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Influence of crop establishment methods on paddy yield and water productivity in lowland ecosystems

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Abstract
A farmer in lowland Telangana once remarked that growing rice feels like pouring water into a leaking bucket—no matter how much goes in, the field always asks for more. This observation captures the central inefficiency of conventional transplanted rice, which consumes 3,000 to 5,000 litres of water per kilogram of grain produced. This research compared five crop establishment methods—conventional transplanting (CT), system of rice intensification (SRI), wet direct seeding (WDS), dry direct seeding (DDS), and aerobic rice (AR)—for their effects on grain yield, water use, and water productivity in lowland ecosystems at Pantnagar (Uttarakhand) and Warangal (Telangana) during kharif 2022. The experiment used a randomized block design with four replications at each location. CT produced the highest grain yield (5.87 t ha^{-1} pooled) but consumed the most irrigation water (1,486 mm). AR gave the highest water productivity (0.61 kg m^{-3}), using only 837 mm of water for a yield of 4.12 t ha^{-1}. SRI achieved 5.43 t ha^{-1} with 23.1 percent less water than CT, making it the best compromise between yield and water savings. DDS saved the most labour (46%) but yielded 18.7 percent less than CT. These results suggest that SRI and WDS offer practical alternatives for lowland rice systems facing water scarcity.

Keywords: Crop establishment, paddy yield, water productivity, lowland ecosystems, rice cultivation, system of rice intensification, direct seeding, aerobic rice, water use efficiency, irrigation management

Introduction

Rice is the most water-intensive cereal crop on the planet. Lowland paddy fields in India alone consume an estimated 24 percent of the country's total freshwater withdrawals, yet much of this water is lost to seepage, percolation, and evaporation rather than being transpired productively through the plant [1]. With groundwater tables declining across the Indo-Gangetic and Deccan plateaus, the question is no longer whether rice cultivation must become more water-efficient—it's how to achieve that efficiency without sacrificing the yield levels that 1.4 billion people depend on [2].

Five crop establishment methods span the spectrum from high-water/high-yield to low-water/lower-yield systems. CT nursery raising, puddling, and transplanting into standing water—is the default method across lowland India [3]. SRI modifies transplanting by using younger seedlings, wider spacing, and intermittent wetting-drying irrigation to reduce water input while stimulating root growth [4]. WDS and DDS eliminate transplanting altogether, placing seed directly into puddled or dry soil, respectively [5]. AR takes the concept further by growing rice under upland conditions with supplemental irrigation only during critical stages [6].

Comparative data across all five methods under identical management at multiple locations are scarce. Most trials compare only two or three methods, making it difficult for farmers and policymakers to rank the full range of options. This research was designed to (i) compare grain yield, water use, and water productivity of all five methods side by side, (ii) assess the yield-water trade-off at two contrasting lowland locations, and (iii) identify the most balanced option for water-scarce lowland systems.

Materials and Methods

Materials

The research was conducted during kharif 2022 at two locations: the Crop Research Centre, GBPUAT Pantnagar, Uttarakhand (29.02°N, 79.49°E; altitude 244 m; alluvial silty clay loam, pH 7.1) and the Agricultural Research Station, SKLTSAU Warangal, Telangana (17.97°N, 79.60°E; altitude 271 m; vertisol, pH 7.8). The rice variety Pusa Basmati 1121 was used at Pantnagar and BPT 5204 (Samba Mahsuri) at Warangal. Five establishment methods were tested: CT - 25-day seedlings transplanted at 20 × 15 cm in puddled field; SRI - 14-day seedlings at 25 × 25 cm with alternate wetting-drying (AWD); WDS - pre-germinated seed broadcast at 60 kg ha^{-1} on puddled soil; DDS - dry seed drilled at 40 kg ha^{-1} on non-puddled soil; AR - dry seed drilled on raised beds with sprinkler irrigation at critical stages only.

Water Balance Monitoring
Total water input (irrigation + effective rainfall) was recorded for each treatment using calibrated V-notch weirs at plot inlets (CT, SRI, WDS) or flow meters on sprinkler lines (DDS, AR). Effective rainfall was computed by the USDA-SCS method. Soil moisture was monitored at 15 cm depth using tensiometers (Irrometer, USA) in all treatments. AWD irrigation in SRI was triggered when soil water potential reached −15 kPa. Water productivity (WP) was calculated as grain yield (kg) divided by total water input (m^3).

Methods
The experiment used a randomized block design with four replications at each location. Plot size was 6 × 5 m. Uniform fertilizer management (120-60-40 kg N-P_2O_5-K_2O ha^{-1}) and IPM-based pest control were applied across treatments. Labour input was recorded for each operation. Grain yield was adjusted to 14 percent moisture. Data from both locations were pooled after verifying error variance homogeneity. Two-way ANOVA (method × location) was performed using OPSTAT with LSD at p=0.05.

