1.38^{ab}	1.52^{ab}
	45–60	0.96^{ab}	0.98^{ab}	1.03^{ab}	1.03^{ab}	1.05^{ab}	1.11^{ab}	1.23^{ab}	1.26^{ab}	1.33^{ab}
$60C_1S_2$	0–15	1.34^{ab}	1.39^{ab}	1.50^{ab}	1.58^{ab}	1.64^{ab}	1.77^{ab}	2.19^{ab}	2.28^{ab}	2.46^{ab}
	15–30	1.24^{ab}	1.27^{ab}	1.35^{ab}	1.45^{ab}	1.48^{ab}	1.58^{ab}	2.00^{ab}	2.04^{ab}	2.17^{ab}
	30–45	1.18^{ab}	1.21^{ab}	1.30^{ab}	1.38^{ab}	1.42^{ab}	1.53^{ab}	1.73^{ab}	1.79^{ab}	1.98^{ab}
	45–60	1.05^{ab}	1.07^{ab}	1.13^{ab}	1.22^{ab}	1.25^{ab}	1.32^{ab}	1.60^{ab}	1.64^{ab}	1.73^{ab}
60S	0–15	1.43^{a}	1.49^{a}	1.61^{a}	1.78^{a}	1.86^{a}	2.01^{a}	2.65^{a}	2.76^{a}	2.98^{a}
	15–30	1.34^{a}	1.36^{a}	1.45^{a}	1.65^{a}	1.68^{a}	1.78^{a}	2.42^{a}	2.47^{a}	2.62^{a}
	30–45	1.27^{a}	1.31^{a}	1.40^{a}	1.56^{a}	1.61^{a}	1.73^{a}	2.04^{a}	2.11^{a}	2.36^{a}
	45–60	1.12^{a}	1.15^{a}	1.21^{a}	1.39^{a}	1.42^{a}	1.49^{a}	1.91^{a}	1.96^{a}	2.06^{a}

Note: Different letters in a row represent significant differences at $p \leq 0.05$

Spatio-temporal distribution of electrical conductivity of saturated soil extract

Figure 5 shows the contour map of EC_e at 45 cm LS under different irrigation treatments in 2019. EC_e increased and decreased with increasing radial distances and soil depths, respectively, under all of the different treatments applied. Further, EC_e was higher at 60 cm LS compared to corresponding treatments at 45 cm LS (Fig. 6). This may be due to more effective overlapping of the soil moisture front in 45 cm LS, which caused large movement of soil moisture to lower layers, along with the salts present in the soil. On the other hand, at 60 cm LS, less effective overlapping of soil moisture fronts due to a higher midpoint distance (i.e. 30 cm) than for 45 cm LS (i.e. 22.5 cm) tends to push lateral movement of salts continuously outwards, leading to comparatively higher salt concentration at a radial distance of 30 cm. Further, EC_e just below the dripper was high at 45 cm LS in all the treatments as compared to corresponding treatments with 60 cm LS for a given DAT and soil depth. This may be due to the high irrigation time (i.e. application of higher water volume near the dripper) in 60 cm LS, as compared to treatments with 45 cm LS, providing a better opportunity for lateral and downward movement of salt along with soil moisture.

Regarding irrigation treatments, EC_e was found to be highest under Treatment S, followed by C_1S_2, C_1S_1 and Treatment C, for a given DAT, radial distance and soil depth. The increased salt concentration in the soil beyond a critical level when irrigated with high salinity water may hinder crop growth as it becomes difficult for the plants to extract moisture from the soil.

Effect of different treatments on crop growth parameters

Table 9 shows the effect of the different treatments applied (LS and IT) on crop growth parameters, i.e., average plant height, polar diameter, equatorial diameter, bulb weight, bulb yield and IWUE at harvest. Maximum growth attributes, i.e., average plant height, polar diameter, equatorial diameter, bulb weight and bulb yield of onion were achieved under Treatment C, whereas minimum growth attributes were recorded for Treatment S under both LS (Table 9). At 45 cm LS, the maximum plant height was reduced up to 2.69–3.04%, 12.81–13.42% and 19.13 to 21.23% in Treatments C_1S_1, C_1S_2 and S, respectively, as compared to Treatment C in the years of 2018 and 2019. However, this reduction was high at 60 cm LS for all the irrigation treatments, i.e., C_1S_1 (3.14–4.10%), C_1S_2 (6.57–7.50%) and S (14.2–15.76%) in both years. The reduction in plant height with increasing salinity level may be due to an effect on plant roots (osmotic effect) and plant tissues (the toxic effect of accumulation of ions) (Allison, 1964; Yohannes et al., 2020).

