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Root morphological responses of Chilli (*Capsicum annum* L.) to smart irrigation scheduling and drip irrigation systems

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ABSTRACT

A field investigation entitled “Root morphological responses of Chilli (*Capsicum annum* L.) to smart irrigation scheduling and drip irrigation methods” was conducted on sandy loam textured soils during 2022–23 and 2023–24 rabi seasons at Water Technology Farm Fields, College of Agriculture, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad, to study the influence of drip irrigation and irrigation scheduling on root traits of chilli. The experiment was conducted in a split-plot design, with drip irrigation methods assigned as main plots, namely surface drip and subsurface drip irrigation, and irrigation scheduling approaches allocated as subplots, comprising of soil moisture sensor based, plant water stress sensor based, ET sensor based irrigation triggering, and manual irrigation scheduled at 1.0 Epan (control). The results revealed that subsurface drip irrigation significantly enhanced root morphology compared to surface drip. Higher root length was recorded under subsurface drip at both first (34.9 and 35.8 cm) and last pickings (66.2 and 66.9 cm) during 2022–23 and 2023–24, respectively. Similarly, root dry weight and volume were also significantly greater under subsurface drip, indicating improved root proliferation and resource acquisition. ET sensor-based irrigation triggering consistently resulted in superior root length, dry weight, and volume and remained comparable with manual irrigation at 1.0 Epan among irrigation scheduling approaches. The interaction effect between drip irrigation methods and scheduling approaches was found to be non-significant for all the root parameters.

Keywords: Artificial Intelligence, Subsurface drip irrigation, ET sensor, Root morphology

Introduction

India is increasingly facing a looming crisis of freshwater scarcity, driven by rapid population growth, climate variability, declining groundwater tables, and competing demands from agriculture, industry, and domestic sectors. Agriculture alone accounts for nearly 80–85% of the total water consumption in the country (Bigas, 2012), especially irrigated agriculture consumes more than two-thirds of the total freshwater on the planet, yet a significant proportion of this water is lost due to inefficient irrigation practices and poor scheduling. This issue causes substantial conflict in freshwater allocation between agriculture and other economic sectors (Chai *et al.*, 2016) [1]. In semi-arid and arid regions, erratic rainfall patterns and prolonged dry spells further aggravate the situation, making water a critical limiting factor for crop productivity. Under such circumstances, improving water use efficiency through advanced irrigation methods and precise scheduling has become imperative for sustaining agricultural production. Efficient irrigation management plays a crucial role in improving crop growth, yield, and water use efficiency. Among various irrigation methods, drip irrigation (surface and subsurface drip) have emerged as promising solutions due to its ability to deliver water directly to the root zone (Simonne *et al.*, 2012) [2], thereby reducing evaporation losses, improving soil physical properties, crop productivity (Bader *et al.*, 2010 and Elhindi, 2012) [3] and water use efficiency (Jones, 2004 and Bhattarai *et al.*, 2008; Kaur and Brar, 2016) [5, 4]. Subsurface drip irrigation (SDI), in particular, offers additional advantages such as minimizes surface evaporation, reduces weed growth (Kanda *et al.*, 2019; Buser *et al.*, 2025) [7, 6] and enhances soil moisture uniformity in the root zone (Lamm and Troien, 2003; Mchugh *et al.*, 2008). These benefits contribute to improved root development (Guo *et al.*, 2016) [8] and nutrient uptake efficiency.

Scheduling irrigation is important for achieving crop-specific water requirements which would help to achieve targeted yield without the wastage of water (Leib *et al.*, 2003) [9]. In recent years, advancements in precision agriculture have led to the development of sensor-based irrigation scheduling techniques which enables real-time monitoring and precise irrigation application based on crop demand (Jones, 2004; Thompson *et al.*, 2007) [5, 10]. These technologies, often integrated with artificial intelligence and automation, help optimize irrigation scheduling, reduce water wastage, and enhance crop performance under varying environmental conditions.

