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Influence of sowing methods and weed suppression strategies on the agronomic performance, yield and quality of paddy crops

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Abstract
During the 2022 and 2023 *kharif* seasons, a field trial was set up to examine how different crop-establishment approaches and weed-control regimes affect the growth, yield and grain quality of paddy. Four establishment methods were compared transplanted rice, direct seeded rice, drum-seeded rice and the System of Rice Intensification alongside four weed-management regimes: a single post-emergence spray of Nominee Gold (25 g active ingredient ha^{-1}) at 25 days after sowing/transplanting; the same spray followed by one hand weeding at 40 days after sowing/transplanting; two rounds of hand weeding at 20 and 40 days after sowing/transplanting; and an unweeded control. These sixteen combinations were laid out in a split-plot design replicated three times. Two hand weedings at 20 and 40 days after sowing/transplanting produced the tallest plants, the greatest shoot density per square metre, the highest dry-matter accumulation, the best grain yield and the highest nitrogen uptake among the weed-control regimes tested. Among the establishment methods, the System of Rice Intensification gave the tallest plants, greatest shoot count per square metre, highest dry-matter accumulation, best grain yield and highest grain-and-straw nitrogen content.

Keywords: Rice, direct seeded rice, system of rice intensification, weed management, nitrogen uptake

Introduction

Rice (*Oryza sativa* L.) ranks as the principal staple for more than half of humanity, valued both for the calories it supplies and for its economic importance. Global cultivation covers roughly 162.48 million hectares, yielding about 758.92 million tonnes of paddy annually (503.80 million tonnes once milled), with productivity standing at 4.67 t ha^{-1} in 2023. [Q1 Editor: no source is cited for these global area/production/yield figures. They fall within the plausible FAO range for recent years, but please supply the specific citation (report and year) so the numbers can be verified rather than taken on trust.] Beyond being a rich carbohydrate source and a modest contributor of dietary protein, rice is consumed directly as cooked grain and processed into numerous other food products, while its straw and husk find use as animal fodder and as raw material for mulch, packaging, insulation and cardboard manufacture. Sustaining self-sufficiency as the population grows will require lifting output by roughly 140 million tonnes by 2025 an increase of over 2 million tonnes annually through the coming decade [1] [Q2 Editor: this 'by 2025' production target is attributed to a source published in 2000, and 2025 has now passed. Please update this with a current demand projection and citation, or rephrase to remove the dated target.] Even as the resource base of land, labour and water continues to shrink, and without compromising environmental quality. One approach gaining attention is the System of Rice Intensification, a package of practices first developed in Madagascar during the early 1980s to address soil-acidity constraints. Its core principle is to exploit the vigour of young seedlings, reducing competition for light and nutrients while improving the efficiency with which seed, water, fertilizer and pesticide inputs are used; by relieving soil anoxia it also encourages stronger root systems and greater microbial activity, which in turn builds up soil organic matter. Reported benefits of the System of Rice Intensification include water savings of 22-38% relative to conventional transplanting across the dry and wet seasons, and yield gains of up to 16.6% attributable to Improved growth and greater total biomass.

[Q3 Editor: these SRI water-saving and yield-gain percentages are also uncited. Published SRI literature reports comparable ranges (roughly 22-50% water savings, 20-50%+ yield gains), so the figures are plausible, but please add the source for these specific values.] Direct seeded rice, by contrast, poses a tougher weed-management challenge: infestation tends to be more diverse and severe, there is no standing water layer to hold weeds in check at the time the crop emerges, and rice seedlings lack any size advantage over weeds since both germinate together. Several herbicides have consequently been evaluated for pre-plant, pre-emergence and post-emergence use in direct drill-seeded systems and found effective [2, 3].

