GROWTH OF COTTON CROP (*GOSSYPIUM HIRSUTUM* L.) HIGHER UNDER DRIP IRRIGATION BECAUSE OF BETTER PHOSPHORUS UPTAKE

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Abstract. The uptake of phosphorus (P) by plants is strongly dependent on the root distribution in the soil profile. The root architecture of crops changes significantly under different irrigation methods. A field experiment was conducted in 2016 and 2017 to investigate the root growth and P uptake responses to drip irrigation (DI) and flooding irrigation (FI) for cotton crop (*Gossypium hirsutum* L.). Plant growth, P concentration and P uptake of cotton plants were higher under DI compared to FI. Although the total root length of a cotton plant was not significantly different between DI and FI. While root system was more shallowly distributed in the soil profile under DI than FI (48.8% of the total roots length were distributed in the 0–10 cm soil layer under DI, and 31.5% under FI). Greater overlap in roots distribution and P concentration in soil was observed under DI. The P content in the 0–10 cm soil layer was significantly lower under DI than FI, because of P absorbed by cotton plants roots for above-ground biomass production. The contribution of unit root length of P uptake towards shoot was higher under DI. It was concluded that shallow roots distribution in response to DI may improve the P nutrition of cotton plants.

Keywords: *plant development, watering techniques, nutrients, soil profile, roots distribution*

Introduction

There are many macro- and micro- nutrients, that boost plant growth, among which phosphorus (P) is the most important nutrient. Concentrations of P in plant dry weight varies from 0.05% to 0.5% (Malhotra et al., 2018). P plays an important role in the metabolic process and energy transformation because it contain proteins, adenosine di-phosphate (ADP), nucleic acid, sugar phosphate and plenty co-enzymes (Husain et al., 2019). The concentration of P in the soil much higher than in the plant, but its availability under the soil in the form of calcium/iron or magnesium phosphates reduces P availability for plants uptake (Cong et al., 2020). Therefore, the plant is facing P deficiency in many agricultural fields. P deficiency reduces plant growth because the plant increased its energy investment by securing the photosynthesis (Schneider et al., 2019). It has been estimated that 20 to 40% crops growth were reduced by P deficiency (Wen et al., 2021).

In plant growth process, roots are the main parameter that can get nutrients and water from soil and transferred into different growth parameters for their development (Haling et al., 2016a). Morphological Characteristics and distribution of roots are critical for efficient uses of water- nutrients in the soil for different crops (Zhou et al., 2019; Wu et al., 2022). Mostly crops roots distribution are mainly in the range of 0-0.6m under conventions irrigation and fertilizers strategy (Cheng et al., 2020). While soil nutrients are mainly available in the upper soil horizons, that’s create the mismatch between soil nutrients availability and roots distribution (Su et al., 2019). Furthermore, water-nutrients

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in the deeper soil may not be used many plants effectively due to low roots density (Zhang et al., 2022). Therefore, optimizing the water and nutrients strategy by using latest techniques like drip irrigation can enhance the roots soil-water relationship and finally plant growth was increased (Al-Ghobari and Dewidar, 2018). There are many nutrients that helps to boost plant growth but P played important role for roots and growth development of plants (Wahid et al., 2020). To enhance P acquisition, plants involved plenty of strategies, according to the environmental conditions such as modified root architecture and morphology by adjusting root diameter, enhancing specific root length along with higher hair and density (Haling et al., 2016a,b; Beltayef et al., 2021). These different roots morphological adaptations make them able to exploit large volume of soil by enhancing root surface area and excess to P-rich patches (McLachlan et al., 2020).

In agriculture sector, water is the main factor that effect crop growth but water resources are going to be scared, because of using conventional irrigation methods (Qiang et al., 2022). In water scare areas people using different efficient irrigation methods, like sprinkle and drip irrigation (DI) to get maximum production from different crops (Hou et al., 2022). DI is the more accurate method to improve crop growth, fruit quality and water saving technique as compared to sprinkle irrigation (Shabbir et al., 2020a). DI is also effective for fertilizer control along with water saving for different crops (Abd El-Mageed et al., 2018). Fertilization (nitrogen and phosphorous) along with irrigation improve soil nutrients availability, that improved roots growth and crops production (Jha et al., 2019). Nutrients along with water uptake from different soil surfaces are greatly influenced by roots morphology (root diameter, root surface area, root density and root length) and roots distributions (Li et al., 2017).

The concentration and distribution of P under the soil is different due to different fertilizer methods but under DI, the distribution of P (as a base fertilizer) is very smooth especially 0-20 cm soil depth (Li et al., 2015; Shabbir et al., 2020b). Mostly plants allocate more roots in the upper layer of the soil under DI because of rich resources of P as compared to lower soil layer (Lu et al., 2021). Mostly plants modified their roots architecture, according to the availability of P in the soil (Shen et al., 2011). In DI mostly plants obtained shallow roots development because of higher P resources in the top soil layer (Shen et al., 2011). Therefore, it can be said that many plants adjust their roots growth according to the availability of nutrients in the soil.

