Wetting pattern under pulse and continuous irrigation

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Abstract

With over 80% of water consumption attributed to irrigation, its conservation stands as a paramount priority. The adoption of cost-effective, efficient irrigation technologies holds the key to reducing water demands while boosting agricultural productivity. Addressing percolation losses beneath the root zone during irrigation is crucialand precision irrigation that aligns with root zone dimensions can mitigate this loss while fostering optimal plant growth conditions. The intricacies of wetting patterns under trickle irrigation are influenced by factors like soil texture, structure, moisture content, emitter spacing, discharge rateand irrigation frequency. This article extensively examines moisture distribution around the root zone, particularly in terms of radial and vertical wetting front distances. Superior wetting front accuracy, lower percolation loss and enhanced uniformity were observed in pulse irrigation compared to continuous drip irrigation. The results show that pulsed drip irrigation with different dripper flow rates can make water spread more sideways and reduce deep percolation compared to steady drip irrigation, especially when using higher flow rates.This research underscores the importance of tailored irrigation methods in optimizing moisture distribution, minimizing water wastageand promoting sustainable water management practices in agriculture.

Keywords: Pulse irrigation,Radial and vertical distances,Soil moisture distribution, Wetting pattern.

Introduction

India is endowed with a diverse and abundant array of natural resources, underscoring the imperative for their meticulous and judicious management and development. Inadequate management and underdeveloped utilization of these waterresources can lead to diminished production levels, thereby exerting adverse impacts on the overall economy(Molden et al., 2010; Cosgrove and Loucks, 2015; Sabale et al., 2023).Addressing these challenges, integrated water management assumes a pivotal role, offering a multifaceted approach that resonates with poverty reduction, sustainable agricultural practices, environmental preservation, and enduring economic progress.In the case study by Gong et al. (2020), planning objective was prioritized to maximizing economic benefit, with careful consideration given to crop evapotranspiration and effective precipitation. The National Water Policy (2002) underscores the significance of development and management of water resourcesin an integrated manner, with a pronounced focus on optimizing irrigation systems. By ensuring judicious and uniform water application in limited quantities, the policy aims to avert plant water stress and excessive drainage. Over-irrigation not only compromises water use efficiency but also exacerbates nutrient leaching (Tan et al., 2021; Rank and Vishnu, 2021a; Darko et al., 2017).

The ascendancy of micro-irrigation systems has gained notable traction, particularly in the irrigation of orchards and horticultural crops. However,

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studies show that continuous water supply can lead to root zone inundation, which undermines the intended benefits.While trickle irrigation facilitates the wetting front, it inadvertently engenders prolonged soil saturation intervals, especially in heavy clay or vertisols (Rank and Vishnu, 2021a). This condition is deemed unfavourable, as both macro and micro pores become inundated with water.Efforts to refine irrigation practices, such as the adoption of targeted micro-irrigation, must grapple with the challenge of root zone flooding. This highlights the challenge of keeping the right amount of moisture in the soil for good crop growth. As India works to improve its agriculture, figuring out how to use water for irrigation effectively is a crucial part of the plan.

In soil with limited drainage capacity, coupled with high moisture atmospheric conditions and heavy soil composition, the displacement of oxygen by water in pores occurs, resulting in reduced oxygen availability near the root zone. This inadequate aeration leads to oxygen deficiency in the crop's root zone, thereby diminishing crop yields and potentially impeding water and nutrient absorption by the roots (Balliu et al., 2021; Zhu et al., 2022). Essential processes such as root respiration, soil microbial activity, and soil-dwelling organisms rely on adequate air in the soil, making them susceptible to compromise due to oxygen scarcity in the root zone.To address this challenge, two strategies have been proposed: irrigating crops with aerated irrigation water or adopting pulse irrigation with higher trickle application rates. With an ever-increasing population, the needto enhance productivity with limited resources become crucial.This can only be achieved through the implementation of various technological interventions in water management (Rank and Vishnu,2021b; Rank and Satasiya, 2022; Rank and Vishnu, 2023; Rank et al., 2022; Rank et al., 2023a), one of those technological interventions is the Pulse drip irrigation system. Pulse irrigation involves a cyclical approach, alternating between operating and resting phases, designed to optimize aeration levels in the root zone (Rank and Vishnu, 2021a). This approach aims to enhance oxygen availability and alleviate oxygen-related stress on crops.

This article delves into the distribution of the wetting front under both pulse and trickle irrigation methods, shedding light on how these approaches impact moisture distribution. Rank and Vishnu (2021b) previously explained how pulse irrigation works, giving us a detailed plan to use it. This study looks at how moisture spreads in the soil under different irrigation methods, helping us see how pulse irrigation can make the root area better for crops, leading to more productivity and sustainability.

Materials and Methods

Irrigation, a pivotal agricultural practice, involves the controlled application of water to fields using various techniques, each characterized by distinct application and field efficiencies. The adoption of heat-resistant crop varieties coupled with frequent, shallow irrigation via micro irrigation systems during summer holds potential to mitigate the adverse impacts of elevated temperatures (Rank et al., 2020; 2023b, Kumar and Rank, 2023). While drip irrigation typically delivers water proximal to the root zone, the continuous flow may flood both macro and micro pores. In contrast, pulse irrigation administers water in cyclic patterns, allowing for adequate soil aeration intervals and facilitating robust plant growth (Mohammadi et al., 2023). Evaluating irrigation efficacy can encompass diverse approaches, from crop yield measurements to the analysis of water distribution within the soil. In this context, the present study scrutinizes the movement of the wetting front at varying discharge rates and intervals, comparing the outcomes of continuous irrigation with pulse irrigation for a comprehensive assessment.