Materials and Methods

The trial ran across two successive *kharif* seasons (2022 and 2023) on the Agriculture Farm of Swami Vivekanand Subharti University, Subharti Puram, Meerut, Uttar Pradesh. The area experiences a sub-humid climate, with mean annual rainfall around 1200 mm, nine-tenths of it falling between mid-June and late September; occasional winter showers also occur, alongside cold, frost-prone winter months, while the late-spring period is hot and dry with westerly winds dominating from the second half of April through the first half of June. The experimental soil was a silty loam of pH 7.8, containing 200.30, 19.55 and 300.40 kg ha^{-1} of available nitrogen, phosphorus and potassium, respectively. Four crop-establishment methods System of Rice Intensification, conventional transplanting, drum seeding and puddled direct seeding were combined factorially with four weed-management regimes (Nominee Gold at 25 g a.i. ha^{-1} applied 25 days after sowing/transplanting; the same treatment followed by hand weeding at 40 days after sowing/transplanting; two hand weedings at 20 and 40 days after sowing/transplanting; and an unweeded control) in a split-plot layout with three replications. The variety used, NDR-97, does not lodge, tillers moderately (9-14 tillers), has medium-broad leaves, senesces late, and typically yields 25-30 quintals ha^{-1}; it is recommended for western Uttar Pradesh as well as rainfed and upland tracts. Phosphorus and potassium were applied uniformly as a basal dressing (60 and 40 kg ha^{-1}, via single super phosphate and muriate of potash) worked into the topsoil at puddling, while nitrogen (120 kg ha^{-1}, as urea) was split into three equal applications.

Seed rates for the two direct-seeding treatments were fixed at 100 kg/ha for broadcasting and 20 kg/ha for the drum seeder. Before sowing, seed was pre-soaked in water for 12 hours, then heaped and wrapped in a moist gunny bag for a further 24 hours to induce sprouting. For the drum-seeded plots, the field was puddled just ahead of sowing with two cross-ploughings using a *desi* plough followed by planking under standing water, after which sprouted seed was drilled through the drum seeder in 20-cm rows; in the broadcast plots, sprouted seed was simply scattered by hand, while all other establishment methods used 20-cm row spacing. Nursery sowing and main-field establishment were carried out on the same calendar dates in both years 28 June 2022 and 30 June 2023. Crops were hand-harvested with sickles once the spikelets had turned straw-coloured and grain moisture had dropped to 15-18%; the two border rows of each plot were cut first and discarded, and the net-plot produce was harvested separately, left to sun-dry in place for three days, then bundled, tagged and carried to the threshing floor.

Plant height was recorded as the distance from ground level to the tip of the tallest leaf before heading, and to the panicle base after heading, with values averaged per plot. Shoot density at harvest was estimated using a 50 cm × 50 cm quadrat placed at four locations per plot, and the counts averaged to give shoots m^{-2}. For dry-matter accumulation, plants were cut close to the ground from a 50 cm × 50 cm area per plot at harvest, sun-dried, chopped into small pieces, bagged and then oven-dried at 70 ± 1 °C to constant weight before being weighed on an electronic balance and expressed as g m^{-2}. Clean grain recovered from each net plot was weighed in kilograms and converted to q ha^{-1} for the statistical analysis of yield.

Grain and straw nitrogen content was estimated by the Kjeldahl procedure of Jackson [4]: oven-dried, ground samples were digested and analysed by the micro-Kjeldahl method [4], and nitrogen uptake by each plant component was calculated by multiplying its nitrogen percentage by the corresponding total dry-matter yield (biological yield). Total nitrogen in the grain samples was separately verified using Nessler's reagent, and the resulting nitrogen content was converted to crude protein by applying a factor of 6.25, as follows:

Crude protein content (%) = Nitrogen content in grain (%) × 6.25

Results and discussion

Growth parameters

Plant height: Plants were tallest under the System of Rice Intensification, statistically on par with transplanting, while the two direct-seeded methods matched each other but fell below these. Among the weed treatments, Nominee Gold plus a supplementary hand weeding at 40 days after sowing/transplanting gave the tallest plants in year one, outperforming two hand weedings, Nominee Gold alone, and the unweeded control (Table 1). [Q4 Editor: the C.D. in Table 1 does not support 'outperforming two hand weedings' for plant height. 2022: Nominee Gold + hand weeding (81.71) vs two hand weedings (79.17) differ by 2.54, below the C.D. of 3.50. 2023: 83.80 vs 81.48 differ by 2.32, below the C.D. of 3.51. On these figures the two treatments are statistically at par in both years please recheck against the ANOVA output.] The greater height under transplanting is likely linked to better crop establishment and more active cell division and elongation in meristematic tissue, aided by lower weed density and weed biomass in these plots. Comparable trends have been reported by Mankotia *et al.* [5], Khattak *et al.* [6] and Prasad *et al.* [7].