In China, Xinjiang Province have semi-arid and arid areas containing soil with low nutrients availability. Major crops, wheat and cotton (*Gossypium hirsutum* L.) are growing in mostly areas of Xinjinag. Large number of cotton crop is grown in Xinjinag because of its exceptional climate that suitable for cotton crop. While growth of cotton crop in this region facing problem of major nutrients deficiency (Nitrogen and Phosphorus) in the soil and shortage of water because of less rainfall and intense evaporation due to harsh climate. Therefore, in this region many researchers grown cotton crop under DI along with fertigation. While the role of cotton plants for roots development under fertigation with DI has not been so cleared. Therefore, in this present study, we hypothesized under DI, cotton plants develop shallow roots distribution, that is beneficial for plant growth in every development stage by increasing P uptake.

Materials and methods

Experimental site

Field experiments were conducted on cotton plant (*Gossypium hirsutum* L.), for the period of 2016-2017 in Korla, experimental station of Xinjiang, academy of agricultural sciences, Urumqi, China. This site belongs to arid climate with mean annual rainfall, 56mm, mean annual evaporation 2497 mm and mean annual temperature 11°C. Chemical properties of the soil layer at 0-30 cm was analyzed before sowing. Soil containing, NO_3^--N 36.54 mg kg^{-1}, NH_4^+-N 6.53 mg kg^{-1}, pH (H_2O) 8.0, soil density 1.33 g cm^{-3}, Olsen-P 2.88 mg kg^{-1}, NH_4OAc-extracted K 152.5 mg kg^{-1}, and organic matter 7.65 g kg^{-1}.

Experimental design

In these experiments, two water treatments, consisting of drip irrigation (DI) along with mulch film and flooding irrigation (FI) along with mulch film were used. There were six plots with area of each 10 m × 12 m were used with three replicates in a randomized block design. Seeds of cotton were sown on 25 April 2016 and 2 May 2017 at an identical density of 220,000 plants ha^{-1}. The plant spacing and irrigation system used in these experiments are summarized in *Fig. 1*. All irrigation drip lines in the drip irrigation treatment plots were connected to the main irrigation pipe, and a fertilizer tank. Switch and water meter were installed on the main irrigation pipe to control the amount of water and fertilizer applied. Irrigation was directly applied by flooding to the plots for FI treatment through a pipeline, for which the amount of irrigation was controlled by a water meter.

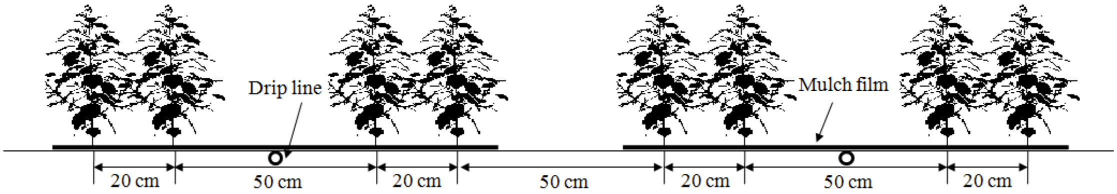

Figure 1. *Plant spacing and drip line spacing used in these experiments. Four rows of cotton plants were planted under mulch film, and an irrigation drip line was laid in the center of the mulch film (the drip line was not used in the flood irrigation treatment)*

The volume of water supplied by DI and FI during the experiments were 4000 m^3 ha^{-1} and 6000 m^3 ha^{-1}, respectively. Water was supplied on 10 times at weekly intervals under DI, and 4 times at 2-to-3-week intervals for FI (*Table 1*). The water supply was ended in mid and late August under FI and DI, respectively. 150 kg P_2O_5 ha^{-1} (superphosphate) and 150 kg K ha^{-1} (potassium chloride) were applied as base fertilizer before sowing. Urea was applied at rates of 350 kg N ha^{-1} and 400 kg N ha^{-1}, out of which 20% and 50% was applied as base fertilizer under DI and FI, respectively, and the remaining was applied with irrigation intervals (*Table 1*).

Plant harvest

Plants were harvested at the peak flowering stage, after 96 days of sowing (DAS) in 2016 and 98 DAS in 2017, respectively. Randomly selected eight uniform plants of every treatment and divided into stems, leaves and reproductive organs (flowers and buds) of the above ground part of every plant respectively. All samples were over-dried at 72°C for 48 hours (Azeem et al., 2021) to obtained constant dry weight.