The minimum and maximum reductions in polar diameter, of 1.02–3.08% and 17.92–19.16%, were seen under Treatments C_1S_1 and S, respectively, in comparison to Treatment C at 45 cm LS. A similar type pattern was witnessed at 60 cm LS in both years. For equatorial diameter at 45 cm LS, Treatment S caused the maximum reduction (19.16–21.11%), followed by C_1S_2 (12.77–13.47%) and C_1S_1 (2.95–3.08%). The percentage increase was less at 60 cm LS compared to 45 cm LS. This higher decrease in crop growth parameters under Treatment S may be due to difficulty in absorption of water and nutrients by the roots due to the reduction in osmotic potential caused by salts present in the soil solution. Furthermore, reduction in onion plant height may be due to a decline in cell expansion and cell division under stress conditions, which ultimately reduces the overall growth of the plants (Ghodke et al., 2020). Yohannes et al. (2020) also reported that increasing levels of salinity reduce the crop growth parameters. These results also confirmed the findings of Jha et al. (2017) for loamy sand soil and Garg et al. (2022) for sandy loam soil, who stated that plant height significantly reduced with increasing salinity of irrigation water. Similarly, Nagaz et al. (2012) observed that the germination % and root length (cm) among various cultivars of onion were significantly reduced due to excessive salt concentration. Attributes such as seed germination (%) and germination intensity decrease with increasing levels of salinity, as salinity and germination have an antagonistic response (Baba et al., 2010; Patel et al., 2020).