1. Continuous Drip Irrigation System

The investigation encompassed the measurement of both radial and vertical extents of the wetted bulb.The experimental setup was at KCAET, Tavanur farm in the open field with variour components including pump, water tank and drip laterals. The irrigation water was supplied to farm through nearest well. The water tank was connected with main line adjoining sub main and laterals. The Observations were takenat intervals of 1 hour, 2 hours, and 3 hours after irrigation for Inline lateral dripperswith flow rates of 2 lph, 4 lph, and 8 lph Online dripper (Kyada and Munjapara, 2013). The measure tape was used to measure the wetted distance. The pressure was maintained continuously by bypass valve and checking the pressure at the end of the lateral by pressure gauge. The observed wetting front delineates water flow patterns, offering insights into dripper discharge determination and optimal timing for specific soil and plant conditions. This knowledge serves as a lever for curbing deep percolation losses. The horizontal distances were measured using the measure tape, while soil profiling allowed depth measurement. The profile configuration facilitated easy assessment of the wetting pattern as a semicircular segment of wetting was extracted, affording a frontal view to discern the distribution pattern.In the context of the current study, wetting front measurements were conducted for dripper laterals with flow rates of 2 lph, 4 lph, and 8 lph. These measurements were taken at intervals of 1 hour, 2 hours, and 3 hours during continuous irrigation. Notably, the measurements were undertaken both with and without accounting for the phenomenon of redistribution.

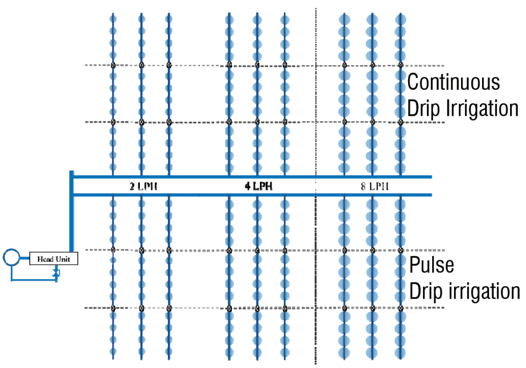

Plate 1 Experimental Layout

2. Pulse drip irrigation system

The wetting front under pulse irrigation was assessed using the same methodology, with measurements taken upon completion of an entire pulse cycle. In the case of pulse irrigation, discharge rates of 2 lph, 4 lph, and 8 lph were also considered; however, it is important to note that the timing of the irrigation pulses differed from the continuous irrigation setup.The Pulse Irrigation was deigned based on the procedure by Rank and Vishnu (2021b) with different intervals and flowrates.

The study was conducted in the sandy loam soil, with measurements undertaken to ascertain the extent of the wetted bulb beneath the root zone for diverse irrigation pulses across varying discharge rates. In addition, the moisture distribution within the wetted bulb was meticulously examinedas proposed in Table 1. The research critically elucidates the contrasting wetting patterns inherent to pulse and continuous irrigation methods, underscoring the pivotal role of aeration in optimizing root zone conditions.

Results and Discussion

Distinguishing the distribution of water within the root zone, a disparity arises between pulse and continuous trickle irrigation methods, yielding variations in soil aeration at the root zone. Soil aeration is typically assessed in terms of dissolved oxygen percentage or fractional representation, rather than mere saturation levels. This investigation reveals that enhanced aeration within the root zone amplifies root respiration, consequently contributing to improved crop yield outcomes.

After completing all the planned cyclesas shown in Table 1, the wetting pattern was accurately measured and subsequently compared with data acquired from continuous drip irrigation. Moisture samples extracted from the selected cuts enabled the assessment of moisture movement within the soil. The following results were smoothly illustrated through graphical representations, serving as a basis for comprehensive comparison. A cautious mixture of these results were added by contextualized writing and critical reviews, enriching the understanding of the observed wetting patterns and their implications.

1. Evaluation of Continuous Drip Irrigation System

I. *Wetting front movement under continuous drip irrigation*

The measurements were meticulously recorded using a measuring tape, and the resultant data was thoughtfully plotted graphically. The wetting front measurements corresponding to discharge rates of 2 lph, 4 lph, and 8 lphare presented below, providing a comprehensive visual representation of the observed wetting patterns.

a. Wetting front movement under 2 LPH continuous drip irrigation

The horizontal and vertical expansion of the wetting front emanating from the emitter was meticulously gauged for a discharge rate of 2 lph across varying time intervals, and the findings are visually depicted in Fig. 1. Notably, the horizontal progression rate exhibited a discernible decrease over subsequent time intervals. This reduction in advancement rate