***Table 1.** Water and nitrogen fertilizer applications in the drip irrigation (DI) and flooding irrigation (FI) treatments*

Treatment		Years 2016 2017	Date of application[1]									
			12 Jun 14 Jun	19 Jun 22 Jun	26 Jun 29 Jun	3 Jul 7 Jul	10 Jul 12 Jul	17 Jul 20 Jul	24 Jul 26 Jul	1 Aug 5 Aug	8 Aug 12 Aug	16 Aug 21 Aug
Water (m^3/ha)	DI	4000	260	300	420	500	500	500	500	400	340	280
	FI	6000	–	1200	–	–	1800	–	1800	–	1200	–
Nitrogen (kg N/ha)	DI	270	–	10	10	30	40	40	40	40	30	30
	FI	200	–	48	–	–	–	–	100	–	52	–

[1] The amounts of water and fertilizer applied were identical in both cropping seasons. '–' indicates no nitrogen or no irrigation application

Roots were harvested by using monolith method (Smit et al., 2013). Soil cubes with 10 cm sides (1000 cm^3) were dug individually in a soil volume of 70 cm × 20 cm, to a depth of 60 cm surrounding of the randomly selected four plants (*Fig. 2*). The total number of monoliths for the four plants were 84. Roots were sieved with a stainless-steel mesh (1 mm diameter) and stored at –20°C until measurement of the roots length (Mai et al., 2013). Soil samples were collected from each soil block after the roots were sieved, then air-dried and sieved (1 mm mesh) for soil available P analysis. Roots collected from each soil block were scanned with a digital scanner (Epson V700, Djakarta, Indonesia) at 200 dpi with grayscale pixels and saved as TIF image files (Mai et al., 2013). The images were analyzed using DELTA-T SCAN version 1.0 software (Delta-T Devices, Burwell, UK). After scanning, the root fractions were dried at 72°C for 48 hours to obtain constant weight and weighted by weight balance.

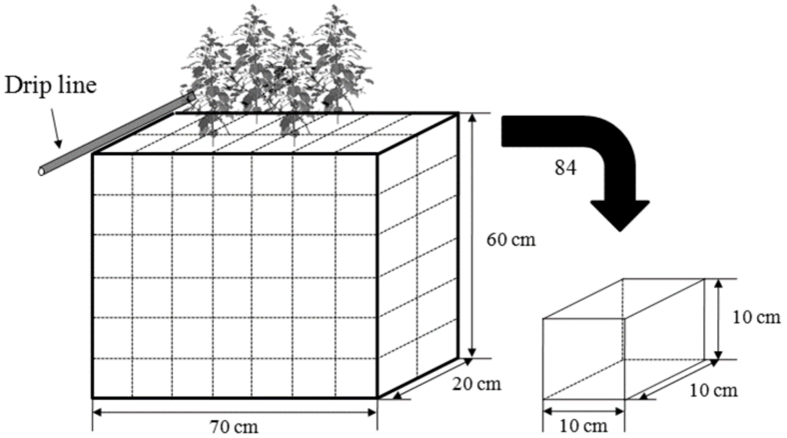

***Figure 2.** Method of root and soil collection. To determine the influence of drip irrigation (DI) treatment on the spatial distribution of cotton roots in the soil profile, the root system of eight cotton plants was collected by means of a monolith method in the 2016 and 2017 cropping seasons. Under flooding irrigation, although the drip line was not used, the root sampling procedure was consistent with that of the DI treatment*

Dried samples of roots, stems, leaves and reproductive organs were converted into a powder and the total P content was determined using the ascorbic acid method (Bao, 1999).

Soil available P was extracted using 0.5 mol L^{-1} $NaHCO_3$ (2.5 g soil, 50 ml solution, 25°C, shaken for 30 min), and the inorganic P concentration was measured calorimetrically using the molybdate-ascorbic acid method (Murphy and Riley, 1962).

The spatial distribution of root length density in the soil profile is presented as wireframe diagrams. The mean root length per plant (m $plant^{-1}$) was calculated by dividing the total root length for the 84 soil blocks by four (the number of plants sampled). The ratio of shoot P uptake/root length reflects the ability of the root system to supply P to the shoot.

Data analysis

Assumptions of parametric statistics were tested to verify normality and homogeneity of variance using the Shapiro–Wilk normality test and Levene’s test before further analysis. Data were analyzed using one-way analysis of variance (ANOVA) with treatment as main factor, to determine the main effect and interaction effects of each growth trails ($P < 0.05$). Furthermore, a posthoc Tukey test $P < 0.05$ was performed to determine significant difference within treatments (SPSS 22). Graphs were made by using origin Pro9.

