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EFFECT OF SOWING TECHNIQUES ON GROWTH, YIELD, AND ECONOMIC PERFORMANCE OF FINE RICE (ORYZA SATIVA L.) UNDER THE ARID CONDITIONS OF DERA ISMAIL KHAN, PAKISTAN

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Abstract

Direct-seeded rice (DSR) has emerged as a resource-efficient alternative to conventional puddled transplanted rice (PTR), particularly in arid regions where irrigation water and agricultural labor are increasingly constrained. This study evaluated the effects of DSR and PTR on the growth, yield, water-use efficiency, soil properties, and economic performance of fine rice (Oryza sativa L.) under the arid conditions of Dera Ismail Khan, Pakistan. A field experiment was conducted using a randomized complete block design with four replications. Growth attributes, yield components, grain yield, irrigation-water requirement, water productivity, post-harvest soil indicators, and economic returns were assessed. Direct-seeded rice consistently outperformed PTR in vegetative and reproductive traits. At flowering, DSR produced taller plants, greater tiller density, and a higher leaf area index. Panicle length, filled grains per panicle, and 1000-grain weight were also improved under DSR. Grain yield increased from 4.63 t ha^{-1} under PTR to 5.21 t ha^{-1} under DSR, representing a 12.5% improvement. Moreover, DSR reduced irrigation-water use by 29.5%, from 13,200 to 9,300 m^3 ha^{-1}, while increasing water productivity by 59.7%, from 0.351 to 0.560 kg m^{-3}. Economic analysis showed that DSR reduced production costs and increased net returns from PKR 172,050 to PKR 258,850 ha^{-1}, with the benefit–cost ratio improving from 1.78 to 2.41. Modest improvements in post-harvest soil chemical properties were also observed under DSR. These findings demonstrate that direct seeding is a productive, water-efficient, and economically viable establishment method for sustainable fine-rice cultivation in arid environments.

INTRODUCTION

Rice (Oryza sativa L.) is an important cereal production, main staple food and one of the important exports sectors of Pakistan which plays a pivotal role in the national agricultural economy (Naeem et al., 2024). Those fine aromatic rice cultivars are premium in terms of grain quality and world market value, but indeed on optimisation of any agronomic practices (Akbar et al., 2010; Khan et al., 2025). Puddled transplanting however may enable lesser utilization of water and lower farm profitability, particularly in arid climate regions such as in Der Ismail Khan in Pakistan, where both water level and evaporative demand is low (Akbar et al., 2025; Bakhsh, 2008). The plans for the future have to be able to sustain the competitive grain production while being water saving and labour saving with the use of alternative sowing methods such as direct seeded rice (DSR) (Bista, 2018; Mallareddy et al., 2023; Naeem et al., 2024). The implementation of localised sowing practices in other areas is not new but studies specific to the agro-climatic conditions and resource depletion of Dera Ismail Khan (Bakhsh, 2008; Khan et al., 2025) on the efficiency of such localised sowing practices are yet to be conducted. The deficiency should be improved recognising that the increase in productivity by improving vegetative growth and reproductive development and thus by improving sowing methods in the localized areas of the region could play a crucial role in the short term in the improvements in fine rice in the region (Naeem et al., 2024). The objective of this study is therefore, to evaluate the growth, yield and economic return of different sowing techniques to fine rice to draw a conclusion about the sustainable and high yielding sowing techniques for the dry areas of the local farmer's practice.The conversion to direct seeded rice also has a number of indirect benefits apart from its negative labour and high water consumption consequences which reduce the profitability of rice production currently, in terms of overall economic adjustment in the cost structure of the rice-wheat cropping system.The transition to direct seeding rice could also bring about a variety of secondary changes, such as the cost structure of the rice-wheat cropping system which is reduced through a reduction in labour input and high water consumption that are manually performed in the cropping system with rice traditionally seeded (Bista, 2018; Mallareddy et al., 2023). The use of direct seeded methods will also address the critical labour shortages encountered because of managing small field areas in the region and better utilization of scarce water supplies (Akbar et al. 2025; Mallareddy et al. 2023). Puddled transplantation is often accompanied by the excessive use of water sometimes by a big margin, which is not sustainable, given the severe hydrological condition prevailing in Dera Ismail Khan (Akbar et al., 2025). Dry-seeded methods, on the