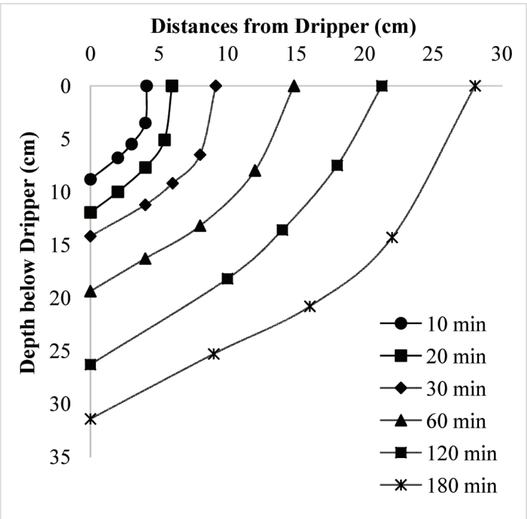

Figure 1. Wetting front movement under continuous drip irrigation using 2 lphdripper

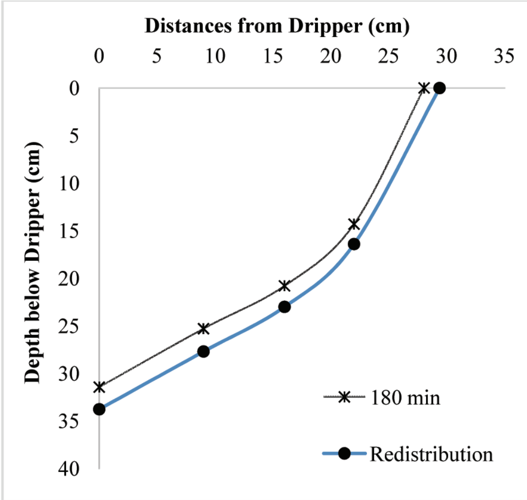

Figure 2. Wetting front movement after redistribution under continuous drip irrigation using 2 lphdripper

can be attributed to the augmented wetted surface area of the expanding wetting bulb. The results are in similar lines as reported by Shein, et al. (1988), Subbaiah &Mashru (2013).

The ultimate wetting front, subsequent to the redistribution of soil water within the wetted bulb, was further gauged after a 24-hr period, as visually illustrated in Fig. 2. Following the redistribution process, it was observed that vertical expansion surpassed horizontal expansion, primarily attributed to the prevailing influence of gravity forces in contrast to matric forces within the soil. These observationsare consistent with findings reported by Elmaloglou andDiamantopoulos (2007); Diamantopoulos and Elmaloglou (2012).

b. Wetting front movement under 4 LPH continuous drip irrigation

Fig. 3 portrays the progression of the wetting front in both horizontal and vertical directions, stemming from a 4 lphdripper, across diverse time points following the initiation of irrigation. Notably, the horizontal progress rate showed a visible reduction in comparison to later time intervals, a phenomenon attributed to the expanding wetted surface area of the wetting bulb. This trend aligns harmoniously with the findings of Gontia (1990) and Catzflis and

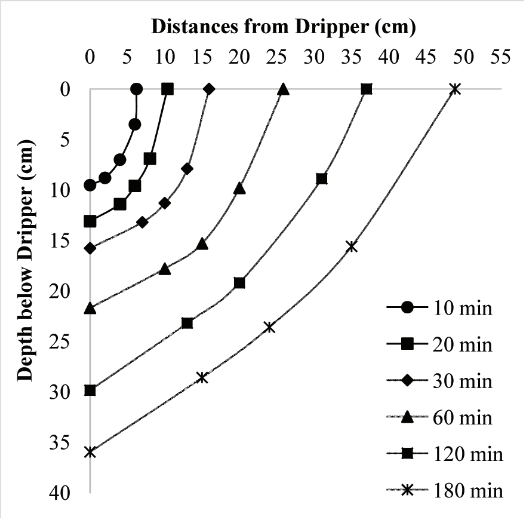

Figure 3. Wetting front movement under continuous drip irrigation using 4 LPH dripper

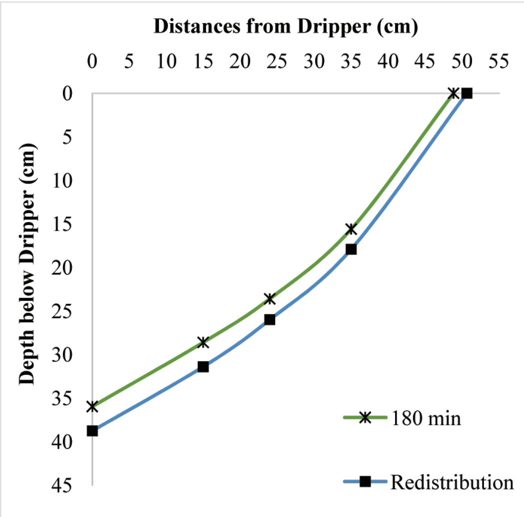

Figure 4. Wetting front movement after redistribution under continuous drip irrigation using 4 LPH dripper

Mortononi (1993). However, it is noteworthy that the outcomes reported for clay loam soils by Kyada and Munjapara (2013) exhibited some variance, contending that under drip irrigation employing 4 lph drippers, the formation of the wetted bulb occurred at the culmination of varying durations spanning 1 hr, 2 hr, 3 hr, 4 hr, and 5 hr.