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Chilli (*Capsicum annuum* L.) is one of the most important crops of tropical and subtropical regions. It is valued not only for its culinary uses but also for its nutritional and economic significance, being a rich source of vitamins A and C, capsaicin, and antioxidants. India is one of the leading producers and exporters of chilli, contributing significantly to global spice trade and farmer income (Devi *et al.*, 2017). However, chilli productivity is often constrained by inefficient water management practices, particularly under semi-arid conditions where water scarcity and erratic rainfall prevail. Root system architecture plays a pivotal role in determining plant productivity (Sonia *et al.*, 2023; Rahnama *et al.*, 2024; Singh *et al.*, 2024) [12, 11, 13], as it governs the uptake of water and nutrients from the soil. Traits such as root length, root volume, and root dry weight are critical indicators of plant health and resource acquisition capacity (Lynch, 2013) [14]. Improved root growth enhances drought tolerance, nutrient absorption, and overall plant vigour, ultimately leading to higher yields. Keeping the above points in view, it is proposed to study the response of chilli root traits under different irrigation scheduling approaches and drip irrigation systems.

Material and Methods

An investigation was performed in chilli crop during *rabi* 2022-23 and 2023-24 on the sandy loam soils of Water Technology Farm Fields, College of Agriculture, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad, Telangana, India. The experimental site is situated at an altitude of 549 m above mean sea level with geographical coordinates of 17°19'28" N latitude and 78°24'32" E longitude. The soil bulk density was recorded as 1.41 g cm⁻³ at 0-15 and 1.45 g cm⁻³ at 15-30 cm layers. The study was executed as split plot design with drip irrigation methods (I) as main plot factor and irrigation scheduling approaches (S) as subplot factor. The levels examined under main plot factor were surface drip irrigation (I₁) and subsurface drip irrigation (I₂), and subplot factor were soil moisture sensor-based irrigation triggering (S₁), plant water stress sensor-based irrigation triggering (S₂), ET sensor-based irrigation triggering (S₃) and irrigation scheduling at 1.0 E_{pan} by manual (control) (S₄). The gross plot dimensions for each plot is 6.0 m x 7.2 m. The laterals for both surface and subsurface drip methods were laid at 1.2 m apart and 0.15 m depth below soil surface for subsurface drip. Capacitance soil moisture sensor (SW-10) was used for soil moisture based automatic irrigation triggering with 16.8 and 23.6% soil moisture as lower and higher threshold values. The canopy (NTC-10K) and ambient temperature sensors were used for the irrigation triggering under plant water stress system with 0.3 and 0 crop water stress index as the lower and higher threshold values. Evapotranspiration system was coupled with solar radiation (EMC-01) and ambient temperature sensors which triggers the irrigation at 1.0 ET_c. Irrigation was scheduled in the control treatment on every alternate day on the basis of pan evaporation data received from USWB class A open pan evaporimeter situated at Meteorological Observatory, Agro-Climatic Research Centre, Agricultural Research Institute, Rajendranagar. The root parameters such as root length (cm), root dry weight (g plant⁻¹) and root volume (cm³) were recorded at first and last picking of chilli by carefully uprooting three randomly selected plants and the mean values were computed. Root volume was determined following the method suggested by Sattelmacher (1987) [15]. The data collected during the experimental period for various parameters were analyzed statistically using the analysis of variance (ANOVA) technique appropriate for a split-plot design.

Results and Discussion

Root length (cm)

The data furnished in the Table 1 indicated that the root length of chilli at first and last pickings was significantly influenced by drip irrigation methods and irrigation scheduling approaches. On contrary, the interaction between these two factors could not exert any signifi-

cant effect on root length at first and last pickings during both the years of study.

At first picking, in between drip irrigation methods, significantly higher root length was registered with subsurface drip (34.9 and 35.8 cm) and was 5.7 and 5.9% higher than surface drip during 2022-23 and 2023-24 respectively. At last picking, during both the years, significantly higher root length was recorded under subsurface drip (66.2 and 66.9 cm) over surface drip respectively. The mean of both the years also adhered to the similar pattern of superiority during first and last pickings.

