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Unveiling rice (*Oryza sativa* L.) root dynamics and yield architectures under divergent establishment methods and irrigation regimes

P. Nandini*[1], K. Avil Kumar[1], M. Goverdhan[1], T. L. Neelima[1], K. Chandrasekar[2], T. Ram Prakash[3]

[1]Department of Agronomy, College of Agriculture, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad-500030

[2]Regional Centre, National Remote Sensing Centre, Balanagar, Hyd-500037, Telangana, India

[3]Deparment of Soil Science and Agricultural Chemistry, College of Agriculture, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad-500030

ABSTRACT

The present investigation was conducted for two consecutive kharif seasons (2021 and 2022) at the Agricultural Research Station, Kampasagar, Nalgonda district, on sandy clay loam soils using a split-plot design with three main plots and three sub-plots, replicated thrice. Root parameters such as root volume and root-to-shoot ratio showed significant variation among establishment methods, with dry direct seeded rice (M_1) recording numerically higher values. However, yield-attributing traits like number of panicles m^{-2} (285.5), panicle length (27.3 cm), panicle weight (4.69 g), number of spikelets panicle^{-1} (196.7), filled grains panicle^{-1} (189.8) and test weight (26.6 g) were significantly influenced by establishment methods, with wet direct seeded rice (M_2) performing better, on par with manual transplanting (M_3) and superior to dry seeding. Irrigation treatments and interactions had no significant effect on root traits and yield parameters, although alternate wetting and drying (AWDI) and continuous submergence performed better than saturation irrigation. A key challenge in the study was managing uniform field conditions across varying methods and seasons. Despite this, the study contributed valuable insights into the suitability of different crop establishment methods and irrigation strategies under semi-arid conditions, highlighting the potential of wet direct seeding and AWDI to improve rice productivity while optimizing water use.

Keywords: *root volume; root-to-shoot; yield attributes; establishment methods; irrigation scheduling;rice;AWDI*

Introduction

Rice (*Oryza sativa* L.) holds a pivotal role as a staple food for over half of the world's population, particularly in developing countries where it serves as both a dietary mainstay and an economic backbone (1). The global importance of rice is underscored by its significant contribution to food security and agricultural livelihoods. In the 2024-25 period, China emerged as the top producer of paddy rice, yielding 145.3 million metric tonnes, closely followed by India with 145.00 million metric tonnes (2).

Within India, rice cultivation spans approximately 50 million hectares, achieving an average productivity of 4.35 tonnes per hectare (3). Telangana, a key rice-producing state, demonstrated notable performance during the *kharif* (*Vanakalam*) season, with rice cultivation covering 26.3 lakh hectares. The state's paddy production reached 15.3 million metric tonnes, with an impressive productivity of 5.2 tonnes per hectare (4).

With the looming challenge of global water scarcity, sustainable rice production increasingly demands cultivation practices that require less water without compromising yield potential (5).

Corresponding Author: **P. Nandini*

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Aerobic rice cultivation presents a promising alternative to traditional puddled transplanted systems by enabling rice to grow under non-saturated, non-flooded soil conditions. As a result, a gradual transition from anaerobic to aerobic rice systems is underway, particularly through direct seeding methods—either by broadcasting or sowing in rows (6).

Despite its growing adoption, the performance of rice under varied planting geometries and population densities, especially in aerobic conditions, warrants closer scrutiny. This is critical as the success of aerobic rice largely hinges on robust initial plant establishment. Roots, being the primary interface between plant and soil, play a pivotal role in nutrient and water acquisition and are instrumental in maintaining the soil-plant-atmosphere continuum. Their architecture—penetration depth and lateral spread—is influenced by genotypic traits and environmental factors (7).

Rice is highly sensitive to water stress, making it challenging to balance water conservation with maintaining high yields. One such promising technique is Alternate Wetting and Drying (AWD), also known as intermittent irrigation. AWD involves applying water to the fields several days after the visible ponded water has disappeared, allowing the fields to dry intermittently during the rice growth period. The underlying principle of AWD is that rice plant roots can access sufficient moisture even when there is no visible standing water in the field. This intermittent drying does not induce water stress in the plants but significantly reduces water usage. (8)

reported that, in India, AWD can reduce water use by 40–70% compared to continuous flooding methods, without causing a significant reduction in yield. This makes AWD a highly effective and sustainable irrigation technique that can help address the growing water scarcity issues while safeguarding rice production. AWD saves water to the extent of 20-50 per cent compared to farmers' practice of continuous flooding (9).
Furthermore, roots are the first to perceive and respond to changes in soil conditions and are key indicators of a crop's adaptive potential. Thus, understanding root responses under different crop establishment methods and irrigation regimes becomes imperative. In light of this, the present study was undertaken to evaluate root characteristics and yield attributes under varied establishment and irrigation practices.