Results

Growth traits biomass and P uptake

Growth trails of cotton crop under two years of growing seasons were investigated under DI and FI, found very significant results ($p<0.05$). The vegetative organs (roots, stems and leaves) of cotton plants are significantly higher biomass under DI, compared with FI (*Fig. 3A*). Shoot biomass (stems and leaves) under DI was significant different than FI (18.7 g $plant^{-1}$ at DI and 15.6 g $plant^{-1}$ at FI). While on the other hand, reproductive organs biomass under DI was significantly ($P<0.05$) 27.7% lower than FI (6.5 g $plant^{-1}$ and 4.7 g $plant^{-1}$ under FI and DI, respectively).

P uptake in mostly organs of cotton plants were higher in DI than FI. P content in the shoot of plants were significantly ($P<0.05$), 12.1% higher under DI as compared to FI (157.6 mg $plant^{-1}$ and 140.6 mg $plant^{-1}$ under DI and FI, respectively) (*Fig. 3B*). There is no significant ($P>0.05$) difference between root and stem. P concentration under DI and FI but P concentration between leaves and reproductive organs were significant difference under DI (0.71% in leaves and 1.02% in reproductive organ) as compared to FI (0.64% in leaves and 0.85% in reproductive organ) (*Fig. 4*).

Root and available P distribution

Overall root length of cotton plants was showed no significant ($P>0.05$) difference between DI and FI (51.9 m $plant^{-1}$ and 50.3 m $plant^{-1}$, respectively) (*Fig. 5A*). However, significant ($P<0.05$) difference were observed in the distribution of root length in the soil profile (*Fig. 5B*). In the 0–10 cm soil layer, cotton plants, root length under DI (25.3 m $plant^{-1}$) was higher than FI (15.8 m $plant^{-1}$). The cotton plants root length density in the 0–10 cm soil layer was generally greater than 4 m 1000 cm^{-3} within DI, that was considerably lower under FI (*Fig. 5A*). The ratio of cotton plants root length (0–10 cm soil depth as a proportion of the total root length at 0–60 cm soil depth) was significantly higher (48.8%) under DI compared to FI (31.5%). While, at the 10–60 cm soil layers the root length of cotton plants was higher under FI as compared to DI (*Fig. 5B*).

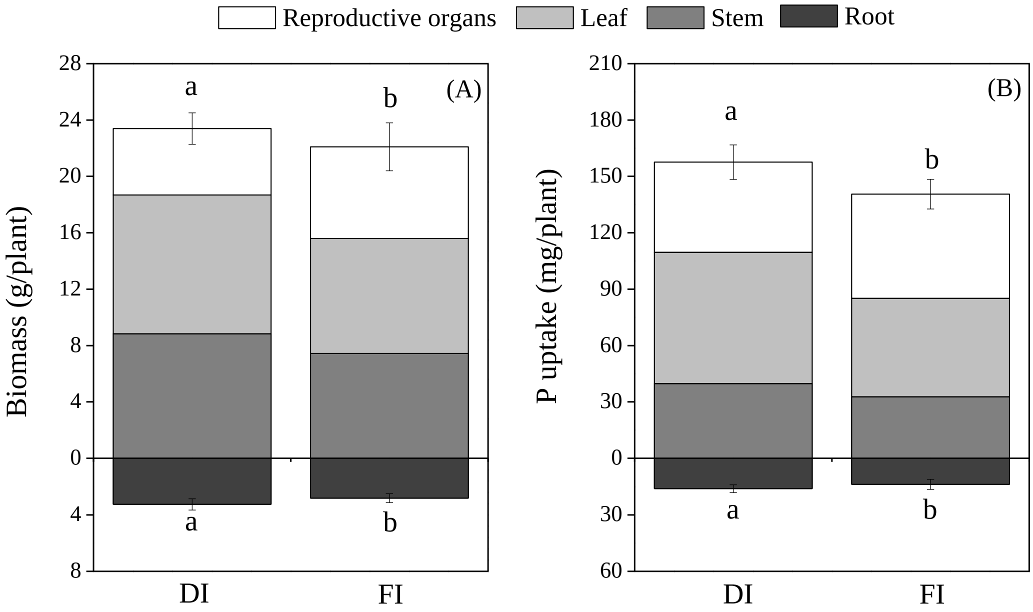

Figure 3. *Cotton biomass (A) and phosphorus uptake (B) under drip irrigation (DI) and flooding irrigation (FI). Bars above zero represent the shoot and bars below zero represent the root. Error bars represent the standard error of the mean (n = 8). Different lower-case letters above and below the bars indicate a significant difference in biomass and Phosphorus uptake in the shoot and root, respectively, between DI and FI at the 0.05 significance level*