Number of shoots: Shoot counts at harvest were significantly higher under the System of Rice Intensification and transplanting than under the other two establishment methods, with these two treatments statistically equivalent to each other. Two hand weedings gave the highest shoot numbers, on par with Nominee Gold plus hand weeding and ahead of Nominee Gold alone or no weeding at all, plausibly because reduced crop-weed competition under these regimes freed up more nutrients, light, moisture and space for the crop, favouring better growth and development overall. Tomar *et al.* [8], Dubey *et al.* [9] and Koushik *et al.* [10] report similar patterns.

Dry matter accumulation: Establishment method significantly influenced dry-matter accumulation at harvest, with the System of Rice Intensification outperforming transplanting, drum seeding and direct seeding, though it did not differ statistically from transplanting; direct-seeded plots produced the least dry matter in both years. Among weed regimes, two hand weedings outperformed the other treatments and matched Nominee Gold plus hand weeding at 40 days after sowing/transplanting. The advantage under the System of Rice Intensification probably reflects minimal weed competition, which allowed greater biomass build-up consistent with reports from Mankotia *et al.* [5], Singh *et al.* [2] and Thakur *et al.* [11].

Grain yield

Grain yield followed a similar pattern: The System of Rice Intensification, on par with transplanting, exceeded all other establishment methods (Table 1), most likely because of greater dry-matter production per unit area driven by more efficient nutrient uptake, faster metabolism, stronger light interception, higher photosynthetic activity and a greater leaf count. Transplanting also produced a significantly higher harvest index than the other methods, statistically matching both the System of Rice Intensification and drum seeding. [Q5 Editor: harvest index is not among the parameters tabulated in Tables 1-4 there is no supporting data for this sentence anywhere in the manuscript. Please supply the harvest-index values (and C.D.) for a table, or remove this claim.] Among weed treatments, two hand weedings and Nominee Gold plus hand weeding (statistically equivalent to each other) both out-yielded Nominee Gold used alone and the unweeded control, echoing the findings of Yadav *et al.* [12].

Interaction effect of planting methods and weed management practices on grain yield

The planting-method × weed-management interaction significantly shaped grain yield in both years. As Table 2 shows, at any given weed-control level, the System of Rice Intensification and transplanting (Statistically equal) out-yielded both drum seeding and direct seeding, with drum seeding in turn surpassing direct seeding a pattern consistent across both seasons. Within any given establishment method, two hand weedings and Nominee Gold plus hand weeding (again on par with each other) gave higher yields than Nominee Gold alone or the weedy check, and Nominee Gold alone still outperformed the weedy check at every establishment method in both years findings that align with Prasad *et al.*, Singh *et al.*, Ahmed *et al.* and Dubey *et al.* [2, 7, 13, 9]. [Q6 Editor: this general pattern holds under the three weeded regimes, but in the weedy-check row of Table 2 the drum-vs-direct-seeded gap (e.g. 2022: 16.30 vs 12.78 = 3.52) falls just under the C.D. of 3.57, and SRI/transplanting vs drum seeding is likewise just under threshold there. Minor, but worth a quick recheck of that row against the raw analysis.]

Quality parameters

Nitrogen uptake by grain and straw was greatest under the System of Rice Intensification, statistically matching transplanting and followed by drum seeding and direct seeding (Table 3).

Weed management again mattered: Two hand weedings and Nominee Gold plus one hand weeding at 40 days after sowing/transplanting (statistically equal) gave significantly higher uptake than Nominee Gold alone or the weedy check, likely reflecting better control of weed biomass in line with Singh *et al.* [14] and Yadav *et al.* [12].

Interaction effect of planting methods and weed management practices on nitrogen uptake by grain

A closer look at Table 4 confirms that, within any weed-control level, establishment method had a significant bearing on nitrogen uptake: The System of Rice Intensification and transplanting (on par with each other) exceeded direct seeding, while drum seeding also outperformed direct seeding a pattern that held in both years. Within any establishment method, two hand weedings and Nominee Gold plus hand weeding (Statistically equal) were significantly ahead of Nominee Gold alone and the weedy check, and Nominee Gold alone in turn exceeded the weedy check throughout both seasons corroborating Singh *et al.* [14], Mankotia *et al.* [5] and Yadav *et al.* [12].