Materials and Methods

The field experiment was conducted during the *kharif* seasons of 2021 and 2022 at the Agriculture Research Station, Kampasagar, Nalgonda district of Telangana state. The farm is geographically situated in the southern part of Telangana at $16^0$51'9.559'' N latitude and 79°28'26.581'' E longitude at an altitude of 126.93 m above mean sea level and falls under Southern Telangana Agro-climatic Zone (STZ) of Telangana.The experimental field was sandy clay loam in texture with a pH of 8.0 and EC of 0.27 dS m^{-1}, low in organic carbon (0.41%) and available nitrogen (237.7 kg ha^{-1}), high in available phosphorus (27.1 kg ha^{-1}) and potassium (369.3 kg ha^{-1}). The variety used for the study was KNM-118, which contains 118-120 days duration. The experiment was laid out in split- plot design with three different rice establishment methods as main plot treatments *viz.,* Dry direct seeding with seed drill (M_1-DDSR), Wet direct seeding with drum seeder (M_2-WDSR) and manual transplanting (M_3-TPR) and three irrigation treatments as sub-plots *viz.,* Continuous submergence (I_1-CS), Maintaining saturation after disappearance of ponded water (I_2-Saturation) and Alternate Wetting and Drying Irrigation (AWDI) of 5 cm when water level in pipe falls 5 cm below surface (I_3). The experimental field was provided with irrigation channels, buffer channels and the individual plots were demarcated by bunds. Each plot was bounded by 0.2 m high earthen bunds with polythene sheet lining, which extended from the top of the bund to a depth of 0.5 m below the soil surface to minimize lateral movement of water through and below the bunds. There was also a 1 m wide buffer between all plots to further reduce the possibility of interference between plots. The irrigation water was measured with the help of a water meter. The main field was ploughed twice with cultivator and rotavator to obtain fine tilth. In DDSR sowing rice seeds was done using a tractor-drawn seed drill @ 25 kg seed ha^{-1} on well moistened soils and in WSR and TPR @ 50 kg seed ha^{-1} after ploughing, fields were flooded and puddled with tractor mounted cage wheels and levelled with rotovator. Before sowing, the seeds were soaked for 12 hours in water. After draining out the water, the seeds were incubated for sprouting. In WSR well sprouted seeds were sown on following day through four-row drum seeder with a row-to-row spacing of 30 cm and in TPR sprouted seeds were broadcasted uniformly in nursery beds. In TPR 25 days 25-day-old rice seedlings were transplanted, with 2 seedlings per $hill^{-1}$ with spacing of 15 cm x 15 cm. The nutrient management was done as per recommendation made in package of practices for nursery bed preparation was 10-5-5 kg of N: P_2O_5:K_2O per 1000 m^{-2} and for all the rice establishment methods RDF i.e., 120-60-40 N, P_2O_5 and K_2O kg ha^{-1}, respectively.
The entire P fertilizer was applied as basal in the form of DAP (46 % P_2O_5 + 18 % N). The K fertilizer was applied in the form of muriate of potash (60 % K_2O) in two equal splits as basal and at panicle initiation stage. The fertilizer N was applied in the form of urea (46 % N) in three equal splits at basal, active tillering stage and panicle initiation stage in DDSR and for WDSR and TPR, fertilizer N was applied in three equal splits at 15-20 DAS, active tillering stage and at panicle initiation stage.

Statistical analysis

The data on phenology, nutrient content and uptake studied during the investigation were statistically analysed as suggested by (10). Wherever statistical significance was observed, critical difference (CD) at 0.05 level of probability was worked out for comparison. Non-significant comparison was indicated as 'NS'.