contrary, offer more flexibility in sowing dates, which is useful to optimize resource-use efficiency and minimize the need to sow at the early season where attention is largely focused on achieving saturation, reduced nutrient uptake and competition from weeds (Akbar et al., 2010; Bista, 2018). Furthermore, economic power of finet is also closely linked to input utilization efficiency since irration of unnecessary input investments in irrigation and labour intensive land preparation in the field for ensuring maximum net returns of production is a prerequisite for the economic strength of the production activity (Khan et al., 2025). This study will systematically compare these methods in a rigorous manner and provide a detailed analysis on how these methods can be integrated to optimize the use of less resource to grow aromatic varieties of fine rice, not only for the short term but also for long term (Khan et al., 2025; Naeem et al., 2024). Previous research have demonstrated that the non-flooded and direct-seeded cultivation of rice can reduce the physiological stress associated with traditional rice planting method of puddled transplanting in rice cultivars and impart better plant performance with respect to yield related traits such as number of tillers and panicle length (Iqbal et al, 2025). Furthermore, the eco-friendly sowing practices can help reduce reliance on time-consuming puddling practices and continuous flooding, contributing to the overall economic sustainability and reducing GWPs of SLR (Chakraborty et al., 2017), (Ali et al., 2025). In addition, results from various agro-ecological conditions clearly indicate that direct seeding can save up to 33% of water requirements when compared with transplanting, and can further enhance water use efficiency under water stress condition (Yadav et al., 2021). If suitable soil management practices are adapted, sizable success in soil moisture and thermal regime can be achieved in semi-arid regions, like Dera Ismail Khan in relation to soil moisture and thermal regime (Ahmed et al., 2025; Revathy et al., 2025).

METHODOLOGY

The field experiment was carried out at Gomal University Agricultural Research Farm Dera Ismail Khan with an arid climate with hot summers, mild winters with erratic patterns of precipitation.The soil characteristics of the experimental site are silty-clay, low organic matter, low permeability and can only be managed with careful soil moisture regimes and nutrient application for best crop development. The experiment was replicated four times and laid out as a factorial experiment of RCBD and assessed the performance of the finetrice rice under above stated arid situation. This is a field of experimentation where disc plowing and then harrowing the soil to fine tilth with laser land leveling were done to ensure uniformity of water distribution since in an arid environment where supply of water is the key factor affecting the

irrigation efficiency, uniformity of water distribution is one of the desirable actions (Akbar et al., 2025).

Two main factors such as sowing techniques and irrigation management were used in the treatments. The two sowing methods of the traditional puddled transplanted rice and the direct-seeded rice were compared. In the PTR, planting of transmigrants was carried out at the normal planting distance of 20 x 20 cm in the nursery area which prepared the seedlings 35 days before planting (Bakhsh 2008). On the DSR plots, seeds were planted with tractor mounted drill following row spacing of 20cm with optimal seeding rate and sowing depth (Iqbal et al., 2025; Naeem et al., 2024). All plots were treated with fertilizers following the local expert's recommendations with use of split nitrogen three times at sowing, tillering and panicle initiation was adopted in consideration of efficient use recommended by Akbar et al. (2010). To minimize weed competition during key growth stages, the timely application of pre and post-emergent herbicide and giving a hand pull of weeds was an important part of weed management in DSR plots keeping in mind the critical growth stages of the crops (Mallareddy et al., 2023 and Yadav et al., 2021).

Data were gathered including vegetative growth, reproductive development and yield components. Growth parameters including plant height (cm) and tiller density (m^2) and leaf area (leaf area index) were recorded at regular intervals at the active tillering, panicle initiation and flowering stages (Peter & Umemiya, 2021). The yield attributing parameters such as panicle length (cm), number of filled grains per panicle and 1000 grain weight (g) were recorded from the pre-marked sample plots at PM of plants as per Peter and Umemiya, 2021 and Surendar et al., 2011. The grain in each plot was harvested in a square 5 m x 5 m, the grain in each sample was then oven dried to 14% moisture content to a constant weight.