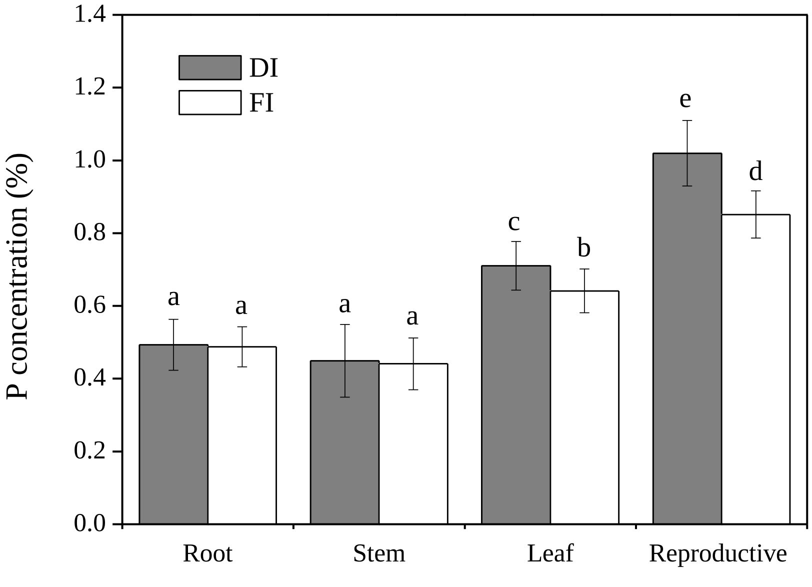

Figure 4. *Phosphorus concentration in cotton plant organs under drip irrigation (DI) and flooding irrigation (FI). Error bars represent the standard error of the mean (n = 8). Different lower-case letters above the bars indicate a significant difference between DI and FI at the 0.05 significance level*

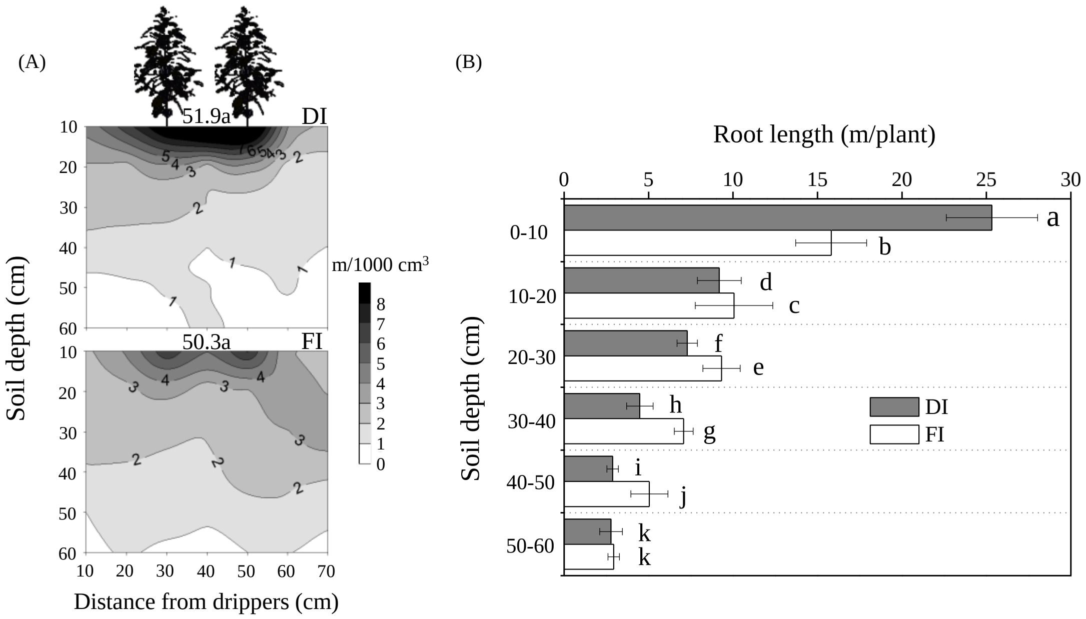

Figure 5. *Spatial distribution in the soil profile of root length density (m per 1000 cm^3 soil) (A) and root length at 0–60 cm soil depth (B) of a cotton plant under drip irrigation (DI) and flooding irrigation (FI). In (A) the value above each diagram corresponds to the total root length of a single cotton plant at 0–60 cm soil depth (m/plant). Different lower-case letters indicate a significant difference in total root length between DI and FI at the 0.05 significance level. In (B), the error bars represent the standard error of the mean (n = 8). The values on the right-hand side of the graph indicate the ratio (%) of the cotton root length (m) in each 10 cm soil layer to the total root length (0–60 soil depth). Different lower-case letters beside bars indicate a significant difference in root length between DI and FI in each soil layer at the 0.05 significance level. Although the drip line was not used under FI, the sampling method for the FI treatment was consistent with that used for DI; therefore, the abscissa in (A) is indicated by the "distance from drippers", regardless of whether the drip line was used*

Available P content in soil showed different results under different layer of soil profile within DI and FI (*Fig. 6*). There is a significant ($P<0.05$) between DI and FI at 0-20 cm soil layer (*Fig. 6*). At 0-10 cm soil depth, available P content in soil under DI (23.6 mg kg^{-1}) was significantly ($P<0.05$) lower than FI (29.5 mg kg^{-1}). While, at 10-20 cm soil depth, available P content in soil under DI (27.5 mg kg^{-1}) was significant ($P<0.05$) higher than FI (21.7 mg kg^{-1}), respectively (*Fig. 6*). In soil layer below 20 cm, there is no significant ($p>0.05$) difference between DI and FI (*Fig. 6*).