Following the redistribution of soil water within the wetted bulb, the ultimate wetting front was measured after a 24-hour interval, as depicted in Fig. 4. Notably, the vertical expansion exhibited dominance over the horizontal expansion, attributed to the prevailing influence of gravity forces in contrast to the matric forces within the soils. This characteristic aligns consistently with findings reported by Elmaloglou and Diamantopoulos (2008, 2010), thus establishing a shared phenomenon observed across these studies.

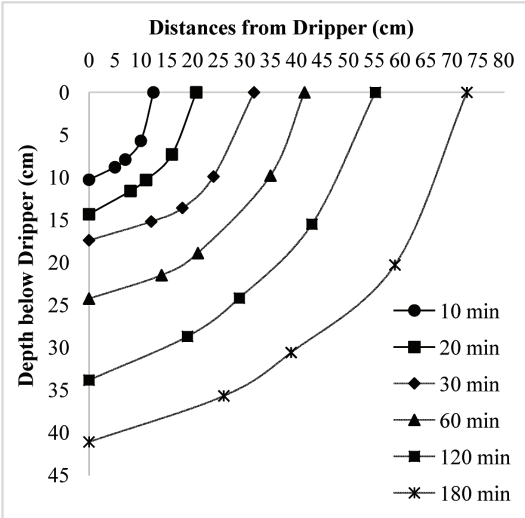

Figure 5. Wetting front movement under continuous drip irrigation using 8 LPH dripper

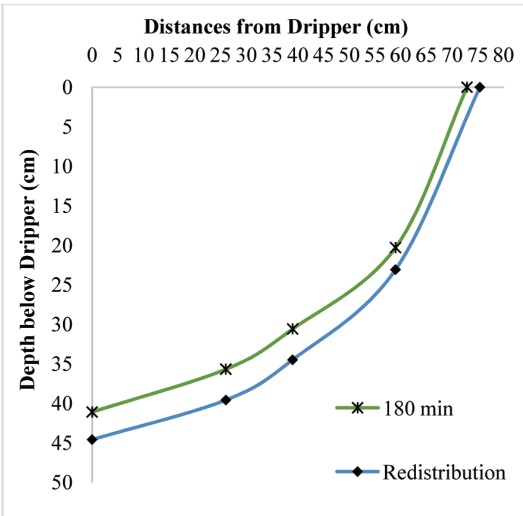

Figure 6. Wetting front movement after redistribution under continuous drip irrigation using 8 LPH dripper

c. Wetting front movement under 8 LPH continuous drip irrigation

Fig.5 illustrates the dynamic movement of the wetting front both horizontally and vertically, emanating from an 8 lph dripper, across diverse time intervals following the commencement of irrigation. It is noteworthy that the horizontal advancement rate exhibited a discernible decrease in comparison to subsequent time intervals, attributed to the expanding wetted surface area of the wetting bulb. This trend corresponds closely to outcomes reported by Singh et al. (1990), Hammami et al. (1994), Maheswarappa et al. (1997), and Battam et al. (2002), thereby underscoring a consistent alignment of findings across these studies.

The ultimate wetting front following the internal redistribution of soil water within the wetted region was measured after a 24-hour period, as depicted in Figure 6. Notably, this redistribution yielded a vertical expansion that surpassed the horizontal expansion due to the preeminence of gravitational forces over matric forces within the soil. In a related context, Rank et al. (2019) underscored the necessity of emitter rate and line spacing design, basedon soil texture, to achieve optimal wetted strip width for adequate root coverage of crops. This rationale resonates with findings elucidated by Elmaloglou and Diamantopoulos (2007) as well as Diamantopoulos & Elmaloglou (2012).

II. *Effects of dripper discharge rate on wetted bulb size*

The wetting front behavior for an 8 lph discharge significantly differs from that observed with 2 lph and 4 lph discharges, attributable to the higher flow rate resulting in a greater volume of water delivered within a given time frame. Consequently, this augmented water volume induces more pronounced radial and vertical movements of the water front. Discharge of 8 lph gives the highest radial and vertical water movement for equal time of irrigation.This phenomenon implies that moisture distribution could be substantially more pronounced when employing an 8 lph discharge.

At a discharge rate of 4 lph, the horizontal dimension of the wetted bulb at the surface increased by 1.74 times compared to 2 lph and by 1.49 times at 8 lph relative to 4 lph. Doubling the dripper discharge from 2 lph to 4 lph and from 4 lph to 8 lph resulted in a 1.14 times increase in vertical wetted bulb depth. After 24 hours, redistributions of soil water led to an expanded wetted bulb size. Specifically, the horizontal dimensions of the 2 lph, 4 lph, and 8 lph wetted bulbs increased by 4.74%, 3.69%, and 3.43%, respectively. Concurrently, vertical wetted bulb depth extended by 7.38%, 7.79%, and 8.51%, respectively. The percentage increase due to redistribution of soil water after 24hr in vertical depth was found higher as compared to horizontal dimension for all dripper rates of 2 lph, 4 lph and 8 lph due to more stimulus effects of gravity forces as compared to matric and capillary forces particularly in sandy textured soils.