The reason for the higher root length in subsurface drip irrigation could be attributed to the efficient utilization of available soil moisture due to less exposure of surface wetted soil to sun as well as optimized uptake of nutrients without losses promotes the robust and extensive root system crucial for plant productivity and resilience to environmental stresses. The above results coincide with the conclusions drawn by Rehan (2005) [16] in tomato and Elsharkawy *et al.* (2015) [17] in common bean.

During first year, among irrigation scheduling approaches, significantly higher root length was observed under ET sensor based irrigation triggering (36.0 and 69.5 cm) than other sensor based irrigation triggering and remained at par with irrigation scheduling at 1.0 E_{pan} by manual (35.3 and 67.6 cm). On the other hand, during second year, ET sensor based irrigation triggering registered significantly higher root length (36.8 and 70.3 cm) than other treatments, and comparable with irrigation scheduling at 1.0 E_{pan} by manual (36.1 and 68.2 cm) at first and last pickings, respectively. The mean of two crop seasons also followed the same line of trend at both the pickings.

The results of lower root length under surface drip were in accordance with the findings of Nisha (2007) [18] in ladies finger who reported that high infiltration rates and more atmospheric interactions at the soil surface resulted in low moisture availability eventually effecting root length.

Root dry weight (g plant⁻¹) and volume (cm³)

Significant influence of drip irrigation methods and irrigation scheduling approaches on root dry weight (g plant⁻¹) and volume (cm³) was opined from the data furnished in Table 2 and Fig. 1 at first and last pickings of chilli crop.

Between the drip irrigation methods, at first picking, subsurface drip recorded significantly higher root dry weight (24.06 and 24.81 g) and root volume (27.85 and 28.74 cm³) over surface drip during first and second year of study respectively. An overview of the data, revealed that at last picking also, the higher root dry weight (42.30 and 43.29 g) and root volume (54.59 and 55.19 cm³) was registered with subsurface drip irrigation than surface drip during both the years of study respectively. The mean values at first and last pickings also adhered to the similar trend as above. The reason for the improved root dry weight could be ascribed to development of dense and extensive root system absorb more water and nutrient from the deeper layers of soil leading to increased root dry weight. These results are in accordance with the findings of Neama *et al.* (2014) [19] in eggplant and Abdelhady *et al.* (2017) [20] in tomato. These results collaborate with the findings of Dashtgol *et al.* (2023) [21] who reported that roots under subsurface drip system grown extensively and occupied larger volume of soil compared to conventional irrigation methods.

Among irrigation scheduling approaches, at first picking, ET sensor based irrigation triggering registered significantly higher dry weight of roots (25.55 and 26.36 g) and root volume (29.56 and 30.42 cm³) over other sensor based irrigation triggering treatments, but was on par with irrigation scheduling at 1.0 E_{pan} by manual (25.12 and 25.69 g) and root volume (28.90 and 29.80 cm³) during both the years of study respectively. At last picking, during first and second years of study, significantly higher root dry weight (45.05 and 46.05 g) and volume (57.50 and 58.22 cm³) were recorded in ET sensor based irrigation triggering and over other treatments and was comparable with irrigation scheduling at 1.0 E_{pan} by manual (43.27 and 44.20 g) and

(55.61 and 56.36 cm³) respectively. Increased root volume could be attributed to continuous frequent supply of irrigation water based on crop evapotranspiration losses provided ample amount of water to the crop resulted in higher volume to access and absorb more nutrients from the soil and ultimately supported the crop overall growth and development. The mean values at first and last picking also adhered to the similar trend as above.

On contrary to the above, root dry weight and volume at first and last pickings were not significantly influenced by the interaction of drip irrigation methods and irrigation scheduling approaches during both the years of study respectively.