Root length densities between <1 to 4 m 1000 cm^{-3}, increased soil available P content with the increased in root length density (*Fig. 7*). When root length density >4 m 1000 cm^{-3}, soil available P content was decreased as compared to 3-4 m 1000 cm^{-3}, root length density (*Fig. 7*).

Ratio of shoot P uptake/root length

There are -significant ($P<0.05$) results of ratio of shoot P uptake/root length between DI and FI. While ratio of shoot P uptake/root length was higher in DI (3.1 mg m^{-1}) than FI (2.8 mg m^{-1}), respectively (*Fig. 8*).

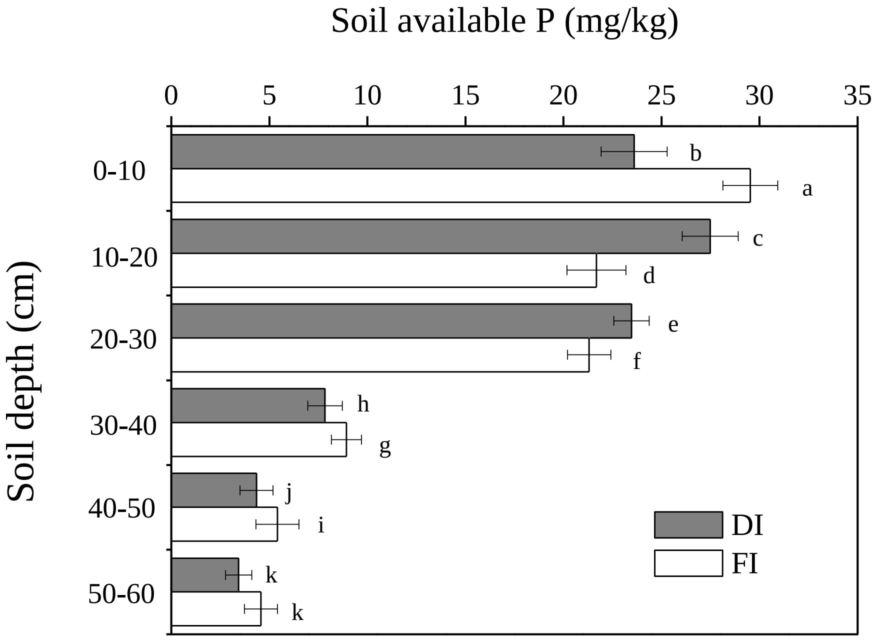

Figure 6. *Soil available phosphorus (P) content at 0–60 cm soil depth under drip irrigation (DI) and flooding irrigation (FI). The error bars represent the standard error of the mean (n = 8). Different lower-case letters beside bars indicate a significant difference in soil available P between DI and FI in each soil layer at the 0.05 significance level*