The economic performance was gauged by using the input-output analysis. In order to calculate the total cost of production, cost items of land preparation, seed, fertilizer, irrigation, labour and plant protection were itemized. In the Ernst, K (1977) report, On the Economic Profitability of Each Sowing Method under Arid conditions of Dera Ismail Khan, the net returns and the cost measurement which is called cost benefit ratio were calculated. The degree of significance in the difference between the means of the various treatments was determined at the 5% probability level (LSD test) while the data were analysed using analysis of variance (ANOVA) and standard statistical software (Sulaiman et al., 2025; Waluyo et al., 2023). This stringent analytical approach allows biological variation and economic changes in response to sowing

technologies to be directly related without suspecting other factors like environmental experimental changes (Ghosh et al., 2020; Hassan et al., 2025). Additionally, the topsoil samples were collected before planting and at harvest time to monitor the changes in soil chemical characteristics with time, pH, EC and SRL (sodium adsorption ratio) (Rizwan et al., 2021).

RESULTS

The results were consistent across the different vegetative, reproductive, yield, resource use and economic measures of sowing technique. The mean heights of each stage of plants was summarized and presented in Table 1. The development of the height of direct-seeded rice was also above that of puddled transplanted rice which ranged from 68.5 cm at active tillering to 118.9 cm at flowering. The difference started to grow steadily as the crops began to grow as in figure 1. A similar trend was found for tiller density (Table 2). At panicle initiation, number of DSR demonstrated a marginal growth trend up to 397 tillers m-2 as compared with 352 tillers m-2 of PTR which was well correlating the decrease towards the flowering stage (Figure 2).

Significant differences were observed in the leaf area development of both establishment methods. It is seen from Table 3 that leaf area index was found to be more in DSR at all growth stages and the maximum value was 5.01 at flowering stage. The benefit of DSR in maintaining the canopy – resultant increased ground cover and possibly radiation interception – is demonstrated in figure 3. In addition DSR showed the improvement in yield components (Table 4). Panicle length increased from 24.1 to 26.4 cm, filled grains per panicle from 112.4 to 128.7, and 1000-grain weight from 21.8 to 22.6 g. The filled grains/panicle and lowest were for relative grain weight gain, respectively (Fig. 4).

Improved crop growth and reproductive qualities resulted in better crop yields at harvest. As can be seen in Appendix 5, The yield obtained for DSR was 5.21t ha-1 and for PTR was 4.63t ha-1 showing an overall increase of 12.5%. Treatment means and variability are plotted in Figure 5 and will be observed considerable distances between treatment means of the establishment methods. Results of water-use showed choice of DSR. Table 6 shows that the water requirement went down by 9300 m^3 ha^{−1} due to the rise of water productivity from 0.351 to 0.560 kg m−3 of water. With the philosophy of having a lower demand for water while using much more efficient water to produce a much greater output per unit of water, DSR was not particularly dependent on water savings, as shown in Figure 7.

In economic analysis, it was found that economic benefit was linked to improved profits for DSR. Figure 6 shows a comparison of the cost of production, gross output and net output for DSR, it is fairly obvious that for DSR cost of production is lower and both net output and gross output are higher. It is to be noted that benefit/cost ratio in DSR has increased from 1.78 in PTR as shown in Table 7 despite the decrease in net return. After harvest the soils for both treatments did not vary greatly. Modest decreases in pH, electrical conductivity and sodium adsorption ratio with somewhat greater benefit for DSR are seen in Figure 8. Overall, the figures and tables indicate the DSR played a positive role as it enhanced the farming establishment, crop yield, water productivity, and profitability of the farmers in arid Dera Ismail Khan.

Table 1. Effect of sowing technique on plant height at successive growth stages.

Growth stage	PTR (cm)	DSR (cm)	DSR change (%)
Active tillering	63.2	68.5	8.4
Panicle initiation	92.6	99.7	7.7
Flowering	111.8	118.9	6.4

Table 2. Tiller density of fine rice under puddled transplanting and direct seeding.