Conclusion

The above study concluded that improved root traits under subsurface drip between drip irrigation methods and ET sensor based irrigation scheduling among irrigation scheduling approaches were attributed to

efficient soil moisture distribution, reduced evaporation losses, and enhanced nutrient uptake. Overall, irrigation scheduling using AI based sensors and subsurface drip proved to be an efficient strategy for promoting root growth and optimizing water use in chilli cultivation, thereby improving the crop productivity.

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Competing Interests

Authors have declared that no competing interests exist

Table 1. Effect of drip irrigation methods and irrigation scheduling approaches on root length (cm) of chilli

Treatments	At first picking			At last picking		
	2022-23	2023-24	Mean	2022-23	2023-24	Mean
Main Plot-Drip irrigation methods (I)						
I ₁ - Surface drip irrigation	33.0	33.8	33.4	63.0	63.5	63.3
I ₂ - Subsurface drip irrigation	34.9	35.8	35.3	66.2	66.9	66.5
S.E.m±	0.2	0.3	0.3	0.5	0.5	0.4
CD (p = 0.05)	1.5	1.7	2.0	2.9	3.2	2.5
Sub plot-Irrigation scheduling approaches (S)						
S ₁ - Soil moisture sensor based irrigation triggering	31.1	31.9	31.5	58.4	59.0	58.6
S ₂ - Plant water stress sensor based irrigation triggering	33.4	34.2	33.8	62.8	63.4	63.1
S ₃ - ET sensor based irrigation triggering	36.0	36.8	36.4	69.5	70.3	69.9
S ₄ - Irrigation scheduling at 1.0 Epan by manual (control)	35.3	36.1	35.7	67.6	68.2	67.9
S.E.m±	0.4	0.5	0.6	0.8	0.8	0.7
CD (P = 0.05)	1.2	1.5	1.7	2.4	2.6	2.2
Interaction (M x S)						
S.E.m±	0.5	0.6	0.8	1.1	1.2	1.0
CD (P = 0.05)	NS	NS	NS	NS	NS	NS
Interaction (S x M)						
S.E.m±	0.6	0.7	0.8	1.1	1.2	1.0
CD (P = 0.05)	NS	NS	NS	NS	NS	NS

Table 2. Effect of drip irrigation methods and irrigation scheduling approaches on root dry weight (g plant⁻¹) of chilli

Treatments	At first picking			At last picking		
	2022-23	2023-24	Mean	2022-23	2023-24	Mean
Main Plot-Drip irrigation methods (I)						
I ₁ - Surface drip irrigation	22.61	23.41	23.01	40.28	41.16	40.72
I ₂ - Subsurface drip irrigation	24.06	24.81	24.43	42.30	43.29	42.80
S.E.m±	0.17	0.22	0.13	0.28	0.33	0.22
CD (p = 0.05)	1.05	1.34	0.79	1.69	2.01	1.34
Sub plot-Irrigation scheduling approaches (S)						
S ₁ - Soil moisture sensor based irrigation triggering	20.47	21.29	20.88	37.00	37.87	37.44
S ₂ - Plant water stress sensor based irrigation triggering	22.20	23.09	22.64	39.85	40.78	40.32
S ₃ - ET sensor based irrigation triggering	25.55	26.36	25.96	45.05	46.05	45.55

(continued on next page)

Treatments	At first picking			At last picking		
	2022-23	2023-24	Mean	2022-23	2023-24	Mean
S ₄ - Irrigation scheduling at 1.0 Epan by manual (control)	25.12	25.69	25.41	43.27	44.20	43.73
S.E.m±	0.27	0.35	0.21	0.51	0.65	0.71
CD (<i>P</i> = 0.05)	0.83	1.08	0.65	1.58	2.00	2.19
Interaction (M x S)						
S.E.m±	0.37	0.48	0.29	0.69	0.86	0.90
CD (<i>P</i> = 0.05)	NS	NS	NS	NS	NS	NS
Interaction (S x M)						
S.E.m±	0.38	0.49	0.30	0.73	0.92	1.00
CD (<i>P</i> = 0.05)	NS	NS	NS	NS	NS	NS