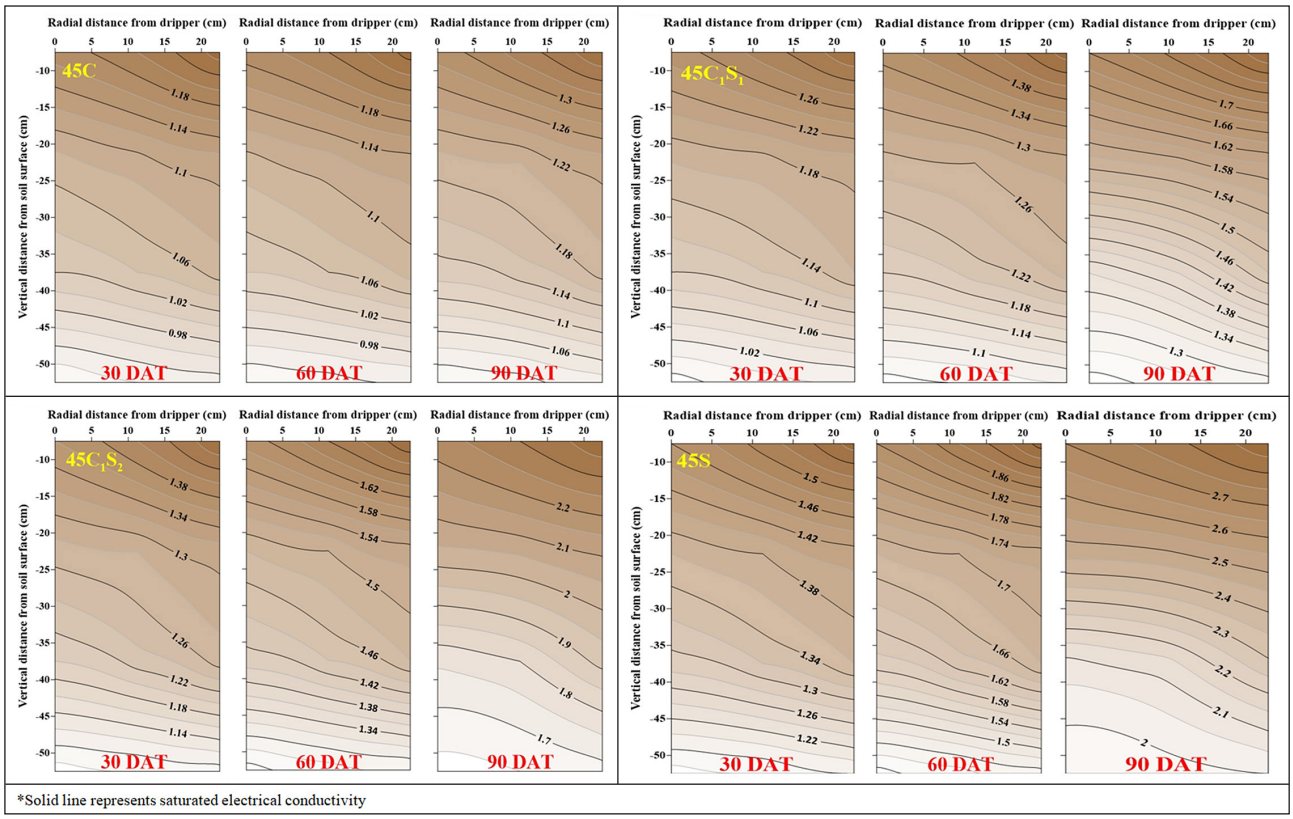

Figure 5. Spatial distribution of EC_e (dS/m) at 45 cm lateral spacing under different treatments at 30, 60, and 90 days after transplanting (DAT) in 2019

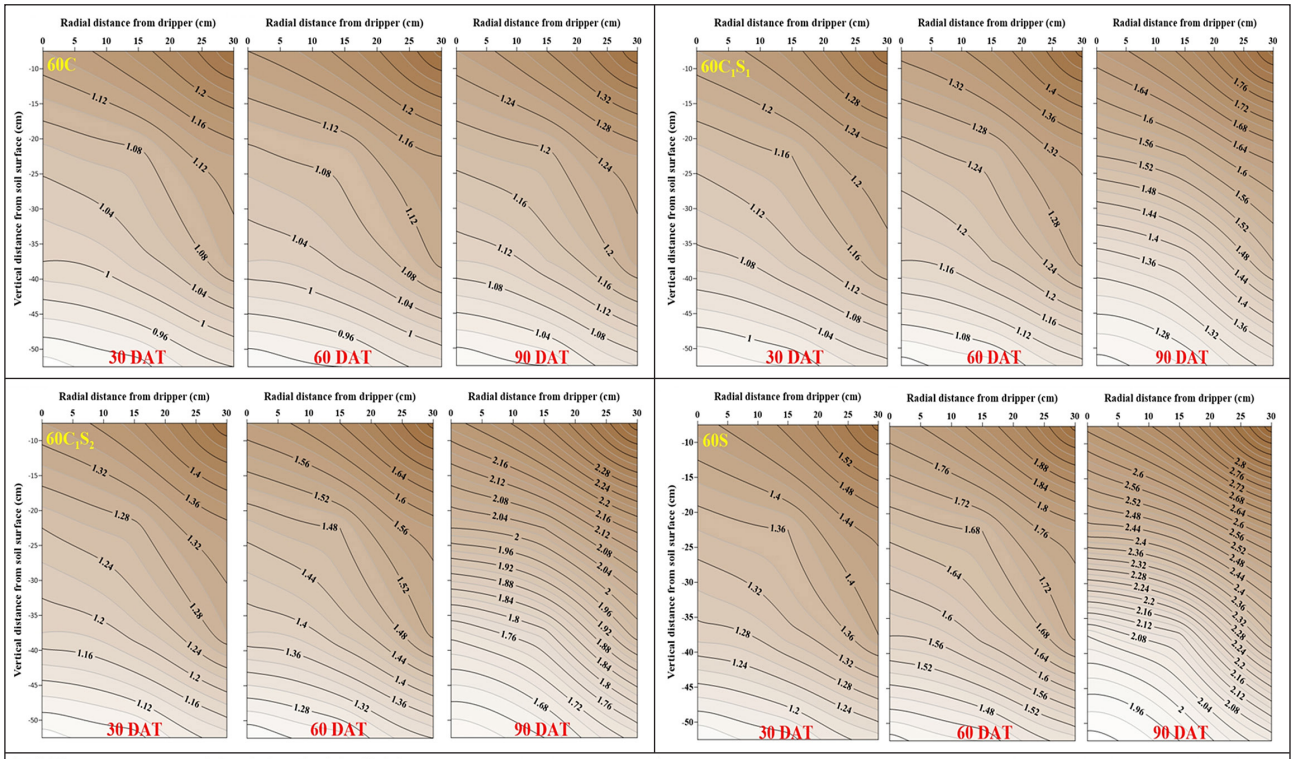

Figure 6. Spatial distribution of EC_e (dS/m) at 60 cm lateral spacing under different treatments at 30, 60, and 90 days after transplanting (DAT) in 2019