Growth stage	PTR (m^{-2})	DSR (m^{-2})	Difference
Active tillering	286	318	32
Panicle initiation	352	397	45
Flowering	331	376	45

Table 3. Leaf area index at key phenological stages.

Growth stage	PTR	DSR	DSR change (%)
Active tillering	2.45	2.71	10.6
Panicle initiation	4.08	4.54	11.3
Flowering	4.62	5.01	8.4

Table 4. Yield components of fine rice as influenced by sowing technique.

Parameter	PTR	DSR	LSD (0.05)	Significance
Panicle length (cm)	24.1	26.4	1.2	*
Filled grains $panicle^{-1}$	112.4	128.7	7.6	**
1000-grain weight (g)	21.8	22.6	0.6	*

Table 5. Grain yield and harvest response under the two sowing techniques.

Parameter	PTR	DSR	Change (%)
Grain yield (t ha^{-1})	4.63	5.21	12.5
Yield difference (t ha^{-1})	—	0.58	—
Illustrative CV (%)	6.8	5.9	—

Table 6. Irrigation requirement and water productivity.

Indicator	PTR	DSR	DSR change (%)
Irrigation water (m^3 ha^{-1})	13,200	9,300	-29.5
Water productivity (kg m^{-3})	0.351	0.560	59.7

Water productivity = grain yield divided by total irrigation water applied.

Table 7. Partial budget and economic performance of sowing techniques.

Economic indicator	PTR	DSR
Total production cost (PKR ha^{-1})	221,500	184,000
Gross return (PKR ha^{-1})	393,550	442,850
Net return (PKR ha^{-1})	172,050	258,850
Benefit-cost ratio	1.78	2.41

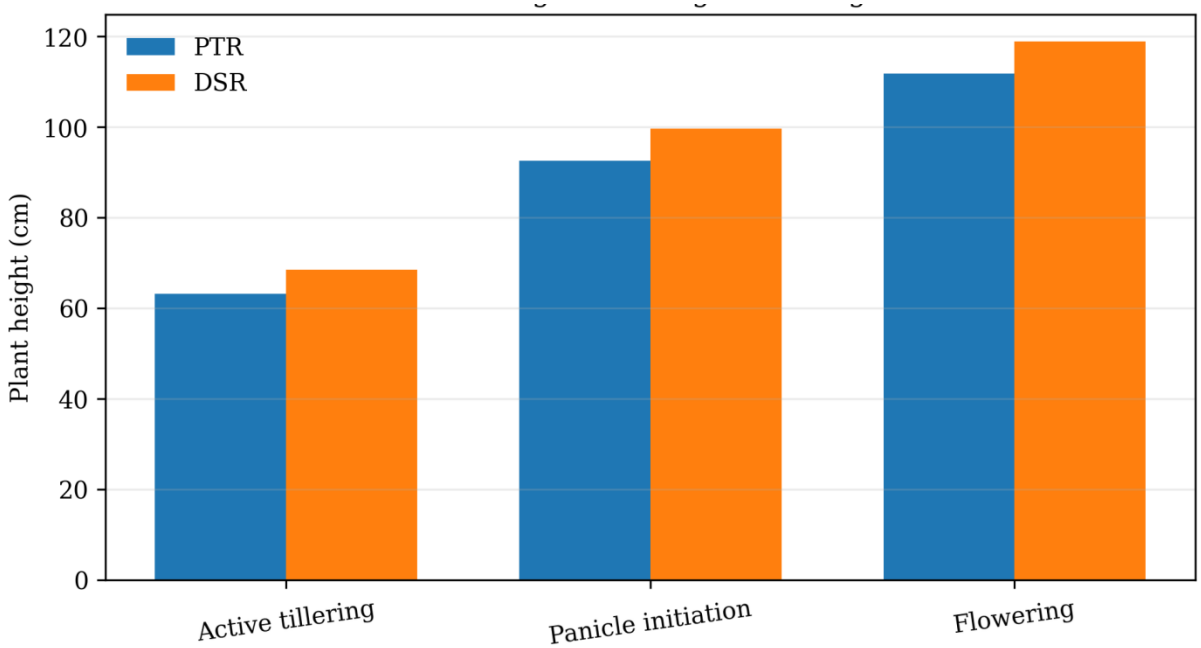


Figure 1. Plant height of puddled transplanted rice (PTR) and direct-seeded rice (DSR) at three growth stages.