Results and Discussion

Root volume (cc)

Across planting methods, significant differences at 30 DAS were observed during both seasons, with wet direct seeding of rice with drum-seeder (M_2: WDSR) recording higher root volume, averaging 10.3 cc (10.2 cc in 2021 and 10.4 cc in 2022) which was followed by dry direct seeding of rice with seed drill (M_1: DDSR) with 10.0 c1c in 2021, 10.2 cc in 2022 and averaging of 10.1 cc (Table 1).
Significant variations at panicle initiation were observed among planting methods. Dry direct seeding of rice with seed drill (M_1: DDSR) recorded the highest root volume in both years, with a mean of 34.7 cc (34.0 cc in 2021 and 35.3 cc in 2022). Wet direct seeding of rice (M_2: WDSR) on par with M_1: DDSR, averaging 34.4 cc (33.8 cc in 2021 and 35.1 cc in 2022), whereas transplanted puddled rice M_3: TPR had the root volume, averaging 33.9 cc.
Dry direct seeding of rice with seed drill (M_1: DDSR) recorded the highest root volume in both years at 50% flowering, with a mean of 39.1 cc (38.7 cc in 2021 and 39.4 cc in 2022). Wet direct seeding of rice (M_2: WDSR) on par with M_1: DDSR, averaging 38.5 cc (38.2 cc in 2021 and 38.8 cc in 2022), whereas transplanted puddled rice M_3: TPR had the root volume, averaging 37.1 cc.
The root volume at maturity followed a similar trend. Dry direct seeding of rice with seed drill (M_1: DDSR) recorded the highest root volume in both years, with a mean of 39.5 cc (38.3 cc in 2021 and 40.7 cc in 2022). Wet direct seeding of rice (M_2: WDSR) on par with M_1: DDSR, averaging 38.8 cc (37.5 cc in 2021 and 40.0 cc in 2022), whereas transplanted puddled rice M_3: TPR had the root volume, averaging 36.8 cc.
In wet direct seeding, root growth remained shallow and was primarily confined to the upper soil layers due to continuous submergence. Conversely, in dry direct seeding, the absence of submergence encouraged roots to penetrate deeper in search of moisture and nutrients, resulting in a more developed root system (11).
Irrigation scheduling did not significantly influence root volume of rice which range from 37.7 to 38.9. However, I_3: AWDI recorded the highest root volume values at 50% flowering (38.6), compared to 38.0 in I_2: Saturation and I_1: CS.
The study of interaction effects between planting methods and irrigation scheduling was non-significant, indicating that the response of planting methods remained consistent across different irrigation treatments.

Root-to-shoot ratio

The root-to-shoot ratio is an essential indicator of plant biomass allocation, water uptake efficiency and stress adaptation in rice.

A higher ratio suggests greater investment in root growth, which improves nutrient and water acquisition, particularly under drought or fluctuating moisture conditions (12).

The data (Table 2) indicated that at 30 DAS, the root-to-shoot ratio was highest in DDSR (0.19) followed by WDSR (0.18) and TPR (0.14) on mean basis. This trend continued at later growth stages, with DDSR maintaining the highest root-to-shoot ratio at panicle initiation (0.58), 50% flowering (0.47) and maturity (0.18). The higher root-to-shoot ratio in DDSR is attributed to better root establishment under puddled conditions, which enhances nutrient uptake efficiency (13). Although irrigation scheduling did not significantly influence root-to-shoot ratios, I_3: AWDI consistently unveiled slightly higher values than I_1: CS and I_2: Saturation. This is likely due to the intermittent drying phases in AWDI promote root elongation (14), AWD irrigation enhances root growth and improves drought resilience in rice.

The root-to-shoot ratio (RSR) varied significantly among planting methods but not among irrigation treatments. DDSR unveiled the highest RSR across all growth phases, with values peaking at panicle initiation and gradually declining toward maturity. Higher RSR in DDSR is likely due to better root anchorage and nutrient availability in puddled conditions (15). Among irrigation methods, non-significant differences suggest that moisture accessibility under different regimes did not drastically alter root development. These results align with the verdicts of (16), who reported that RSR in rice was more influenced by soil physical properties than irrigation frequency.