Table 9. Effect of lateral spacing (LS) and irrigation treatment (IT) on average plant height, polar diameter, equatorial diameter and bulb weight

Parameter	Year	LS	IT				
			C	C_1S_1	C_1S_2	S	*P*
Plant height (cm)	2018	45	68.38^{a}	66.30^{a}	59.20^{b}	55.30^{b}	**0.02**
		60	60.76^{A}	58.85^{AB}	56.77^{AB}	52.10^{B}	0.09
	2019	45	67.91^{a}	66.08^{a}	59.21^{b}	53.49^{b}	**0.04**
		60	59.70^{A}	57.25^{AB}	55.22^{AB}	50.29^{B}	0.12
Polar diameter (cm)	2018	45	4.91^{a}	4.86^{a}	4.38^{b}	4.03^{b}	**0.003**
		60	4.39^{A}	4.25^{A}	4.10^{AB}	3.76^{B}	**0.046**
	2019	45	6.16^{a}	5.97^{a}	5.33^{b}	4.98^{b}	**0.003**
		60	5.47^{A}	5.29^{AB}	5.11^{AB}	4.69^{B}	0.09
Equatorial diameter (cm)	2018	45	6.16^{a}	5.97^{a}	5.33^{b}	4.98^{b}	**0.003**
		60	5.47^{A}	5.29^{AB}	5.11^{AB}	4.69^{B}	0.09
	2019	45	6.11^{a}	5.93^{ab}	5.33^{bc}	4.82^{c}	**0.005**
		60	5.37^{A}	5.16^{AB}	4.97^{AB}	4.53^{B}	0.12
Bulb weight (cm)	2018	45	63.29^{a}	61.37^{a}	54.79^{b}	51.17^{b}	**0.003**
		60	56.30^{A}	54.53^{AB}	52.60^{AB}	48.27^{B}	0.09
	2019	45	62.87^{a}	60.98^{ab}	54.86^{bc}	49.60^{c}	**0.005**
		60	55.27^{A}	53.04^{AB}	51.16^{AB}	46.64^{B}	0.12
Yield (t·ha^{-1})	2018	45	36.69^{a}	35.57^{a}	31.76^{b}	29.66^{b}	**0.003**
		60	32.64^{A}	31.61^{AB}	30.49^{AB}	27.98^{B}	0.09
	2019	45	36.47^{a}	35.49^{a}	31.80^{b}	28.73^{b}	**0.04**
		60	32.07^{A}	30.75^{AB}	29.66^{AB}	27.01^{B}	0.12
IWUE (kg·ha^{-1}·m^{-3})	2018	45	14.37^{a}	13.93^{a}	12.44^{b}	11.62^{b}	**0.03**
		60	12.78^{A}	12.38^{AB}	11.94^{AB}	10.96^{B}	0.09
	2019	45	16.17^{a}	15.73^{a}	14.10^{b}	12.73^{b}	**0.004**
		60	14.21^{A}	13.63^{AB}	13.15^{AB}	11.97^{B}	0.117

Note: Different letters in a row in a particular year represent significant differences at $p \leq 0.05$

Table 10. Effect of irrigation methods on yield and yield parameters under different treatments