Elmaloglou and Diamantopoulos (2007) provided support to the present findings, emphasizing that vertical depth expansion in the wetted bulb due to soil water redistribution surpasses the increase in its horizontal dimensions. After the field studies and modelling through volume balance by Subbaiah and Mashru (2013) have also found that the diameter of the formed wetted soil bulb at surface increased with the increase in time and discharge rate.Their study reveals a direct proportionality between the diameter of the wetted surface and the square root of the

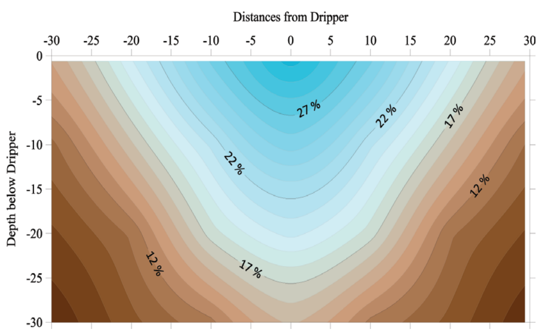

Figure 7. Soil moisture distribution under continuous drip irrigation using 2 LPH dripper

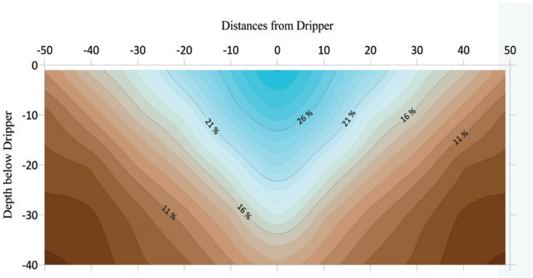

Figure 8. Soil moisture distribution under continuous drip irrigation using 4 LPH dripper

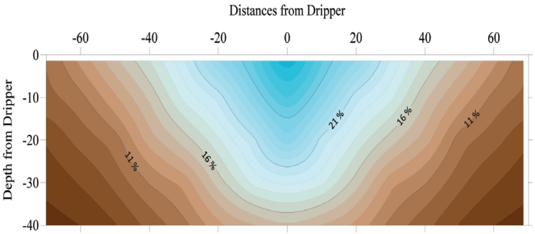

Figure 9. Soil moisture distribution under continuous drip irrigation using 8 LPH dripper

dripper discharge rate at any given time. The depth of wetted bulb remains less influenced by the discharge rate until it remains lower than the soil's infiltration capacity or encounters a resistive soil layer during penetration. After looking at how water moves in the soil, the effect of the water flow on how deep the soil gets wet is almost unimportant. This agrees with studies on sandy soils done by Elmaloglou and Diamantopoulos in 2007.The slight deviation of the present investigation may be due to different initial soil conditions as reported by Shein, et al. (1988), Elmaloglou and Diamantopoulos (2008, 2009b) stating that the shape and size of the wetted bulb depended on the initial moisture content of the soil.

III. *Soil moisture distribution under continuous drip irrigation*

The spatial distribution of moisture beneath the soil surface is intricately influenced by the hydraulic attributes of the soil and the discharge rate of the dripper. Employing the gravimetric method, the process of moisture redistribution was meticulously quantified across all three dripper discharge rates. These distributions are visually presented in Fig. 7, 8, and 9, corresponding to discharge rates of 2 lph, 4 lph, and 8 lph, respectively (Kyada and Munjapara, 2013; Rank and Vishnu, 2021a).

2. Evaluation of Pulse Drip Irrigation System

The horizontal and vertical extents of the wetting bulb were meticulously gauged across all three laterals, each featuring distinct pulse discharges. Comprehensive readings were documented and subsequently visualized through graph plotting. These measurements were accurately taken using a measuring tape. The wetting front dynamics for discharge rates of 2 lph, 4 lph, and 8 lphare visually illustrated, encapsulating the observed behavior.

I. *Wetting front movement under pulsed drip irrigation*

The pressing water scarcity concerns and heightened awareness in India regarding the significance of drip irrigation have facilitated a substantial push towards its widespread implementation. Nonetheless, certain design challenges arise in continuous water application for drip irrigation. Notably, emitter clogging stemming from the finer water path within drippers results in diminished discharge and the need to align the wetted bulb shapes with root zones, particularly in sandy soil groups. When applied to sandy loam soil, dripping water manifests as higher vertical depth yet diminished horizontal spread, potentially leading to water wastage beneath the root zone.

Table 1. Details of the considered parameters for pulse drip irrigation

Treatments	Discharge(LPH)	No. of Pulse cycles	Duration*(min)		Pulse cycle –1(min)		Pulse cycle –2(min)		Pulse cycle –3(min)	
			t_{ON}	t_{OFF}	t_{ON}	t_{OFF}	t_{ON}	t_{OFF}	t_{ON}	t_{OFF}
T4	2	3	60	60	20	20	20	20	20	20
T5	4	3	30	90	10	30	10	30	10	30
T6	8	3	15	105	5	35	5	35	5	35

*Irrigation depth is 4mm

The mitigation of this loss can be achieved through the implementation of high- discharge drip irrigation within sandy loam soil. However, it's noteworthy that opting for high- discharge rates may inadvertently leads to an expansion in both the vertical and horizontal dimensions of the wetted bulb, as evidenced by Ismail et al. (2014). A potential solution to counter this challenge involves the utilization of high- discharge drippers managed through a series of cyclic pulses.