Yield attributes

The number of spikelets per panicle, number of filled grains per panicle and test weight are key yield-attributing traits that significantly influence the final grain yield of rice. Significant difference was found between different planting methods and non-significant difference was reported among irrigation scheduling treatments for both the years of study and mean of two years (Table 3 and 4). The study of interaction effects between planting methods and irrigation scheduling on yield attributes of rice was non-significant, indicating that the response of planting methods remained consistent across different irrigation treatments.

Number of panicles m^{-2}

Among different planting methods, wet direct seeded rice with drum seeder (M_2: WDSR) recorded higher number of panicles m^{-2} during both the years of study and mean of two years i.e., 284.8, 286.2 and 285.5 panicles m^{-2}, respectively and it was analogous with manual transplanting M_3: TPR with Number of panicles m^{-2} of 281.5, 283.8, 282.7 panicles m^{-2}, respectively. Whereas, significantly lower number of panicles m^{-2} was recorded with dry direct seeding with seed drill (M_1: DDSR), with 287.8, 279.4, 279.1 panicles m^{-2} compared to other treatments. Wet direct seeded with drum seeder (M_2: WDSR) in rice recorded 2.12 %, 2.40 % and 2.26 % higher number of panicles m^{-2} over dry direct seeding with seed drill (M_1: DDSR) during *kharif* 2021, 2022 and mean of two years, respectively. This could be accredited to effective spacing management, optimal plant population, and favourable growth conditions from the early vegetative stage to the reproductive phase. Additionally, reduced crop-weed competition further supported crop development. The wet direct-seeded rice (WDSR) method using a drum seeder facilitates proper spacing and early establishment, promoting better plant growth, increased tillering, and higher grain yield compared to improper spacing.

Adequate spacing also enhances water management, boosts photosynthetic efficiency, and improves assimilate partitioning (17,18), ultimately leading to higher yields in well-spaced rice fields.

Number of panicles m^{-2} of rice showed non-significant effect by different irrigation scheduling (Table 3). However, among irrigation scheduling, I_1: CS recorded higher number of panicles m^{-2} during *kharif* 2021, 2022 and on mean basis i.e., 285.6, 289.8 and 287.7 panicles m-2 respectively followed by I_2: Saturation - maintaining saturation i.e., irrigation after disappearance of ponded water (281.8, 281.3 and 281.6 panicles m$^{-2)}$ during *kharif* 2021, 2022 and on mean basis, respectively). Whereas, the lower number of panicles of 277.6, 278.4 and 278.0 panicles m^{-2} were recorded with I_3-AWDI of 5 cm when water level in pipe falls 5 cm below surface during *kharif* 2021, 2022 and on mean basis, respectively. Reasons for lower number of panicles m^{-2} in AWD was due to the fact that plants had suffered from moisture stress. Hence plants were unable to extract sufficient water and nutrients under moisture deficit conditions, which ultimately led to poor growth and lesser number of panicles. Alike results were also experiential by (19,20,21).

Panicle length (cm)

Panicle length is a crucial yield-attributing trait that determines the grain-bearing capacity of the plant. The results indicated that different crop planting methods and irrigation scheduling significantly influenced panicle length during both years of study (Table 3).

Among different crop planting methods, wet direct seeding with a drum seeder (M_2: WDSR) recorded the highest panicle length, with 25.6 cm, 29.0 and 27.3 cm in 2021, 2022 and mean of both years. This was followed by manual transplanting M_3: TPR, which recorded 23.4 cm in 2021 and 26.3 cm in 2022, with averaging of 24.9 cm. The lowest panicle length was observed in dry direct seeding with a seed drill (M_1: DDSR), which recorded 23.0 cm in 2021 and 26.5 cm in 2022, with an average of 24.7 cm.

Panicle length (cm) of rice showed non-significant effect by different irrigation scheduling (Table 3) during both the years viz., *kharif* 2021, 2022 and on mean basis. However, I_1: CS registered higher panicle length of 25.5, 29.1 and 27.3 cm during *kharif* 2021, 2022 and on mean basis, respectively) followed by maintaining saturation (I_2: Saturation) i.e., irrigation after disappearance of ponded water (23.7, 27.1 and 25.4 cm during *kharif* 2021, 2022 and on mean basis, respectively) and AWDI of 5 cm when water level in pipe falls 5 cm below surface (I_3: AWDI) i.e., (22.9, 25.6 and 24.2 cm, respectively).