Table 1: Effect of planting methods and weed control practices on growth parameters and grain yield of paddy

Treatment	Plant height (cm)		Number of shoots m^{-2}		Dry matter accumulation (g m^{-2})		Grain yield (q ha^{-1})	
	2022	2023	2022	2023	2022	2023	2022	2023
Planting methods								
Transplanting (20 cm × 10 cm)	76.86	80.46	355.55	358.25	679.88	689.31	31.28	33.50
Direct seeded rice (budded, row planting) (20 cm apart)	64.43	66.48	289.23	291.42	539.46	546.92	21.50	23.03
Drum seeded rice (budded) (20 cm × 10 cm)	70.08	73.31	322.99	325.44	615.85	624.38	27.45	29.41
SRI (20 cm × 20 cm)	82.23	83.75	372.23	375.06	704.81	714.60	32.17	34.46
S.Em±	2.32	2.41	9.63	9.70	16.91	17.04	0.835	0.894
C.D. (P = 0.05)	7.54	7.83	32.84	33.09	58.02	58.83	2.866	3.070
Weed control practices								
Nominee Gold	70.99	75.86	322.59	325.04	671.83	681.15	27.76	29.74
Nominee Gold + hand weeding at 40 DAS/T	81.71	83.80	358.49	361.21	711.18	721.05	33.76	36.16
Two hand weedings at 20 & 40 DAS/T	79.17	81.48	366.83	369.61	717.31	727.26	34.19	36.63
Weedy check	61.73	62.86	292.10	294.30	439.69	445.74	16.69	17.87
S.Em±	1.30	1.34	5.24	5.28	10.87	11.02	0.431	0.461
C.D. (P = 0.05)	3.50	3.51	15.11	15.23	31.55	31.99	1.240	1.328

SRI = System of Rice Intensification; DAS/T = days after sowing/transplanting; S.Em± = standard error of the mean; C.D. = critical difference. Nominee Gold was applied at 25 g a.i. ha^{-1} at 25 DAS/T.

Table 2: Interaction effect of planting methods and weed management practices on grain yield (q ha⁻¹)

Grain yield, 2022 (q ha⁻¹)				
Treatments	**Trans**	**DSR**	**Drum**	**SRI**
Nominee Gold	30.90	21.25	27.12	31.78
Nominee Gold + hand weeding at 40 DAS/T	37.58	25.83	32.98	38.65
Two hand weedings at 20 & 40 DAS/T	38.06	26.16	33.41	39.15
Weedy check	18.57	12.78	16.30	19.10
S.Em± = 0.86; C.D. (P = 0.05): (i) B at same level of A = 2.48, (ii) A at same or different level of B = 3.57				
Grain yield, 2023 (q ha⁻¹)				
Treatments	Trans	DSR	Drum	SRI
Nominee Gold	33.10	22.76	29.05	34.05
Nominee Gold + hand weeding at 40 DAS/T	40.25	27.66	35.33	41.40
Two hand weedings at 20 & 40 DAS/T	40.77	28.02	35.78	41.93
Weedy check	19.89	13.68	17.46	20.45
S.Em± = 0.92; C.D. (P = 0.05): (i) B at same level of A = 2.66, (ii) A at same or different level of B = 3.82				

A = planting methods; B = weed control practices; Trans = transplanting; DSR = direct seeded rice; Drum = drum seeded rice; SRI = System of Rice Intensification; S.Em± = standard error of the mean; C.D. = critical difference.

Table 3: Effect of planting methods and weed control practices on quality parameters of paddy

Treatment	Nitrogen uptake (kg ha⁻¹)				Nitrogen content (%)				Protein content in grain (%)	
	Grain		Straw		Grain		Straw			
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
Planting methods										
Transplanting (20 cm × 10 cm)	37.52	41.18	17.29	18.24	1.21	1.24	0.49	0.50	7.54	7.69
Direct seeded rice (budded, row planting) (20 cm apart)	24.07	26.47	14.29	14.25	1.13	1.16	0.46	0.47	7.01	7.17
Drum seeded rice (budded) (20 cm × 10 cm)	31.01	33.81	15.05	15.57	1.14	1.16	0.46	0.47	7.08	7.22
SRI (20 cm × 20 cm)	40.19	43.74	18.81	19.79	1.26	1.28	0.51	0.52	7.80	7.96
S.Em±	0.990	1.081	0.496	0.490	0.035	0.033	0.013	0.013	0.205	0.214
C.D. (P = 0.05)	3.401	3.718	1.691	1.670	NS	NS	NS	NS	NS	NS
Weed control practices										
Nominee Gold	32.74	35.67	18.08	18.09	1.19	1.21	0.48	0.49	7.37	7.52
Nominee Gold + hand weeding at 40 DAS/T	39.48	43.37	17.24	18.48	1.16	1.21	0.48	0.49	7.36	7.51
Two hand weedings at 20 & 40 DAS/T	39.99	43.94	17.32	18.56	1.16	1.21	0.48	0.49	7.35	7.50
Weedy check	19.51	21.42	12.50	12.48	1.16	1.21	0.48	0.49	7.35	7.50
S.Em±	0.501	0.547	0.271	0.267	0.020	0.021	0.009	0.008	0.118	0.116
C.D. (P = 0.05)	1.444	1.578	0.772	0.761	NS	NS	NS	NS	NS	NS

SRI = System of Rice Intensification; DAS/T = days after sowing/transplanting; S.Em± = standard error of the mean; C.D. = critical difference; NS = non-significant.