Achievingwetted bulb dimensions and shapes that align with the root zone during different growth stages requires precise data on dripper discharge, pulse cycle ON and OFF times, as well as the number of cycles, with specific soil textures. Unfortunately,empirical findings specific to the study's sandy loam soilsessential informationremains notably absent.

Designing pulse irrigation entails a range of crucial considerations. Parameters such as irrigation depth, valve count, cycle frequency, and emitter discharge constitute pivotal design factors for pulse irrigation systems. The specifics of the system, irrigation depth, dripper discharge, effective irrigation rate, pulse count, and pulse cycle durations are meticulously outlined in Table 1, serving as the foundational variables underpinning the scope of the present investigations.

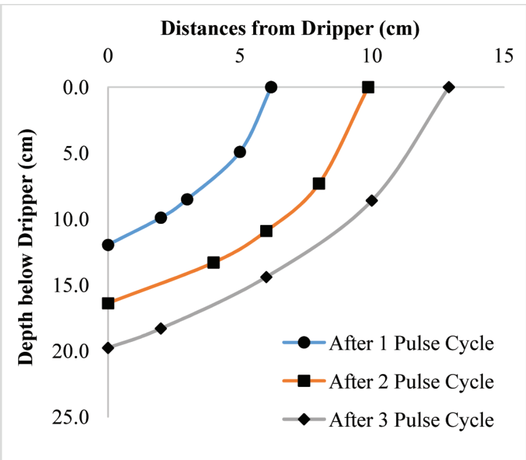

Figure 10. Wetting front movement after various pulse cycles under pulsedrip irrigation using 2 LPH dripper

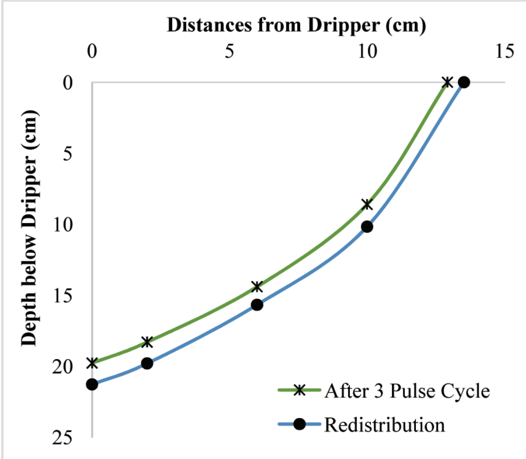

Figure 11. Wetting front movement after redistribution under pulsed drip irrigation using 2 LPH dripper

As illustrated in the above-mentioned Table 1, acomparable quantity of water (2 litersat 4 mm irrigation depth) is managed, although with varying time-basedsupply across different discharge rates. Evidently, pulse irrigation offers the advantage of harnessing higher discharge rates for shortened time intervals, thereby effectively justifying the existence of deep percolation losses. This strategic approach aligns with the primary objective of optimizing water utilization.

a. Wetting front movement under 2 LPH pulse drip irrigation

Fig. 10 visually illustrates the horizontal expansions of the wetted soil bulb at the soil surface, specifically beneath a 2 lph dripper, subsequent to the 1st, 2nd, and 3rd pulse cycles. Notably, the horizontal expansion rate of the wetted bulb displays a discernible reduction in subsequent pulse cycles when contrasted with earlier ones. Correspondingly, the vertical expansion of the wetted bulb is comparatively diminished during successive pulse cycles, primarily attributed to lower infiltration rates encountered in the latter pulses relative to their antecedents. This phenomenon is a result of the

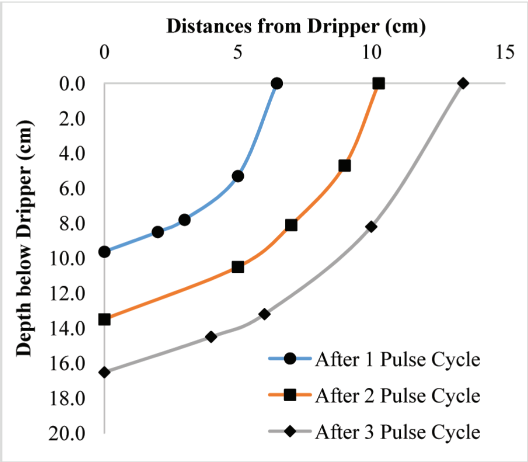

Figure 12. Wetting front movement after various pulse cycles under pulsed drip irrigation using 4 LPH dripper

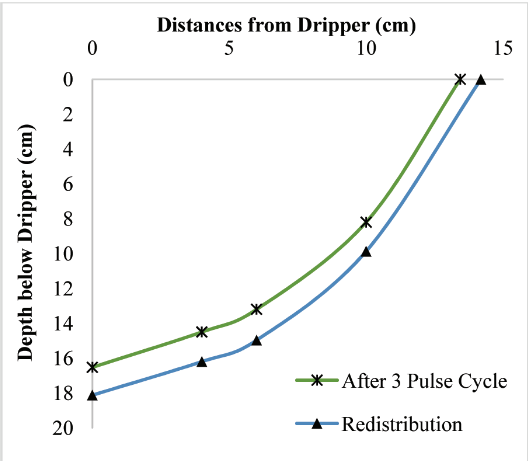

Figure 13. Wetting front movement after redistribution under pulsed drip irrigation using 4 LPH dripper

progressive diminution in soil water infiltration capacity over successive pulse cycles.