Parameter	Year	LS	C		C_1S_1		C_1S_2		S	
			Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
Bulb Weight (cm)	2018	45	62.59[a]	63.29[a]	61.22[a]	61.37[a]	55.05[a]	54.79[a]	51.52[a]	51.17[a]
		60	56.14[B]	56.30[B]	54.21[B]	54.53[B]	52.61[B]	52.60[B]	48.55[B]	48.27[B]
	2019	45	62.20[a]	62.87[a]	60.21[a]	60.98[a]	54.32[a]	54.86[a]	49.88[a]	49.60[a]
		60	55.58[B]	55.27[B]	52.72[B]	53.04[B]	51.17[B]	51.16[B]	46.94[B]	46.64[B]
Yield (t·ha^{-1})	2018	45	36.28[a]	36.69[a]	35.49[a]	35.57[a]	31.92[a]	31.76[a]	29.87[a]	29.66[a]
		60	32.55[B]	32.64[B]	31.43[B]	31.61[B]	30.49[B]	30.49[B]	28.15[B]	27.98[B]
	2019	45	36.02[a]	36.47[a]	34.97[a]	35.49[a]	31.49[a]	31.80[a]	28.89[a]	28.73[a]
		60	32.24[B]	32.07[B]	30.57[B]	30.75[B]	29.66[B]	29.66[B]	27.18[B]	27.01[B]
IWUE (kg·ha^{-1}·m^{-3})	2018	45	14.20[a]	14.37[a]	13.91[a]	13.93[a]	12.50[a]	12.44[a]	11.70[a]	11.62[a]
		60	12.75[B]	12.78[B]	12.31[B]	12.38[B]	11.95[B]	11.94[B]	11.03[B]	10.96[B]
	2019	45	15.97[a]	16.17[a]	15.50[a]	15.73[a]	13.96[a]	14.10[a]	12.80[a]	12.73[a]
		60	14.29[B]	14.21[B]	13.55[B]	13.63[B]	13.15[B]	13.15[B]	12.05[B]	11.97[B]

Note: Different letters in a row in a particular year represent significant differences at $p \leq 0.05$. No significant difference was observed in yield and IWUE obtained under surface awatend subsurface drip at $p \leq 0.05$

At 45 cm LS, the effect of various irrigation treatments was significant ($p \leq 0.05$) for yield and IWUE; however, at 60 cm LS, non-significant interactions of various irrigation treatments were found during the study periods. At 45 cm LS, the maximum yield of 36.69 and 36.47 t·ha^{-1} during 2018 and 2019, respectively, was obtained under Treatment C, while for 60 cm LS, a yield of 32.64 and 32.07 t·ha^{-1} during 2018 and 2019, respectively, was obtained under Treatment C. Minimum yield was obtained under Treatment S for both LS. The present finding is supported by Patell et al. (2001), who reported 20% higher yield for non-saline water than saline water under arid conditions. Jha et al. (2017) also reported a 17% decrease in potato yield when irrigated with saline water (EC of 4.0 dS·m^{-1}) relative to normal water (EC of 0.65 dS·m^{-1}), in a loamy sand soil of north-western India.

All of the observed parameters were found to be high at 45 cm LS as compared to 60 cm LS under the respective treatments in both years (Table 9). The reason for this may be that better soil moisture availability and lower soil salinity resulted in significantly higher plant growth and yield parameters under 45 cm LS than 60 cm LS, for all the treatments (Table 9).

Regarding IWUE, a statistically significant ($p < 0.05$) and non-significant ($p > 0.05$) effect was observed at 45 and 60 cm LS, respectively, and IWUE was higher at 45 cm LS than 60 cm LS under all of the respective treatments. Irrespective of IT, IWUE was found to be high under Treatment C (14.7 kg·ha^{-1}·m^{-3} and 16.17 kg·ha^{-1}·m^{-3}, for 2018 and 2019, respectively) and a minimum under Treatment S (10.96 and 11.97 kg·ha^{-1}·m^{-3} for 2018 and 2019, respectively). IWUE at 45 cm LS was reduced by 2.73–3.06%, 12.81–13.43% and 19.14–21.27% under Treatments C_1S_1, C_1S_2 and S, respectively, as compared to Treatment C, in the years of 2018 and 2019. At 60 cm LS, IWUE was decreased by 3.13–4.14%, 6.57–7.48%, and 14.24–15.76% under Treatments C_1S_1, C_1S_2 and S, respectively, as compared to Treatment C. Saxena et al. (2013) also reported a reduction in IWUE by 6% and 22% when drip irrigated with EC of 4 dS·m^{-1} and 8 dS·m^{-1}, respectively, relative to fresh water. Unlukara et al. (2010) also found similar results. By comparing irrigation treatments applied in the present study, it was found that there was a non-significant difference in yield and IWUE between Treatments C and C_1S_1; however, a significant difference between C and C_1S_2 and S was observed in the present study. It can be concluded that Treatments C and C_1S_1 at 45 cm LS are better options to produce maximum onion yield and IWUE in sandy loam soil of semi-arid region of India.

