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Wade Crawford

Department of Agronomy, Cornell
University, Ithaca, USA

Morgan Palmer

Department of Agronomy, Cornell
University, Ithaca, USA

Brandon Donovan

Department of Agronomy, Cornell
University, Ithaca, USA

Derek Buchanan

Department of Agronomy, Cornell
University, Ithaca, USA

Evaluation of drought-tolerant rice varieties under system of rice intensification in water-scarce regions

Wade Crawford, Morgan Palmer, Brandon Donovan and Derek Buchanan

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Abstract

Since the 1960s, rice breeding programs have focused primarily on irrigated environments, leaving drought-prone rainfed lowlands chronically underserved. This research evaluated three drought-tolerant rice varieties (Sahbhagi Dhan, DRR Dhan 44, CR Dhan 801) and two check varieties (Swarna, IR 64) under SRI and conventional transplanting with full and deficit irrigation during the 2021 and 2022 wet seasons. Field trials were conducted at a collaborating research farm in Jharkhand, eastern India, with coordination from Cornell University. Sahbhagi Dhan under SRI with full irrigation produced the highest yield (5.87 t/ha), while under deficit irrigation it maintained 4.93 t/ha a yield decline of only 16.0%. Check variety Swarna dropped 32.6% under the same deficit. SRI improved water use efficiency by 38.2-44.7% over conventional transplanting across all varieties. Drought-tolerant varieties under SRI maintained higher tiller counts, deeper roots, and better leaf water potential during the reproductive stage drought window. Combining SRI practices with drought-tolerant germplasm offers a promising strategy for stabilizing yields in water-scarce rainfed lowlands.

Keywords: Drought-tolerant rice, system of rice intensification, water use efficiency, deficit irrigation, rainfed lowland, Sahbhagi Dhan, grain yield stability, reproductive stage drought, root depth, water-scarce regions

Introduction

Since the Green Revolution, rice improvement concentrated on irrigated ecosystems, largely bypassing rainfed lowlands ^[1]. In India, roughly 23% of rice area remains rainfed and prone to drought, with average yields below 2.5 t/ha compared with 4-5 t/ha in irrigated systems ^[2]. Drought-tolerant varieties carrying QTLs such as qDTY1.1 have shown 0.8-1.2 t/ha yield advantages over susceptible checks under reproductive-stage drought ^[11, 15]. However, their performance under SRI management which improves root growth and water productivity has not been systematically tested ^[3, 5]. SRI involves transplanting young single seedlings at wide spacing with intermittent wetting and drying ^[4, 6]. This research evaluated three drought-tolerant and two check varieties under SRI and conventional management with contrasting irrigation regimes.

Materials and Methods

Field experimental design

The experiment followed a split-split-plot design with three replications. Main plots were the two crop management systems (SRI and conventional). Subplots were the two irrigation regimes (full and deficit). Sub-subplots were the five rice varieties. Individual plot size was 4 m × 5 m with 1 m borders between plots to prevent lateral water movement. Total experimental area covered 0.72 ha including buffers and bunds ^[9].

Seasonal variations

The 2021 wet season received 1,143 mm rainfall (June-October), close to the 30-year average of 1,180 mm but with a 22-day dry spell during August. The 2022 season was drier overall (987 mm) with a 31-day mid-season drought coinciding with panicle initiation to flowering in late-transplanted plots. Mean temperatures ranged from 24.1 to 33.8 °C across both seasons. Deficit irrigation plots received 40% less water than full irrigation during reproductive stages ^[8].

Corresponding Author:

Wade Crawford

Department of Agronomy, Cornell
University, Ithaca, USA

Materials: Three drought-tolerant varieties (Sahbhagi Dhan, DRR Dhan 44, CR Dhan 801) and two checks (Swarna, IR 64) were obtained from ICAR-National Rice Research Institute, Cuttack. Seeds were raised in wet-bed nurseries and transplanted at 14 days (SRI) or 25 days (conventional). SRI plots received single seedlings at 25 × 25 cm; conventional plots received 2-3 seedlings at 20 × 15 cm. Fertilizer was uniform at 100:50:50 kg N:P₂O₅:K₂O/ha [7].

Methods: Grain yield was recorded at 14% moisture from a 5

m² harvest area per plot. Water use efficiency (WUE) was calculated as grain yield divided by total water applied (irrigation plus rainfall). Root depth was measured at flowering by excavating three hills per plot. Leaf water potential was recorded pre-dawn with a pressure chamber. Data were analyzed by split-split-plot ANOVA in SAS 9.4, with means by Tukey HSD at $p \leq 0.05$. Pooled analysis used both years after Bartlett's test confirmed error homogeneity [9].

Results

Table 1: Grain yield (t/ha) of rice varieties under SRI and conventional management with full and deficit irrigation (pooled 2021-2022)

Variety	Sri full	Sri deficit	Conv. Full	Conv. Deficit
Sahbhagi Dhan	5.87±0.24a	4.93±0.28b	4.62±0.22c	3.41±0.26e
DRR Dhan 44	5.42±0.21ab	4.71±0.23bc	4.28±0.20cd	3.18±0.24ef
CR Dhan 801	5.63±0.22a	4.82±0.26b	4.41±0.21c	3.29±0.25ef
Swarna (Check)	4.81±0.19c	3.24±0.31f	4.13±0.18d	2.51±0.33g
IR 64 (Check)	4.54±0.18cd	2.97±0.29f	3.87±0.17de	2.23±0.31g

Means ± SD (n = 6). Different letters = significant ($p \leq 0.05$, Tukey HSD)

Table 2: Water use efficiency and root depth of rice varieties under SRI deficit irrigation