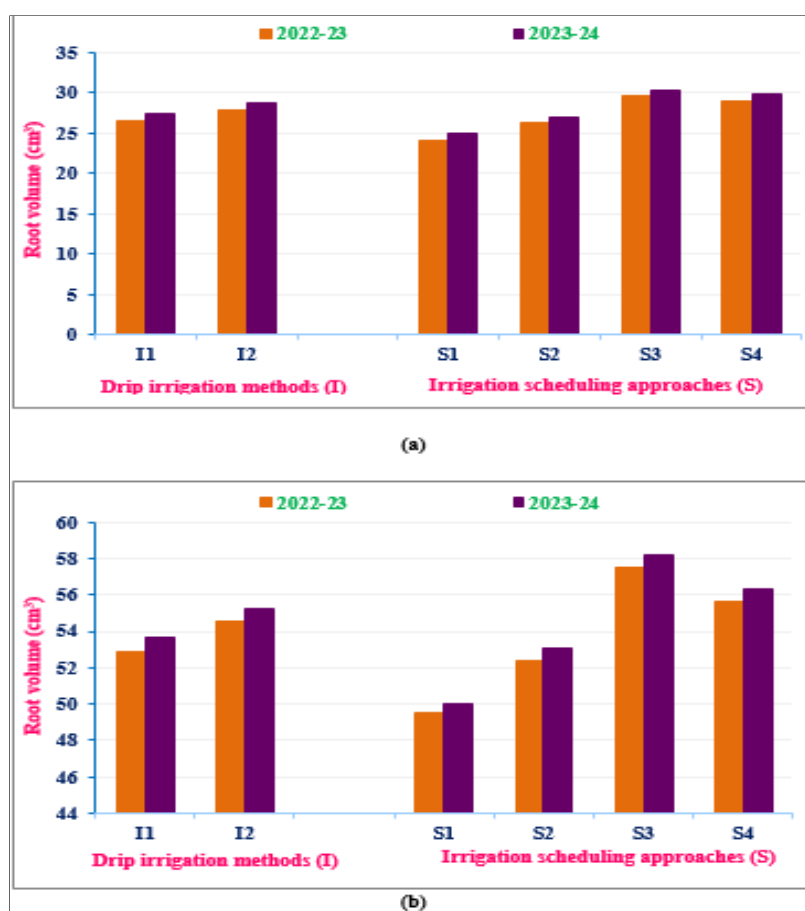


Figure 1. Root volume (cm³) of chilli as influenced by drip irrigation methods and irrigation scheduling approaches at first (a) and last (b) pickings

References

- Chai Q, Gan Y, Zhao C, Xu HL, Waskom RM, Niu Y, Siddique KHM. Regulated deficit irrigation for crop production under drought stress: A review. *Agronomy for Sustainable Development*. 2016;36:1–21.
- Simonne E, Hochmuth R, Brem J, Lamont W, Treadwell D, Gazula A. Drip irrigation system for small conventional vegetable farms and organic vegetable farms. University of Florida IFAS Extension, HS1203; 2012.
- Bader MA, Abo Hussein SD, El-Tohamy WA, Gruda N. Efficiency of subsurface drip irrigation for potato production under different dry stress conditions. *Gesunde Pflanzen*. 2010;62(2):63–70.
- Bhattarai SP, Midmore DJ, Pendergast L. Yield, water-use efficiencies and root distribution of soybean, chickpea and pumpkin under different subsurface drip irrigation depths and oxygenation treatments in vertisols. *Irrigation Science*. 2008;26:439–450.
- Jones HG. Irrigation scheduling: advantages and pitfalls of plant-based methods. *Journal of Experimental Botany*. 2004;55(407):2427–2436.
- Buser C, Hartung J, Graeff-Hönninger S. Subsurface drip irrigation reduces weed infestation and irrigation water use while increasing inflorescence and cannabinoid yield in an outdoor tunnel *Cannabis sativa* L. production system. *Journal of Cannabis Research*. 2025;7:41.
- Kanda EK, Niu W, Mabhaudhi T, Senzanje A. Moisture irrigation technology: A review. *Agricultural Research*. 2019;9:139–147.
- Guo F, Ma J, Zheng L, Sun X, Guo X, Zhang X. Estimating distribution of water uptake with depth of winter wheat by hydrogen and oxygen stable isotopes under different irrigation depths. *Journal of Integrative Agriculture*. 2016;15:891–906.
- Leib BG, Jabro J, Matthews RG. Field evaluation and performance comparison of soil moisture sensors. *Journal of Soil Science*. 2003;168(6):396–408.
- Thompson RB, Gallardo M, Valdez LC, Fernandez MD. Determination of lower limits for irrigation management using in situ assessments of apparent crop water uptake made with volumetric soil water content sensors. *Agricultural Water Management*. 2007;92(1–2):13–28.