Comparison between yield and yield parameters under SD and SSD methods

The effect of irrigation methods, i.e., SD and SSD methods, on yield and yield parameters under different treatments during the experimental years are presented in Table 10. No significant differences were observed between the two irrigation methods for yield or yield-related parameters during the experimental period.

Both the lowest (27.98 and 27.01 t·ha^{-1}) and highest (36.69 and 36.47 t·ha^{-1}) onion yields were recorded under the SSD method, with the lowest at 60 cm LS using saline water and the highest at 45 cm LS using canal fresh water, during both study years. A similar pattern was observed in IWUE during both study periods. The highest IWUEs, of 14.37 and 16.17 kg·ha^{-1}·m^{-3}, were found under the SSD method for Treatment C and 45 cm LS, during 2018 and 2019, respectively. The lowest IWUEs, of 10.96 and 11.97 kg·ha^{-1}·m^{-3}, were observed at 60 cm LS and Treatment S under SSD method during both the study periods. The results show that quality of irrigation water has an effect on the preferred methods of irrigation application. Douh and Boujelben (2010) concluded that the SSD method outperforms the SD method in a case study of Tunisia.

Comparing the effect of lateral spacing on SD and SSD methods, it was noted that 45 cm LS produces the maximum onion yield and IWUE under both application methods. Irrespective of irrigation treatment applied in the present study, IWUE follows the same yield pattern in which the SSD method performed better than the SD method.

CONCLUSIONS

In the present study, a field experiment was carried out to enhance the crop yield and IWUE of drip-irrigated onion grown in a region underlain with poor quality groundwater, by adopting a conjunctive use strategy of fresh and saline water in the semi-arid region of Haryana (India). The effect on soil water–salt dynamics, crop growth parameters, yield and IWUE under 2 LS (viz. 45 cm and 60 cm) and 4 irrigation treatments (viz. C, C_1S_1, C_1S_2 and S) was investigated. High soil moisture and low salinity were observed at 45 cm LS for cultivation of drip-irrigated onion in a sandy loam soil of India. Further, salt accumulation just below the dripper was relatively lower but the concentration of salt increased with increasing radial distance from the emitting source (dripper). The significant and non-significant effects of 45 cm and 60 cm LS were

observed on crop growth parameters, yield and IWUE under all the irrigation treatments during the study periods. The higher yield and IWUE were found under Treatment C, followed by C_1S_1, C_1S_2 and S. But non-significant differences between Treatment C and C_1S_1 were identified, which indicates that conjunctive use of canal fresh water and saline water (ECiw ~ 2.5 dS·m^{-1}) in 1:1 ratio, can be employed successfully for onion cultivation in sandy loam soil using SSD method, without any significant reduction in yield and IWUE. Furthermore, closer LS (45 cm) was found to be better, as compared to wider LS (60 cm), particularly for marginal crop rows, i.e., crop rows lying near the midpoint area between adjacent laterals, from a salinity management point of view. By comparing the results of yield and IWUE under SD and SSD methods, no significant differences were observed between the two irrigation methods for yield and yield parameters during the experimental period. The results depict that quality of irrigation water has a significant effect on the choice of irrigation method in order to obtain the maximum benefit. Overall, it may be concluded that conjunctive use of canal fresh water and saline water in 1:1 ratio with 45 cm LS is the best choice to enhance the income of onion growers in semi-arid regions where availability of fresh water is a big constraint.

AUTHOR CONTRIBUTIONS

Conceptualization and methodology of the study: Mukesh Kumar, Darshana Duhan, Ram Naresh, Raj Kumar Jhorar. Data collection and fieldwork: Mukesh Kumar, Amandeep Singh, Kuldeep Singh. Sample/data analysis, interpretation of results: Mukesh Kumar, Amandeep Singh. Writing of the initial draft: Darshana Duhan, Raj Kumar Jhorar, Amandeep Singh. Revision after review: Mukesh Kumar, Darshana Duhan, Ram Naresh.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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