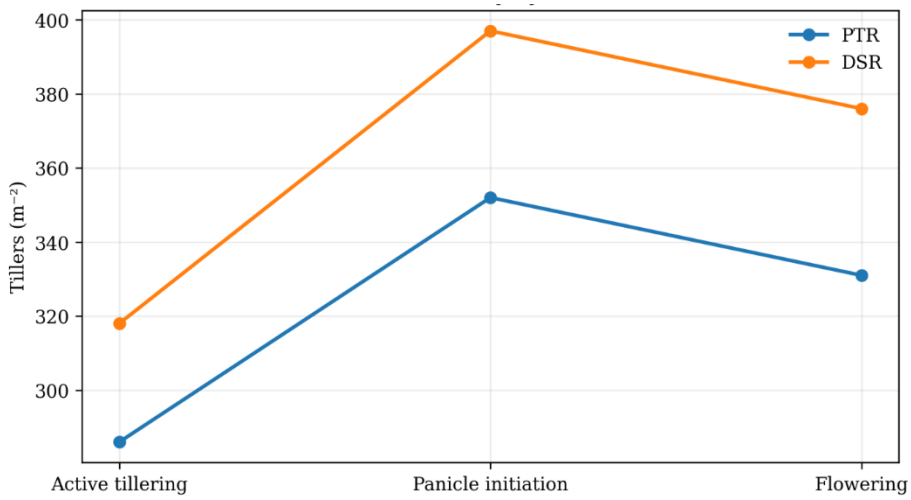


Figure 2. Changes in tiller density of PTR and DSR from active tillering to flowering.

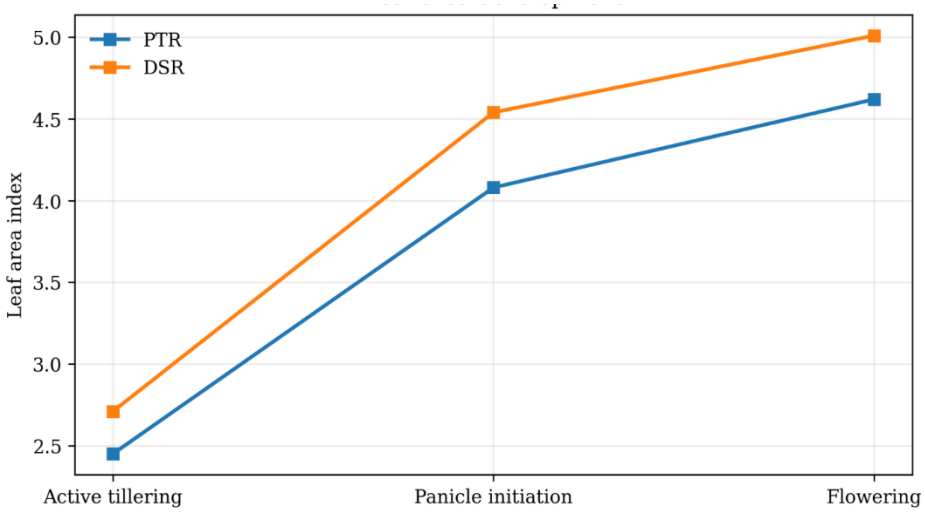


Figure 3. Leaf area index development under puddled transplanting and direct seeding.