Figure 11 visually presents the dimensions of the soil wetted bulb subsequent to the 3rdpulse cycle and post-24-hour soil water redistributions under a 2 lph pulse drip irrigation configuration. Notably, the increment in width is comparatively lesser when juxtaposed with the vertical depth, possibly attributed to the heightened impact of gravity forces relative to soil matric forces. This observation is in line with findings reported by Hammami et al. (1994), Dhanapal et al. (1995), and Maheswarappa

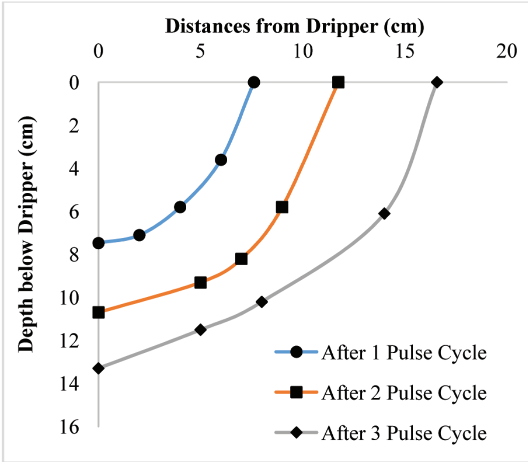

Figure 14. Wetting front movement after various pulse cycles under pulsed drip irrigation using 8 LPH dripper

et al. (1997).

b. Wetting front movement under 4 LPH pulse drip irrigation

In Fig. 12, the horizontal expansions of the wetted soil bulb at the soil surface beneath a 4 lph dripper are presented for the 1st, 2nd, and 3rd pulse cycles. Notably, the horizontal expansion rate of the wetted bulb demonstrates a diminishing trend in later pulses when compared to preceding ones. Similarly, the vertical expansion rate of the wetted bulb exhibits a deceleration in successive pulse cycles relative to previous ones, attributable to the reduced infiltration

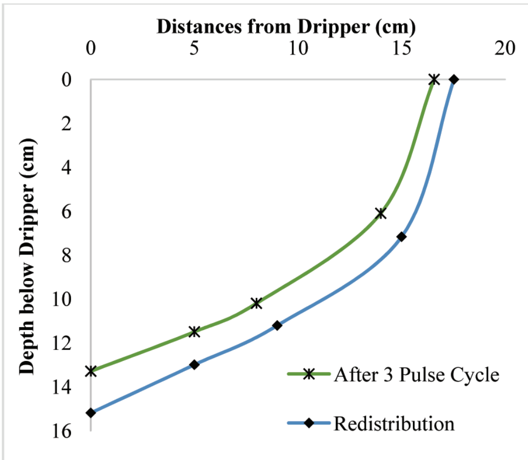

Figure 15. Wetting front movement after redistribution under pulsed drip irrigation using 8 LPH dripper

rate encountered in later cycles. This decrease in infiltration rate is likely due to soil water capacity depletion over successive pulses.

Fig. 13 portrays the dimensions of the soil wetted bulb following the 3rd pulse cycle and subsequent 24-hour soil water redistributions under a 4 lph pulse drip irrigation setup. It is evident that the increase in width is relatively less pronounced in comparison to the vertical depth, potentially due to the heightened influence of gravity forces relative to soil matric forces. These outcomes align closely with findings reported by Rosa et al. (2004) and Thabet and Zayani (2008).

c. Wetting front movement under 8 LPH pulse drip irrigation

Fig.14 visually represents the horizontal expansions of the wetted soil bulb at the soil surface under an 8 lph dripper, sequentially following the 1st, 2nd, and 3rd pulse cycles. Evidently, the horizontal expansion rate of the wetted bulb demonstrates a reduction in subsequent pulses when compared to earlier ones. Similarly, the vertical expansion rate of the wetted bulb exhibits a deceleration during successive pulse cycles, primarily attributed to lower infiltration rates encountered in later pulses compared to preceding ones. This trend in vertical expansion rate underscores the progressive diminution of soil water infiltration capacity over successive pulse cycles.

The soil's wetted bulb, observed at the conclusion of the 3rd pulse cycle, exhibited enlargement subsequent to the 24-hour redistributions of soil water within an 8 lph pulse drip irrigation system, as evident from Figure 15. Notably, the increase in width was comparatively less pronounced than the vertical depth following the soil water redistributions, potentially attributed to the prevailing dominance of gravity forces over soil matric forces. These findings are notably aligned with those reported by Dhanapal et al. (1995) and Rosa et al. (2004).