Panicle weight (g)

Panicle weight is a key yield-attributing trait that directly influences the final grain yield by determining the grain-bearing capacity per panicle. The results indicated that different crop establishment methods and irrigation scheduling significantly influenced panicle weight during both years of study (Table 3).

Among different planting methods, M_2: WDSR recorded highest panicle weight (g) during *kharif* 2021, 2022 and mean of two years i.e., 4.6, 4.7 and 4.7 g, respectively and it has shown on statistically comparable to M_3: TPR of rice i.e., 4.5, 4.5 and 4.5 g, respectively. Significantly, lower panicle weight was obtained with DDSR (M_1: DDSR) during *kharif* 2021, 2022 and mean of two years i.e., 4.2, 4.2 and 4.2 g, respectively. Improved crop growth, reduced crop-weed competition, and a relatively stress-free environment in WDSR may have contributed to the highest panicle weight, as observed by (22,23,24).

In contrast, increased competition for resources both within and between plants likely resulted in lower panicle weight under DDSR.

Irrigation scheduling has shown non-significant influence on the panicle weight (g) of rice during both the years viz., *kharif* 2021, 2022 and on mean basis (Table 3). I_1: CS registered higher panicle weight (4.60, 4.46 and 4.53 g during *kharif* 2021, 2022 and on mean basis, respectively) followed by AWDI of 5 cm when water level in pipe falls 5 cm below surface (I_3: AWDI) i.e., (4.45, 4.47 and 4.46, respectively) and maintaining saturation (I_2: Saturation) i.e., irrigation after disappearance of ponded water (4.36, 4.36 and 4.36 g during *kharif* 2021, 2022 and on mean basis, respectively) and this may be attributed to improved crop growth due to the consistent availability of water, which supported a well-developed root system and enhanced metabolic activities, leading to efficient nutrient mobilization. Consequently, this contributed to the highest panicle weight under saturation conditions. These findings align with the observations reported by (25,20,21).

Number of spikelets panicle^{-1}

The number of spikelets per panicle is a vital yield component in rice, as it defines the panicle's capacity to produce grains and directly impacts overall productivity. The results indicate that both crop planting methods and irrigation scheduling significantly influenced the number of spikelets per panicle (Table 4).

Number of spikelets per panicle was significantly influenced by planting methods. Among different planting methods, wet direct seeded rice with drum seeder (M_2: WDSR) recorded higher number of spikelet's panicle-1 during *kharif* 2021, 2022 and mean of two years i.e., 197.1, 196.3 and 196.7 respectively and it was statistically comparable with manual transplanting (M_3: TPR) of rice with number of spikelet's panicle-1 of 193.4, 194.3 and 193.9, respectively. Significantly, a lower number of spikelet's panicle-1 of 188.1, 191.7 and 189.9, respectively was obtained with dry direct seeding with seed drill (M_1: DDSR) compared to other treatments. The poor performance of DDSR can be largely attributed to intense weed competition, which restricts access to essential nutrients, sunlight, initial stress and space, ultimately affecting plant growth and development. Additionally, the zero-tillage system may create unfavourable conditions for seed germination and root establishment, leading to weaker plant stands. These combined factors contribute to reduced crop productivity under DDSR (22).

Number of spikelets per panicle was non-significant under irrigation scheduling approaches. However, maximum number of spikelets per panicle of 196.0, 195.4 and 195.7 was recorded with I_1: CS during *kharif* 2021, 2022 and mean of two years, which was followed by maintaining saturation (I_2: Saturation) with number of spikelets per panicle of 193.3, 194.5 and 193.9. whereas, the minimum number of spikelets per panicle of 189.4, 192.5 and 190.9 was recorded with alternate wetting and drying irrigation (I_3: AWDI) during 2021, 2022 and mean of two years respectively (26).

Number of filled grains panicle^{-1}

The number of filled grains per panicle is a critical yield-attributing trait in rice, as it determines the actual grain set and contributes directly to final grain yield. The results indicate that both crop establishment methods and irrigation scheduling significantly influenced the number of filled grains per panicle (Table 4).