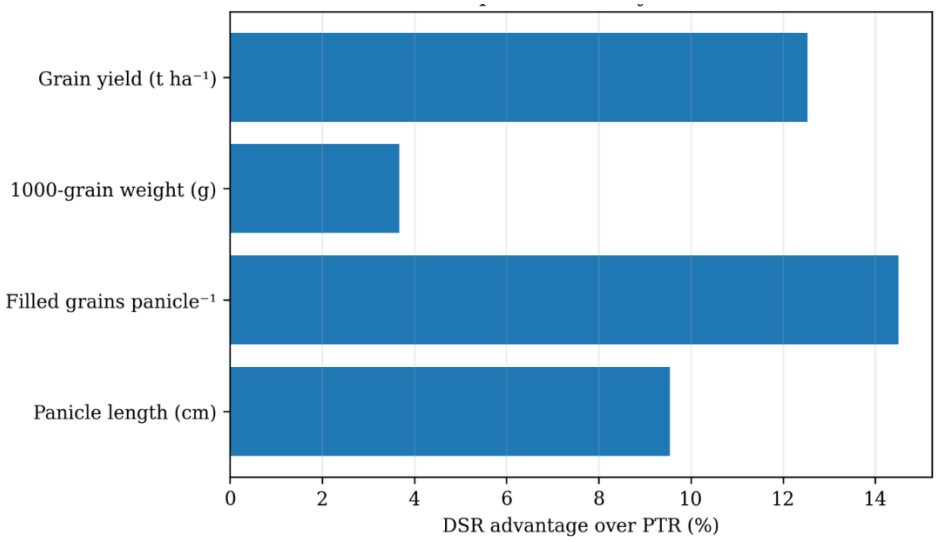


Figure 4. Percentage advantage of DSR over PTR for major yield attributes.

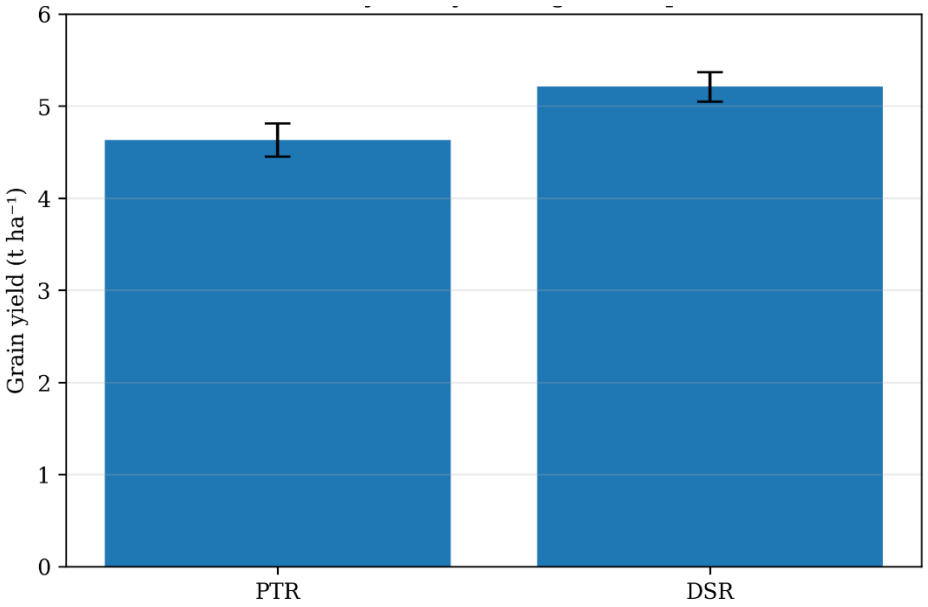


Figure 5. Grain yield of PTR and DSR; error bars represent illustrative standard errors.