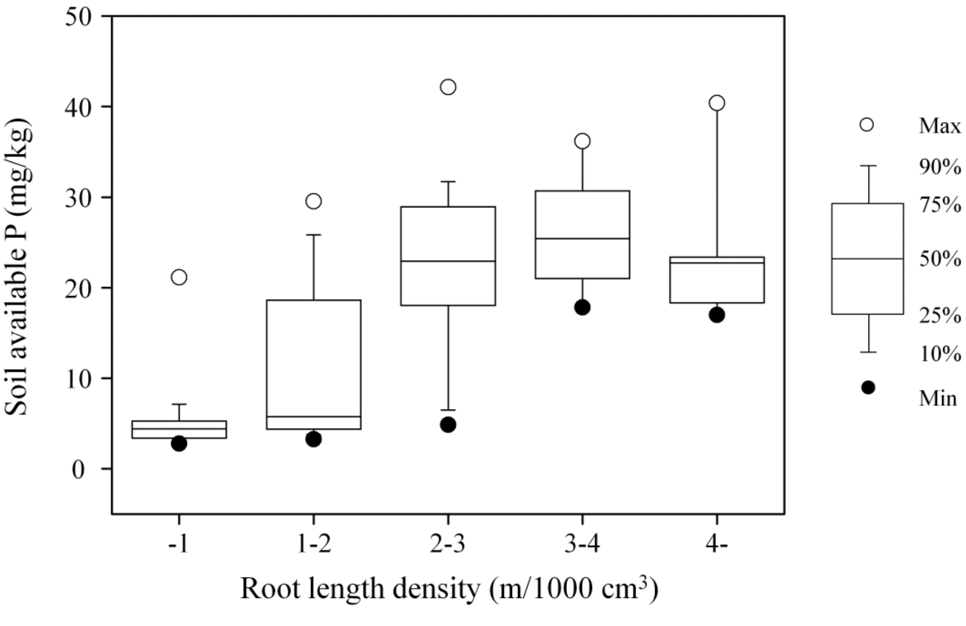

Figure 7. *Soil available P content in different classes of root length density. A key to the box and whisker plots is on the right*

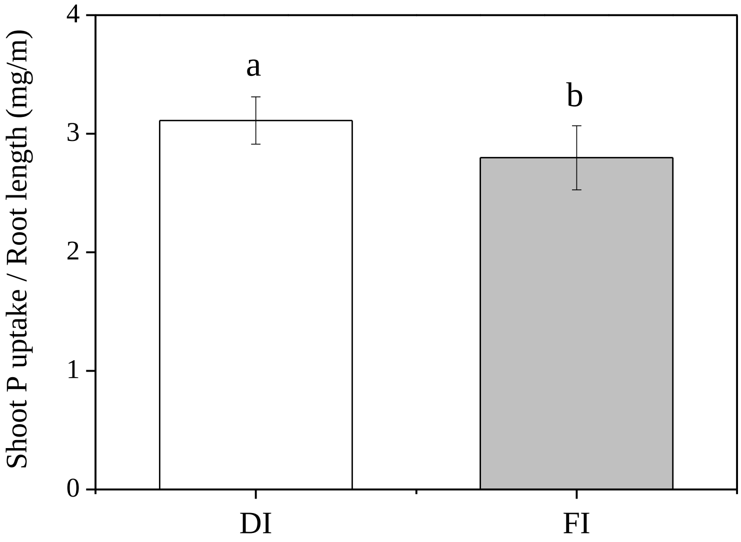

Figure 8. *Shoot P uptake/root length ratio under drip irrigation (DI) and flooding irrigation (FI). The error bars represent the standard error of the mean (n = 8). Different lower-case letters indicate a significant difference at the 0.05 significance level*

Discussion

World population increasing day by day that cause deceased in agricultural land and water deficiency (Azeem et al., 2020). In agricultural practices, people using convention irrigation methods for crop development but these methods or techniques do loss lot of water and fertilizers (Girma and Jemal, 2015). While by using these convention irrigation methods plant of different crops invests a lot in below-ground growth development to capture resources (Azeem et al., 2021). While on the other hand, under drip irrigation plant can get water and fertilizer easily from its roots (Arshad, 2020). Growth of different crops under drip irrigation has been increased as compared to convention methods because resources are available for its growth development (Ghosh et al., 2018). Plant invests less for its roots development because it’s get resources in a defined range (Rank and Vishnu, 2021). In the present study, P uptake of cotton plants was higher under DI as compared to FI (*Fig. 3B*). Plant growth was promoted owing to better water and nitrogen supply under DI, that would stimulate demand of P and resulted in increased P uptake (Hou et al., 2022). The quantity of water and nitrogen supply were significantly different between DI and FI (*Table 1*). The DI is the most suitable irrigation application for cotton plant growth because it’s give water and nutrients more accurately with low volume, that is beneficial for better growth production due to high frequency application (Wang et al., 2015; Leogrande et al., 2016). In DI, shoot growth of cotton plants were higher than roots length because easy excess of water and nutrients make plants able to spend more energy on above-ground biomass as compared to below-ground (*Fig. 3A*) (Wang et al., 2004). Furthermore, plants under DI changing its growth strategy by enhanced its vegetation growth but inhibiting reproductive growth (*Fig. 3A*). Vegetation development demand more P (Wang et al., 2015), that was increased P uptake from roots under DI as compared to FI.

Higher P concentration often produced dilution effect at which growth of plants increased but nutrient concentration in plant tissues were deceased (Jahan et al., 2019). While in the current study, under DI cotton plants have higher growth and P concentration

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in plants tissues were also higher, especially in leaves and reproductive organs, that showed no dilution effect (*Fig. 4*). In FI growth of cotton plants were lower because plants investing same energy in below-ground and above-ground for its growth development (Azeem et al., 2020; Azeem et al., 2021). Higher nutrients concentration along with flooding reduced the growth of plant because it create submergence and eutrophication effects (Azeem et al., 2021), that was found under FI (*Fig. 4*). P uptake capacity of cotton plant under DI was higher and smooth because it can get define amount of water along with nutrients so plant developed shallow roots and make more energy to develop above-ground biomass (Shabbir et al., 2020a,b). While in FI, due to higher infiltration rate, cotton plant spend equal energy to make development in above-ground and below-ground (Sun et al., 2022).