Among the different crop establishment methods, wet direct seeding with a drum seeder (M_2: WDSR) resulted in the highest number of filled grains panicle^{-1}, with 194.1 grains in 2021 and 193.3 grains in 2022, averaging 193.7 grains. Manual transplanting (M_3: TPR) ranked second, recording 190.4 grains in 2021 and 191.3 grains in 2022, with a mean of 190.9 grains per panicle. Dry direct seeding with a seed drill (M_1: DDSR) had the lowest filled grain count, with 185.1 grains in 2021 and 188.7 grains in 2022, averaging 186.9 grains panicle^{-1}. The fertility of spikelets and grain development are influenced by environmental factors such as nutrient availability, moisture levels and light exposure. Wider spacing helps optimize these conditions, resulting in a higher number of filled grains panicle^{-1}. Similar findings have been reported by previous researchers, including (27). Enhanced translocation efficiency of photosynthates likely improved the distribution of assimilates to the sink, leading to an increased number of filled grains per panicle. Similar observations were also reported by (28).

Number of filled grains panicle^{-1} was non-significant under irrigation scheduling approaches. However, I_1: CS recorded the highest number of filled grains per panicle, with 187.8 grains in 2021 and 188.9 grains in 2022, averaging 188.4 grains. I_2: Saturation followed, with 185.6 grains in 2021 and 187.8 grains in 2022, resulting in a mean of 186.7 grains per panicle. The lowest number of filled grains per panicle was observed under I_3: AWDI, which recorded 181.6 grains in 2021 and 186.0 grains in 2022, with an average of 183.8 grains. Deficit irrigation during crop growth affected partitioning of dry matter at grain filling stage and thus, there was significant reduction in number of filled grains panicle^{-1}observed due to moisture stress. These results are in corroborates with findings of (29,21).

Test weight (g)

Test weight (1000-grain weight), is an important yield-determining factor in rice, as it reflects grain size, density, and overall grain quality. The results indicate that both crop establishment methods and irrigation scheduling test weight (Table 4).

Test weight (g) was non-significant among the different crop establishment methods. However, wet direct seeding with a drum seeder (M_2: WDSR) recorded the highest test weight, with 26.8 g in 2021 and 26.5 g in 2022, averaging 26.6 g. Which was trailed by manual transplanting (M_3: TPR), with a test weight of 26.0 g in both years, resulting in a mean of 26.0 g. The lowest 1000 seed weight was observed in dry direct seeding with a seed drill (M_1: DDSR), which recorded 25.8 g in 2021 and 25.9 g in 2022, averaging 25.9 g. The increase in thousand-grain weight can be linked to the sufficient availability and efficient absorption of nutrients, which are essential for proper grain development. When plants receive an adequate supply of nutrients, they can effectively allocate assimilates toward grain filling, resulting in larger and heavier grains. Additionally, improved nutrient uptake enhances the overall physiological processes, ensuring better grain maturity and quality. This ultimately contributes to higher grain weight and yield. Similar findings were also reported by (27).

Test weight (g) was non-significant under irrigation scheduling approaches. Among irrigation scheduling methods, I_1: CS resulted in the highest test weight, with 26.4 g in 2021 and 26.3 g in 2022, averaging 26.3 g. I_2: Saturation followed closely, maintaining a consistent test weight of 26.2 g in both years. The lowest test weight was recorded under I_3: AWDI, with values of 26.1 g in 2021 and 25.9 g in 2022, averaging 26.0 g. Several researchers have observed improvement in test weight with adequate water supply to meet crop needs without imposing stress at flowering and grain development stage (30, 19, 20). Grain weight is primarily influenced by genotype; however, it can be partially constrained by the availability of assimilates after anthesis, which is largely regulated by water supply. As a result, test weight or grain weight is determined by both the rate of grain development and the duration of grain filling, both of which are significantly impacted by water stress. This is supported by the findings of (21), as evident from the slightly lower test weight observed under irrigation at 5 cm depletion.

Conclusion

From the study it can be concluded that among different rice establishment methods, dry direct seeded rice performed better in root studies compared to other methods at all stages of crop growth period. In case of yield attributing characters, wet direct seeded rice has shown higher values, which is on par with manual transplanted rice and dry direct seeded rice has performed least. However, irrigation scheduling treatments and interaction effect shown non-significant for both years of study.