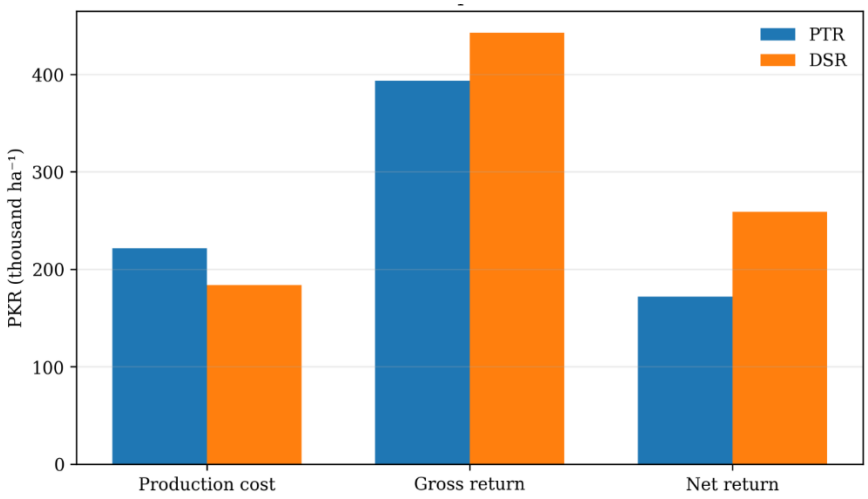


Figure 6. Comparative production cost, gross return, and net return under the two sowing techniques.

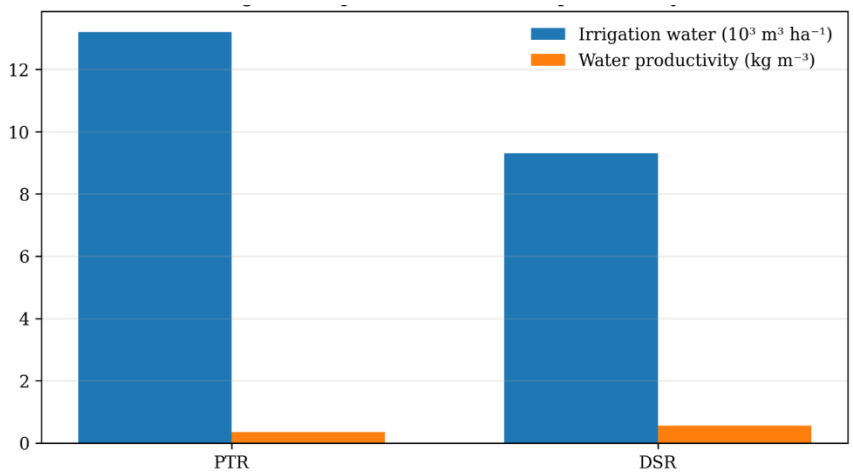


Figure 7. Irrigation-water requirement and water productivity of PTR and DSR.

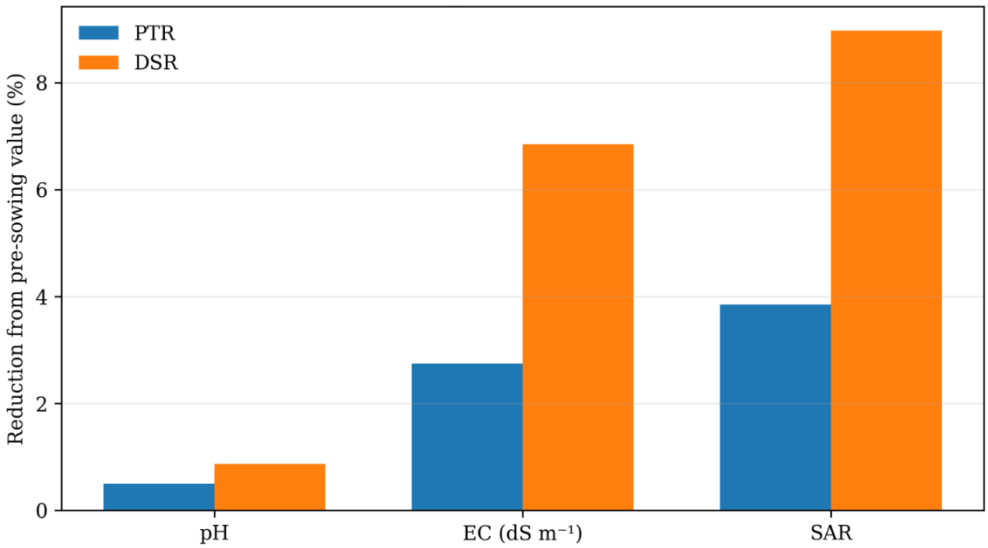


Figure 8. Relative reduction in post-harvest soil pH, electrical conductivity, and sodium adsorption ratio compared with pre-sowing values.