11. Rahnama AH, Hosseinalipour B, Farrokhan FA, Harrison MT, Ghorbanpour M. Root architecture traits and genotypic responses of wheat at seedling stage to water-deficit stress. *Cereal Research Communications*. 2024;52:1499–1510.
12. Sonia K, Kaur V, Yadav SK, Arya SS, Aravind J, Jacob SR, Gautam RK. Development and evaluation of barley mini-core collection for salinity tolerance and identification of novel haplotypic variants for HvRAF. *Plant and Soil*. 2023;497:317–337.
13. Singh S, Yadav SK, Arya SS, Jacob SR, Gautam RK, Singh GP, Kaur V. Unravelling morpho-physiological mechanism and candidate genes associated with salinity tolerance in superior haplotypes of barley (*Hordeum vulgare* L.). *Journal of Agronomy and Crop Science*. 2024;210:e12756.
14. Lynch JP. Steep, cheap and deep: an ideotype to optimize water and N acquisition by maize root systems. *Annals of Botany*. 2013;112(2):347–357.
15. Sattelmacher B. Methods for measuring root volume and for studying root morphology. 1987;150:54–55.
16. Rehan MGA. Surface and subsurface drip irrigation methods and water quality effect on root and shoot growth and fruit quality of tomato. Mansoura University Journal of Agricultural Sciences. 2005;30(7):4277–4289.
17. Elsharkawy GA, Mousa AG, Hegazi HH, Kotb HM. The influence of subsurface drip irrigation and molybdenum application on morphological and yield components of two common bean cultivars under greenhouse conditions. *Egyptian Journal of Horticulture*. 2015;42(1):557–576.
18. Nisha TV. Subsurface drip irrigation of ladies finger in sandy loam soil. M. Tech Thesis, Kerala Agricultural University, Malappuram, Kerala; 2007.
19. Neama AS, Al-Falahi AA, Hamoudi HM. Response of eggplant (*Solanum melongena* L.) to subsurface drip irrigation method in comparison with surface drip and furrow irrigation methods under conventional agriculture. *Iraqi Journal of Agricultural Sciences*. 2014;19(3):215–221.
20. Abdelhady SA, Abu El-Azm NAI, El-Kafafi EH. Effect of deficit irrigation levels and NPK fertilization rates on tomato growth, yield and fruits quality. *Middle East Journal of Agricultural Research*. 2017;6(3):587–604.
21. Dashtgol AS, Naseri AA, Boroomand-Nasab S. Effect of subsurface drip irrigation and furrow irrigation management on water productivity, growth and yield variables and root distribution in sugarcane cultivation. *Water Productivity Journal*. 2023;3(1):51–74.
22. Elhindi KM. Evaluation of composted green waste fertigation through subsurface drip irrigation system on pot marigold plant (*Calendula officinalis* L.) grown on sandy soil. *Australian Journal of Crop Science*. 2012;6(8):1249–1259.
23. Kaur A, Brar AS. Influence of mulching and irrigation scheduling on productivity and water use of turmeric in north western India. *Irrigation Science*. 2016;34:261–269.

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