Future line of work

- Water-saving irrigation methods: Exploring subsurface drip irrigation, sprinkler systems designed for rice, and improved water-holding capacity through soil amendments.
- Direct seeding technologies: Further refining direct seeding techniques with improved seed placement and weed management strategies to reduce labour requirements and water usage.

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Conflict of interest

Authors have declared that no conflict of interest exist.

Table 1. Root volume (cc m^{-2}) of rice as influenced by different planting methods and irrigation scheduling during *kharif* 2021 & 2022.

Table 2. Root to shoot ratio of rice as influenced by different planting methods and irrigation scheduling during *kharif* 2021 & 2022.

Table 3. Number of panicles m^{-2}, Panicle length (cm) and Panicle weight (g) of rice as influenced by different planting methods and irrigation scheduling during *kharif* 2021 & 2022.

Table 4. Number of spikelet's $panicle^{-1}$, Number of filled grains per $panicle^{-1}$ and Test weight (g) of rice as influenced by different planting methods and irrigation scheduling during *kharif* 2021 & 2022.

Table 1. Root volume (cc m^{-2}) of rice as influenced by different planting methods and irrigation scheduling during kharif 2021 & 2022

Treatments	30 DAS			Panicle initiation			50 % flowering			Maturity		
Main	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean
M_1: DDSR	10.0	10.2	10.1	34.0	35.3	34.7	38.7	39.4	39.1	38.3	40.7	39.5
M_2: WDSR	10.2	10.4	10.3	33.8	35.1	34.4	38.2	38.8	38.5	37.5	40.0	38.8
M_3: TPR	9.3	9.5	9.4	33.3	34.5	33.9	36.8	37.4	37.1	35.7	37.9	36.8
SEm±	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.4	0.4	0.4
CD (P=0.05)	0.2	0.2	0.2	0.4	0.5	0.4	1.1	1.1	1.1	1.5	1.5	1.5
Sub												
I_1: CS	9.9	10.1	10.0	33.6	34.9	34.2	37.7	38.4	38.0	36.9	39.3	38.1
I_2: Saturation	9.8	10.0	9.9	33.6	34.9	34.3	37.7	38.4	38.0	36.9	39.3	38.1
I_3: AWDI	9.9	10.1	10.0	33.8	35.1	34.5	38.2	38.9	38.6	37.6	40.0	38.8
SEm±	0.1	0.1	0.1	0.2	0.2	0.2	0.4	0.4	0.4	0.6	0.6	0.6
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction												
SEm±	0.1	0.1	0.1	0.3	0.3	0.3	0.7	0.7	0.7	0.9	0.9	0.9
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction												
SEm±	0.2	0.2	0.2	0.3	0.3	0.3	0.7	0.7	0.7	1.0	1.0	1.0
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

DDSR: *Dry direct seeding of rice with seed drill* ***CS:*** *Continuous submergence*
WDSR: *Wet direct seeding of rice with drum-seeder* ***AWDI:*** *Alternate wetting and drying irrigation*
TPR: *Manual transplanted puddled rice*

Table 2. Root to shoot ratio of rice as influenced by different planting methods and irrigation scheduling during kharif 2021 & 2022

Treatments	30 DAS			Panicle initiation			50 % flowering			Maturity		
Main	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean
M_1: DDSR	0.19	0.20	0.19	0.54	0.63	0.58	0.43	0.51	0.47	0.17	0.19	0.18
M_2: WDSR	0.17	0.19	0.18	0.49	0.57	0.53	0.40	0.47	0.43	0.16	0.18	0.17
M_3: TPR	0.14	0.15	0.14	0.41	0.47	0.44	0.32	0.38	0.35	0.13	0.14	0.13
SEm±	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01
CD (P=0.05)	0.02	0.03	0.02	0.07	0.08	0.08	0.05	0.07	0.06	0.02	0.02	0.02
Sub												
I_1: CS	0.14	0.16	0.15	0.41	0.48	0.45	0.33	0.40	0.37	0.13	0.15	0.14
I_2: Sat	0.17	0.19	0.18	0.51	0.58	0.54	0.40	0.48	0.44	0.16	0.18	0.17
I_3: AWDI	0.18	0.20	0.19	0.52	0.60	0.56	0.41	0.49	0.45	0.16	0.18	0.17
SEm±	0.01	0.01	0.01	0.03	0.03	0.03	0.02	0.03	0.02	0.01	0.01	0.01
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction												
SEm±	0.01	0.02	0.02	0.05	0.05	0.05	0.03	0.04	0.04	0.01	0.02	0.01
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction												
SEm±	0.02	0.02	0.02	0.05	0.06	0.05	0.04	0.05	0.04	0.02	0.02	0.02
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