II. *Effects of discharge on wetting front movement under pulse drip irrigation*

The examination of wetted bulb sizes resulting from different pulse cycles under varied dripper discharge rates revealed notable effects. The width of the wetted bulb exhibited a 4% increase under 4 lph drippers following the 3rd pulse cycle and a 5% increase after the redistribution of soil water, relative

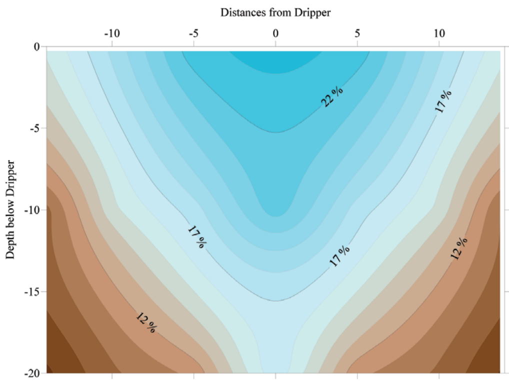

Figure 16. Moisture Distribution below dripper for 2 LPH discharge after 3rd pulse cycle of pulsed irrigation

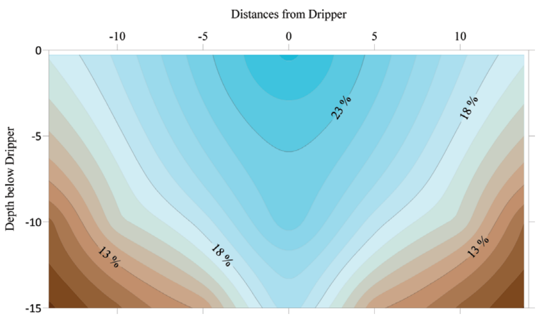

Figure 17. Moisture Distribution below dripper for 4 LPH discharge after 3rd pulse cycle of pulsed irrigation

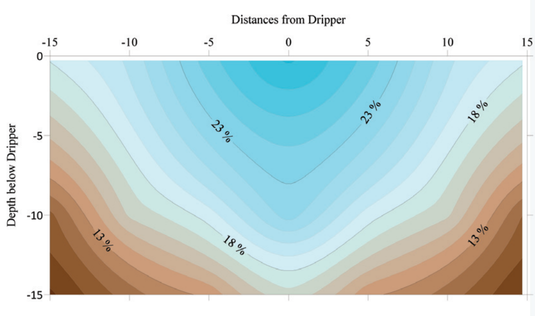

Figure 18. Moisture Distribution below dripper for 8 LPH discharge after 3rd pulse cycle of pulsed irrigation

to the 2 lph drippers. Correspondingly, it experienced a 24% augmentation under 8 lph drippers after both the 3rd pulse cycle and redistribution of water, compared to the 4 lph drippers. Furthermore, the width of the wetted bulb under 8 lph drippers showed a 29% increase after the 3rd pulse cycle and a 30% increase after the redistribution of soil water, in comparison to the 2 lph drippers.

The investigation revealed that the depth of the wetted bulb exhibited reductions of 0.83 times under 4 lph drippers after the 3rd pulse cycle and 0.85 times after the redistribution of soil water, when compared to the 2 lph drippers. Likewise, it alsodecreases to 0.81 times under 8 lph drippers after the 3rd pulse cycles and to 0.84 times after the redistribution of water, relative to the 4 lph drippers. Furthermore, the depth of the wetted bulb under 8 lph drippers demonstrated a reduction to 0.67 times after the 3rd pulse cycle and to 0.71 times after the redistribution of soil water, compared to the 2 lph drippers (Elmaloglou and Diamantopoulos, 2007; Phogat et al., 2012; Rank and Vishnu, 2021a).

III. *Soil moisture distribution under pulse drip irrigation*

The redistribution of moisture below the soil surface during the rest time of the pulse cycle and after the end of irrigation is depending upon factors such as hydraulic conductivities in different directions of soil layers, texture, drainable porosity, and evaporation from the soil surface, pulse flow rate and pulse ratio etc. The gravimetric method was employed to measure the moisture redistribution after a 24-hour period following the last pulse cycle for all three dripper discharge rates, as illustrated in Fig. 16, 17, and 18 respectively for 2 lph, 4 lph, and 8 lph.

By utilizing drippers with higher discharge rates, the distribution of soil moisture can be extended in horizontal directions. Employing pulsed drip irrigation with elevated discharge rates while maintaining the same volume of irrigation water has the potential to mitigate deep percolation losses. Notably, under higher discharge rates, the depth of the wetted zone was observed to be reduced due to shorter ON cycles and longer OFF cyclesof Pulse irrigation in comparison to lower discharge rates. Rank and Vishnu (2019) highlighted that pulsed drip irrigation yielded a more uniform distribution of soil moisture and soil aeration within the wetted bulb, contrasting with continuous drip irrigation. Notably, such disparities were less pronounced as soil water during the rest intervals of pulse cycles predominantly moved downward rather than horizontally in sandy loam soil.

Conclusions

The analysis of the results confirms that the dimensions of wetted bulbs achieved through continuous and pulsed drip irrigation, using drippers with varying discharge rates, can show increased horizontal movement and reduces deep percolation under higher discharge pulse drip irrigation when compared with lower discharge continuous irrigation for the same volume of water application. The intervals of rest during pulse irrigation cycles allow for the redistribution of soil water within macropores after each on-time cycle, resulting in a reduced final redistribution compared to continuous irrigation. Moreover, the rise in wetted bulb size attributed to soil water redistribution in pulsed drip irrigation tends to be less noticeable compared to continuous irrigation.

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