In Xinjiang, China, mostly agriculture lands, having very less P uses efficiency (Wang et al., 2018). The reason behind of low P uses, is that mostly P fertilizers are immobilized in soils, because P is strongly adsorbed to iron, aluminum cations at low soil pH and calcium ions at high soil pH (Husain et al., 2019). Therefore, the P uptake efficiency of a crop is largely depends on the roots distribution in the soil (e.g., greater roots distribution in soil containing a higher P concentration result with higher P absorption potential) (Rank and Vishnu, 2021). Root length is more scientifically meaningful than root dry weight for evaluation of plant root function (Vengavasi and Pandey, 2018), because the uptake of water and nutrients by roots depends on the total soil area at which the root has contact (Niu et al., 2010). In the present study, no difference in cotton total root length between the DI and FI treatments were observed, because amount and mode (base fertilizer) of P was identical under DI and FI. Which suggested that the capacity of nutrients absorption by cotton roots should not differ significantly between DI and FI. Therefore, P uptake of cotton plant increased to fulfil the P demand resulting by increased shoot growth under DI that may be attributed to change roots distribution in the soil. The cotton plant roots distribution were shallow (half of the total root length was distributed at 0-10 cm soil layer, *Fig. 5*) because of smooth water and nutrients supply under DI (Yuan et al., 2019). This was also consistent with the distribution of P available content in the soil profile (*Fig. 6*). While shallow roots distribution in the upper soil layer increased contact area of cotton plant with soil profile that having large amount of P (Haling et al., 2016a). This would enable cotton plant roots to absorb more P under DI. Furthermore, with this interpretation, P supply to the plant shoot per unit root length was higher under DI as compared to FI (*Fig. 8*). While, remaining available P content in the upper soil layer 0-10 cm was less under DI (*Fig. 6*) because due to shallow roots and higher root length density in upper layer of soil 0-10 cm (*Fig. 5*). This enable plant to utilize these P for plant above-ground growth development (Liu et al., 2022). According to the finding of present study, when root length density was higher than 4 m 1000 cm^{-3}, more strong P absorption by roots because of higher root density in the upper soil profile and resulting lower P Content. While FI have opposite results, deep roots distribution within soil profile and less soil contact area in the upper soil layer (*Fig. 5*). Furthermore, non-uniform water and nutrients distribution make plant able to grown equally above- and below-ground to capture resources (Javed et al., 2020; Yan et al., 2022).

According to the results, it cannot be determined that increased P uptake by cotton plant under DI, is due to increase shoot growth, which would enhance P demand of the plants and promote P absorption by changing roots architecture. While it can be confirmed that per unit root length of cotton plant is the greater contributor of P uptake for the development of shoot under DI (*Fig. 8*). Therefore, higher P uptake of cotton plants under DI, is likely to be partially due to a passive increased in P demand cause by the increased in growth, but more likely due to the roots actively absorbing and supplying higher quantities of P under DI (Alcon et al., 2019). Moreover, change in roots architecture under DI, the cotton plant is able to absorb higher quantities of P, leading to P depletion at shallow soil depths. In modern agricultural production techniques, huge quantities of chemical fertilizers are applied to agriculture land (Li et al., 2011; Wang et al., 2017), resulting in accumulation of high concentrations of P in the soil (especially at shallow depths) (Zhang et al., 2010). Therefore, application of DI would be beneficial to increase the utilization of P fertilizer for cotton plant production.

Conclusion

DI is the best irrigation method to save water and fertilizer. In this study plant growth, phosphorus content and phosphorus uptake of cotton plants were higher under DI as compared to FI. Plants having Shallow roots at 0-10 cm soil layer under DI, due to easy access of water and fertilizer as compared to FI. Soil available P content in the 0-10 cm soil layer was significantly lower in the DI, because plant transferred into upper parts for its development. It can be concluded that plant get nutrients and water more easily under DI. Furthermore, water and fertilizer can be used more accurately under DI as compared to FI. In modern agriculture practices, DI is the best recommended method to utilizes less water and nutrients resources for more crops production.

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Conflicts of Interests. The authors declare that they have no conflict of interests.

Author Contributions. Conceptualization, Ahmad Azeem.; methodology, Ahmad Azeem.; software, Mai Wenxuan.; validation, Mai Wenxuan.; formal analysis, Xiangrong Xue.; investigation, Xiangrong Xue.; resources, Mai Wenxuan.; writing–original draft preparation, Ahmad Azeem; writing–review and editing, Mai Wenxuan.; project administration, Mai Wenxuan.; All authors have read and agreed to the published version of the manuscript.

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