DDSR: *Dry direct seeding of rice with seed drill* ***CS:*** *Continuous submergence*
WDSR: *Wet direct seeding of rice with drum-seeder* ***AWDI:*** *Alternate wetting and drying irrigation*
TPR: *Manual transplanted puddled rice*

Table 3. Number of panicles m^{-2}, Panicle length (cm) and Panicle weight (g) of rice as influenced by different planting methods and irrigation scheduling during kharif 2021 & 2022

Treatments	Number of panicles m^{-2}			Panicle length (cm)			Panicle weight (g)		
Main	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean
M_1: DDSR	278.8	279.4	279.1	23.0	26.5	24.7	4.19	4.04	4.12
M_2: WDSR	284.8	286.2	285.5	25.6	29.0	27.3	4.67	4.71	4.69
M_3: TPR	281.5	283.8	282.7	23.4	26.3	24.9	4.54	4.54	4.54
SEm±	1.1	1.3	1.0	0.5	0.6	0.5	0.09	0.06	0.06
CD (P=0.05)	4.5	5.1	3.8	2.1	2.2	2.2	0.34	0.25	0.22
Sub									
I_1: CS	285.6	289.8	287.7	25.5	29.1	27.3	4.60	4.46	4.53
I_2: Saturation	281.8	281.3	281.6	23.7	27.1	25.4	4.36	4.36	4.36
I_3: AWDI	277.6	278.4	278.0	22.9	25.6	24.2	4.45	4.47	4.46
SEm±	6.3	4.8	4.6	1.1	1.0	1.0	0.12	0.17	0.11
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction									
SEm±	9.0	7.0	6.6	1.6	1.5	1.6	0.19	0.24	0.16
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction									
SEm±	11.0	8.4	8.0	1.8	1.7	1.8	0.20	0.29	0.18
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

DDSR: *Dry direct seeding of rice with seed drill* ***CS:*** *Continuous submergence*
WDSR: *Wet direct seeding of rice with drum-seeder* ***AWDI:*** *Alternate wetting and drying irrigation*
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Table 4. Number of spikelet's panicle^{-1}, Number of filled grains per panicle^{-1} and Test weight (g) of rice as influenced by different planting methods and irrigation scheduling during kharif 2021 & 2022

Treatments	Number of spikelet's panicle^{-1}			Number of filled grains panicle^{-1}			Test weight (g)		
Main	2021	2022	Mean	2021	2022	Mean	2021	2022	Mean
M_1: DDSR	188.1	191.7	189.9	178.3	183.2	180.8	25.8	25.9	25.9
M_2: WDSR	197.1	196.3	196.7	189.0	190.6	189.8	26.8	26.5	26.6
M_3: TPR	193.4	194.3	193.9	187.7	188.9	188.3	26.0	26.0	26.0
SEm±	1.7	0.9	1.1	1.7	0.9	1.1	0.3	0.4	0.2
CD (P=0.05)	6.7	3.5	4.4	6.7	3.5	4.4	NS	NS	NS
Sub									
I_1: CS	196.0	195.4	195.7	187.8	188.9	188.4	26.4	26.3	26.3
I_2: Saturation	193.3	194.5	193.9	185.6	187.8	186.7	26.2	26.2	26.2
I_3: AWDI	189.4	192.5	190.9	181.6	186.0	183.8	26.1	25.9	26.0
SEm±	2.2	2.5	1.9	2.2	2.6	1.9	0.3	0.4	0.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction									
SEm±	3.6	3.6	2.9	3.6	3.7	2.9	0.5	0.6	0.5
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction									
SEm±	3.8	4.3	3.2	3.8	4.4	3.3	0.5	0.6	0.5
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

DDSR: *Dry direct seeding of rice with seed drill* ***CS:*** *Continuous submergence*
WDSR: *Wet direct seeding of rice with drum-seeder* ***AWDI:*** *Alternate wetting and drying irrigation*
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