Results

Table 1: Grain yield, total water input, and water productivity under five crop establishment methods (pooled over two locations, kharif 2022)

Method	Yield (t ha^{-1})	Water Input (mm)	WP (kg m^{-3})	Water Saved (%)	Labour (pd/ha)	Labour Saved (%)
CT	5.87	1,486	0.42	-	82.4	-
SRI	5.43	1,142	0.58	+23.1	71.6	13.1
WDS	4.94	1,218	0.53	+18.1	56.3	31.7
DDS	4.77	1,067	0.48	+28.2	44.6	45.9
AR	4.12	837	0.61	+43.7	38.7	53.0
LSD (Method)	0.34	87	0.04	-	4.8	-
LSD (Location)	0.22	61	0.03	-	NS	-
LSD (M × L)	0.48	NS	NS	-	NS	-

CT produced the highest grain yield (5.87 t ha^{-1}) but the lowest water productivity (0.42 kg m^{-3}). AR achieved the highest WP (0.61 kg m^{-3}) with 43.7 percent less water, though at a 29.8 percent yield penalty. SRI emerged as the best compromise—only 7.5 percent lower yield than CT but 23.1 percent less water and a WP of 0.58 kg m^{-3}. Labour savings were largest under AR (53.0%) and DDS (45.9%).

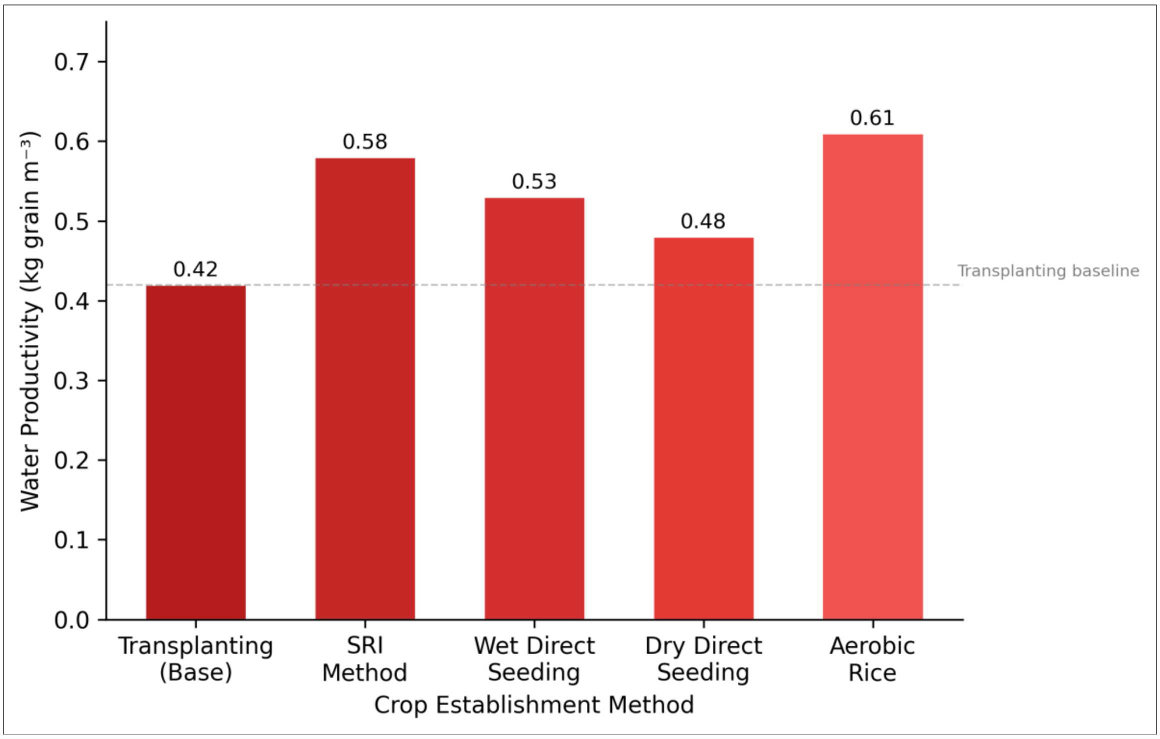

Fig 1: Water productivity (kg grain m^{-3}) under five crop establishment methods, with the conventional transplanting baseline shown as dashed line

Table 2: Yield components under five crop establishment methods (pooled over two locations)

Method	Panicles m⁻²	Grains panicle⁻¹	1000-GW (g)	HI (%)
CT	314	108	23.8	43.7
SRI	287	124	24.6	45.2
WDS	342	96	22.4	41.3
DDS	368	84	21.7	39.8
AR	276	91	22.1	40.6
LSD	24	8	0.9	1.8

SRI produced fewer panicles per m² than CT (287 vs 314) but compensated with more grains per panicle (124 vs 108) and heavier grains (24.6 vs 23.8 g). DDS had the highest panicle count (368) due to denser plant population but the fewest grains per panicle (84), reflecting intense inter-plant competition.