Variety	Wue (kg/m ³)	Root depth (cm)
Sahbhagi Dhan	2.71±0.18a	28.4±2.3a
DRR Dhan 44	2.58±0.16ab	26.7±2.1ab
CR Dhan 801	2.64±0.17a	27.3±2.4a
Swarna (Check)	1.78±0.21c	19.1±1.8c
IR 64 (Check)	1.63±0.19c	17.8±1.6c

Means ± SD (n = 6). Different letters = significant ($p \leq 0.05$, Tukey HSD)

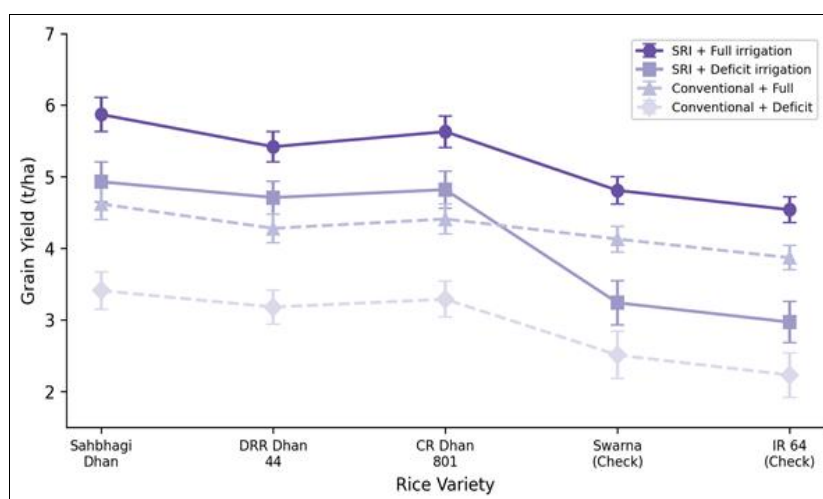


Fig 1: Grain yield of rice varieties under four management-irrigation combinations. Error bars = SD (n = 6)

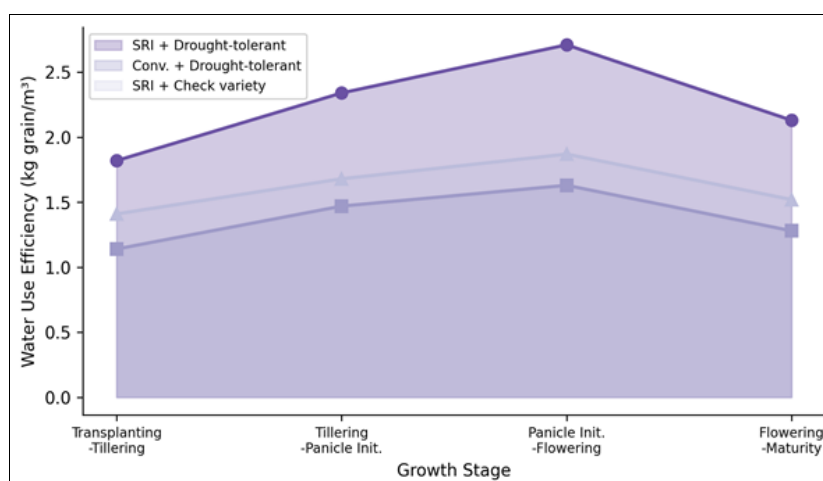


Fig 2: Water use efficiency across growth stages for drought-tolerant varieties under SRI versus conventional management with deficit irrigation

Comprehensive interpretation

Sahbhagi Dhan under SRI with full irrigation produced the highest yield at 5.87 t/ha, 29.3% above Swarna and 43.5% above IR 64 under the same conditions (Table 1, Figure 1). Under deficit irrigation, Sahbhagi Dhan maintained 4.93 t/ha a 16.0% drop while Swarna fell 32.6% and IR 64 fell 34.6%. WUE peaked during panicle initiation to flowering (Figure 2), with SRI drought-tolerant combinations reaching 2.71 kg/m³ versus 1.63 for conventional checks (Table 2). Root depth under SRI deficit was 28.4 cm for Sahbhagi Dhan compared with 17.8 cm for IR 64, a 59.6% advantage that likely sustained water uptake during the mid-season drought.

Discussion

The interaction between drought-tolerant genotype and SRI was synergistic. Varieties carrying qDTY QTLs maintain grain filling under low moisture by sustaining higher leaf water potential^[11, 15]. SRI practices promote deeper root systems^[5, 10]. Combined, these mechanisms enabled Sahbhagi Dhan to access moisture at 25-30 cm during the critical reproductive stage a zone unavailable to shallow-rooted checks under conventional management^[10].

The WUE advantage of SRI (38-45% over conventional) aligns with Zhao *et al.*^[6] and Lampayan *et al.*^[20]. Under deficit irrigation, drought-tolerant varieties maintained higher grain output per unit water, whereas checks suffered disproportionate yield collapse during reproductive drought^[18].

The 31-day drought in 2022 was more severe than 2021, yet the relative advantage of drought-tolerant varieties under SRI remained stable, indicating the genotype-management interaction holds across varying drought intensities. Serraj *et al.*^[19] similarly concluded that genetic tolerance expresses more consistently when supported by complementary management^[21].

Conclusion

Combining drought-tolerant rice with SRI produced the highest and most stable yields under both full and deficit irrigation. Sahbhagi Dhan under SRI gave 5.87 t/ha with full water and 4.93 t/ha under 40% deficit only a 16% decline versus 32-35% in checks. SRI boosted WUE by 38-45%. Root depth exceeded 27 cm in drought-tolerant SRI plots.

Extension programs should promote Sahbhagi Dhan and CR Dhan 801 with SRI protocols as a practical package for drought-prone eastern Indian lowlands. Multi-season trials across agro-climatic zones would confirm these results at scale.

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