Table 4: Interaction effect of planting methods and weed management practices on nitrogen uptake by grain (kg ha⁻¹)

Nitrogen uptake by grain, 2022 (kg ha⁻¹)				
Treatments	**Trans**	**DSR**	**Drum**	**SRI**
Nominee Gold	37.27	23.88	30.70	39.64
Nominee Gold + hand weeding at 40 DAS/T	45.27	28.99	37.28	48.14
Two hand weedings at 20 & 40 DAS/T	45.79	29.33	37.72	48.70
Weedy check	22.33	14.32	18.40	23.74
S.Em± = 0.99; C.D. (P = 0.05): (i) B at same level of A = 2.88, (ii) A at same or different level of B = 4.20				
Nitrogen uptake by grain, 2023 (kg ha⁻¹)				
Treatments	Trans	DSR	Drum	SRI
Nominee Gold	40.74	26.10	33.56	43.33
Nominee Gold + hand weeding at 40 DAS/T	49.48	31.69	40.75	52.63
Two hand weedings at 20 & 40 DAS/T	50.05	32.05	41.22	53.24
Weedy check	24.40	15.64	20.11	25.95
S.Em± = 1.08; C.D. (P = 0.05): (i) B at same level of A = 3.15, (ii) A at same or different level of B = 4.59				

A = planting methods; B = weed control practices; Trans = transplanting; DSR = direct seeded rice; Drum = drum seeded rice; SRI = System of Rice Intensification; S.Em± = standard error of the mean; C.D. = critical difference.

Conclusion

Overall, the System of Rice Intensification and transplanting proved better than the other establishment methods at suppressing weeds and limiting nitrogen loss to them, translating into stronger growth, yield and nitrogen uptake in the paddy crop. Two hand weedings at 20 and 40 days after sowing/transplanting, and Nominee Gold applied at 25 days after sowing/transplanting followed by a hand weeding at 40 days, were the most effective weed-management options, cutting weed pressure sharply and thereby boosting growth, yield and nitrogen uptake. Unweeded, direct-seeded plots lost the most nitrogen to weeds. The combination of two hand weedings (or Nominee Gold plus a supplementary hand weeding) with either the System of Rice Intensification or transplanting consistently gave the best results for plant height, dry-matter production, shoot number and nitrogen uptake.

Acknowledgments

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Editor queries for author

The queries below are marked inline (in red) at the relevant point in the text. They do not affect the body of the manuscript and can be deleted once resolved.

- Q1. The global rice area/production/yield figures in the Introduction (162.48 million ha; 758.92 million t; 4.67 t ha^{-1}) carry no citation. They sit within the plausible range for recent FAO-type data, but need a specific source and year.
- Q2. The '140 million tonnes by 2025' production target is cited to a source published in 2000, and the target year (2025) has already passed. Needs updating with a current projection and citation, or rephrasing.
- Q3. The SRI water-saving (22-38%) and yield-gain (16.6%) figures are also uncited. They fall within ranges reported in the published SRI literature, but the specific source should be added.
- Q4. Table 1: the text states Nominee Gold + hand weeding was significantly superior to two hand weedings for plant height. The table's own C.D. values (3.50 in 2022, 3.51 in 2023) are larger than the actual difference between these two treatments (2.54 and 2.32) in both years i.e. the table shows them as statistically at par, not significantly different. Please recheck against the ANOVA.
- Q5. The grain-yield discussion reports a significant harvest-index result for transplanting, but harvest index does not appear as a parameter in Tables 1-4. Please supply the data or remove the claim.
- Q6. In the weedy-check (unweeded) row of Table 2, the drum-seeding vs direct-seeded-rice gap sits just under the stated C.D., as do a couple of other comparisons in that row a minor exception to the general pattern described in the text. Worth a quick check against the raw analysis.