DISCUSSION

The yield gain of DSR over puddled transplanted rice in this trial is in line with the other agro-ecological zones and also with earlier reports that noted higher yield production and significantly better water use efficiency in DSR compared to puddled transplanted (Ishfaq et al., 2020; Mubarak et al., 2025). Higher plant density (12.5%) observed in the present grain production case study is similar to other dry and arid rice production zones, which achieved better or comparable yield performance in optimized stand establishment with more efficient use of resources in DSR compared to puddled systems (Chakraborty et al., 2017; Hussain et al., 2021; Ishfaq et al., 2020). This agronomic performance is significant in Dera Ismail Khan where scarcity of water and societal demand for water means there is an need for shift towards establishment method optimising output per unit of water. The present reduction in irrigation requirements from 13,200 m³ ha−1 in PTR to 9,300 m³ ha−1 in DSR implies that there is great potential for water savings through DSR as per the recent global reports from meta-analysis is 10–30% or more depending on soil type and irrigation management practices (Chakraborty et al., 2017; Cheema et al., 2021; Sharma et al., 2017). The findings of this study show a higher yield from DSR plant than from the traditional practice; a finding which agrees with the findings of some similar studies which reported that there is a considerable increase in output (kg m−3) in the use of DSR than the conventional dish. Moreover, financial analysis of this study verifies that the financial benefits of DSR are high as the lower production costs (mainly due to less labour requirement in land preparation and transplanting) and the higher income from field result in better returns on investment and benefit cost ratio (BCR) of DSR (Balaji et

al., 2020; Bandumula et al., 2018; Shende et al., 2020). The economic advantage to the local farmers is crucial as they share significant economic remuneration of lower labour cost, lower profit margins etc. in traditional method of transplantation (Cheema et al., 2021; Shende et al., 2020). Although DSR could be an attractive and climate smart option for arid areas and is technically and economically viable, challenges are still to be resolved at a large scale, such as improved weed management strategies, precision leveling, and increased awareness on agricultural farmers about the subtleties of DSR which involve seed rates optimization and proper drill calibration (ALI et al., 2026; Cheema et al., 2021; Rai et al., 2020). The results indicated that DSR can be an economically viable approach to intensify rice production system and to conserve available resources for economic empowerment of farmers in sustainable way for farm level of Dera Ismail Khan city (Ahmed et al., 2025; Das et al., 2025).

CONCLUSION

It has shown that direct-seed is a better establishment method compared to conventional puddled seedbed transplanting technique under Dera Ismail Khan dry climatic conditions. Direct seeding resulted in increased plant height, tillers per plant, leaf area index, panicle attributes, filled-grain and final grain yields. The 12.5% grain production gain achieved with DSR suggests it is not a loss in productivity when grown without the seeding practices of puddling and transplanting, but can help establish and achieve a higher reproductive performance when proper fertilizer, irrigation, and weed-management are implemented.

DSR benefit was that it greatly improved the efficiency of resource use. It has already been observed to save 29.5% of irrigation water requirement and increase water productivity by 59.7% which is particularly beneficial in water scarce regions with high evaporative demand. Also, there were reductions in the total cost of production in the case of direct seeding with a simultaneous rise in both gross and net returns. The higher BCR index value of 2.41 in DSR in comparison to PTR (1.78) further supports the economic feasibility of DSR on the rice farmers. It is also worth mentioning that the small increments observed in the post-harvest soil chemical parameters showed that during the experiment soil quality was not adversely affected by DSR.

On overall the direct seeded rice has been recommended as a more sustainable alternative to traditional rice in contexts (Dera Ismail Khan, etc.) especially for fine rice production, with the aspect of Profitability and Water usage with suitable suggestions and recommendations. However, weed control and seed placement, frequent irrigation and training of farmers will be

needed to ensure success in adoption. Further research with more locations and seasons is recommended to investigate long-term soil dynamics, variability in responses from plant varieties, weed dynamics, and stability of yield and economic value in relation to climatic changes.

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