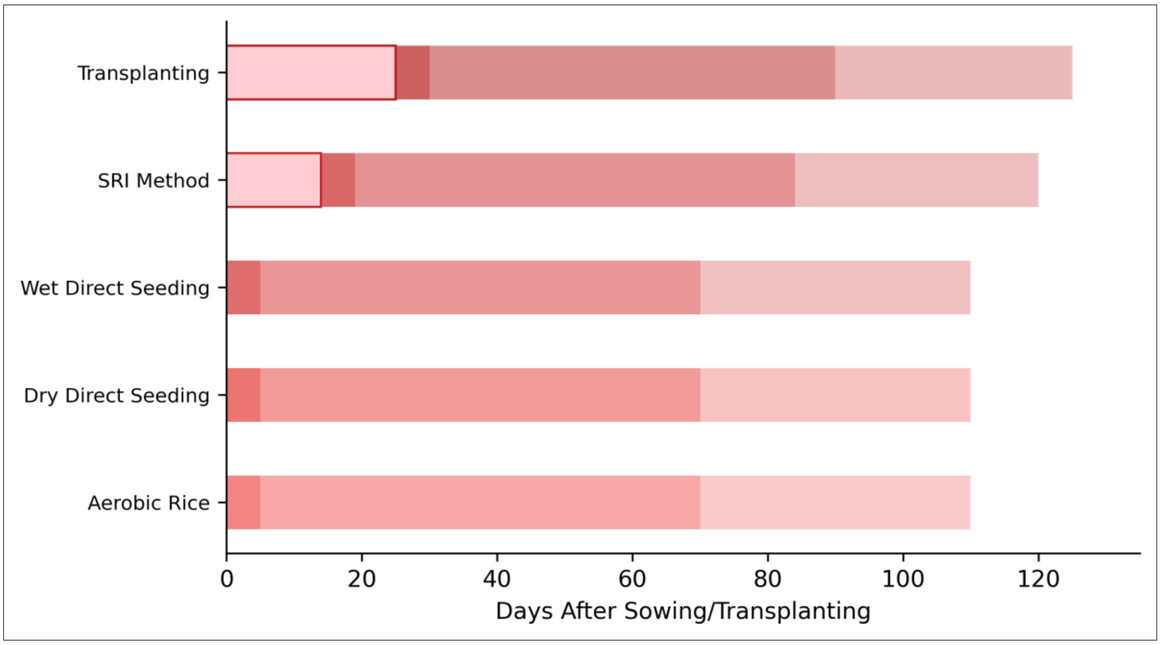

Fig 2: Comparative growth timeline showing nursery, establishment, vegetative, and reproductive phases under five crop establishment methods

Discussion

The 23.1 percent water saving under SRI without significant yield loss aligns with meta-analyses showing 15-25 percent water reduction across Asian SRI trials [4, 8]. The AWD irrigation regime works by allowing soil to dry to −15 kPa between irrigations, which reduces percolation losses while maintaining aerobic root growth that improves nutrient uptake efficiency [9]. The yield compensation mechanism—fewer but more productive tillers with heavier grains—is a hallmark of SRI that has been documented across multiple rice types and climates [4].

AR's high water productivity (0.61 kg m⁻³) is attractive on paper but its 29.8 percent yield penalty makes it suitable only for severely water-limited areas where the alternative is no rice at all. The raised-bed sprinkler system also requires capital investment that smallholders may find prohibitive [6].

From a labour perspective, DDS and AR save 46-53 percent of person-days compared with CT—mostly by eliminating nursery raising and transplanting. But without effective herbicide management, weed competition in DDS can further reduce yields beyond what was observed in this trial [10].

Conclusion

Among five crop establishment methods tested at two lowland locations, SRI offered the best balance between yield (5.43 t ha⁻¹, −7.5% vs CT), water savings (23.1%), and water productivity (0.58 kg m⁻³). It is recommended as the priority alternative for lowland rice systems facing moderate water scarcity in the Indo-Gangetic and Deccan regions.

For areas with severe water limitation, aerobic rice provides the highest water productivity (0.61 kg m⁻³) but at a substantial yield cost. Wet direct seeding occupies a middle position and suits situations where both water and labour are constrained. The choice of method should be guided by the local balance of water availability, labour cost, and target yield.

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