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A Promising Water-saving Technique for Rice Cultivation

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EXECUTIVE SUMMARY

The aim of this study was to identify rice varieties suitable for wet seeding and to assess growth and yield of rice crop established by different direct seeding methods and transplanting. Water-use efficiency of the production systems, comparative weed growth and labour requirements under each method were also evaluated.

Rice crop established by wet seeding method showed increase in seedling emergence, faster seedling growth, shorter plant height, better root development, more tillers and panicle and greater leaf area index (LAI), which are essential for better survivability and subsequent increase in grain yield. Rice varieties Naveen, Kalinga-III, Heera and Khandagiri showed most of these characters and produced grain yield 3.04, 2.96, 2.95 and 3.04 t ha^{-1}, respectively. Among the ten varieties tested, Naveen showed the best performance under anaerobic soil condition.

Different direct seeding methods of crop establishment like dry seeding by broadcast (DSB), wet seeding by broadcast (WSB), wet seeding by broadcast followed by beushening (WSBB), wet seeding in lines (WSL) and wet seeding in spots (WSS) were compared with the traditional transplanting (TPR) method. WSS gave significantly higher yield (11.8%) compared to TPR due to higher tillering, more panicles, and better grain filling. Weed population under DSB, WSB, and WSS were 5, 4, and 2 times more than that under TPR, respectively. Total water requirement for rice crop established by transplanting, wet seeding and dry seeding methods of planting were 1041.2, 941.5 and 915.0 ha-mm, respectively. Water use efficiency (WUE) was lowest under dry seeding and highest under wet seeding in spots. WSL and WSS showed 9.7 and 24.0% higher WUE, respectively, than traditional TPR method. However, commonly adopted wet seeding method, i.e. wet seeding by broadcast (WSB) showed 10% less WUE than TPR. Wet seeding reduced 5-20% labor requirements compared to TPR. More labours were required for the sowing in lines and spots seeding, but weeding was found easier and less labour intensive in these methods. The labour requirement of wet-seeded and dry-seeded rice cultivation was also found less, coinciding with the peak demand of labourers during transplanting season. The results clearly indicate that wet seeding spot method of rice planting is an improved method that gives higher yield with lesser requirement of water and labour and easy weed management than the existing methods.

1. INTRODUCTION

Transplanting of rice is widely practiced in irrigated environment. Main advantage of transplanting is the ease in crop care like weeding and fertilizer application. However transplanting is labour-intensive and requires too much water. In transplanting system, about 5,000 liters of water is required to produce 1 kg of rice (Puttana, 1983). Because of decreasing water resources (falling ground water, silting of reservoirs), decreasing quality (pollution) and increasing industrial and urban users, the water availability for irrigation is increasingly getting scarce day by day. On the other hand, demand for rice is still on rise because of continuous population growth. So, there is a need to "*grow more rice with less water*" (Guerra *et al*., 1998). Expansion of irrigated areas, increasing transplanting cost, unavailability of labour, and declining profitability of rice production have forced many farmers to shift from transplanting to wet seeding (De Datta, 1986). In wet seeded rice (WSR), farmers generally broadcast pre-germinated seeds directly on the puddled and levelled field, which are free from standing water (Moody and Cornova, 1985).

There are a number of constraints to wider adoption of wet seeding rice production. They are: identification of suitable genotypes, poor germination under anaerobic conditions, lodging of crop due to shallow root depth, weed infestation and water control. Weed competition is greater in WSR than in TPR because the weed and rice grow at the same time (Moody, 1983). The similarities in age and morphological features of young grassy weeds and rice seedlings make hand weeding in broadcasted wet seeded rice more difficult than that in TPR (De Datta and Bernasor, 1973). However, such operational problem of weeding in WSR can be minimized through 'line' or 'spot' seeding of pre-germinated seeds in puddled field. So far no attempt has been made in this direction to find out feasibility of 'line' or 'spot' sowing of pre-germinated seeds and their subsequent effect on yield. There are several reports (Erguiza *et al.,* 1990; Polvatana, 1995) maintaining that direct seeding is a labour saving method of rice crop establishment. However detailed investigation on various aspects of the methods of sowing of rice is required along with quantification of labour requirement in different crop establishment methods of rice.

The aim of this project is to identify suitable rice cultivars for wet seeding and to develop a new and alternative method of rice crop establishment so that weeding should be easier and rice growers may get more benefit.

2. MATERIALS AND METHODS

2.1 Experimental design and treatments

Field experiments were conducted at the Deras Farm, Mendhasal in Khurda district, Orissa, India (20° 30′ N, 87° 48′ 10″E) during 2001-2004. Soils of the experimental site were sandy clay-loam in texture (63% sand, 16% silt and 21% clay) having pH 5.5 and were classified as Aeric Haplaquept. Rice crop (*Oryza sativa* L.) was established by following six different methods, viz. transplanting of 3 week old seedlings (TPR), dry seeding by broadcast (DSB), wet-seeding by broadcast (WSB), wet-seeding by broadcast followed by beushening (WSBB), wet-seeding in line (WSL), and wet-seeding in spot (WSS). The seed rates were 35 kg ha^{-1} for transplanting and 80 kg ha^{-1} for all the direct seeding methods. The experiment was laid out in a randomized block design (RBD) using four replications and size of plot was 10 m X 5 m.

Wet-seeding by broadcast (WSB)

Wet-seeding in lines (WSL)

Wet-seeding in spots (WSS)

2.2 Land preparation, seeding and intercultural operations

For DSB, dry rice seeds were sown in the thoroughly plowed and leveled field. For wet seeding, seeds were soaked in water for 24 h and were then wrapped in wet jute bag for germination. The bags were kept wet in shade and water was sprinkled at regular interval to keep it moist. After 48 h germinated seeds were used for sowing.

For all the four methods of wet seeding, germinated seeds were sown in puddled and leveled field with no standing water on the surface. For wet seeding in spots (WSS), 3-7 seeds in each spot were sown. Simultaneously seeds were also sown in the nursery beds for raising rice seedlings. Three weeks old seedlings uprooted from the nursery beds were used for the transplanting. Fertilizers were applied @ 80 kg N, 40 kg P_2O_5 and 40 kg K_2O per hectare. Required N fertilizer was applied in three split doses. Starting from the three-leaved seedling stage (i.e. 7 days after sowing), standing water of 5 cm height was maintained in the field in wet seeding. The plots were drained out seven days before physiological maturity of the crop under all the treatments. Beushening operation in the WSBB plots was done one month after sowing for even distribution of seedlings. Hand weeding was done at 15, 35 and 65 days after seeding in all direct sown plots.

2.3 Data collection

Rice plants were collected from one square meter sample area of each plot for the measurements of the growth parameters such as (1) tiller number, (2) panicle number, (3) panicle length and (4) number of grains per panicle. Weeds were collected from one square meter sample area of each plot thrice, i.e. 15, 35 and 65 days after seeding (DAS). Dry weight of plant samples was determined after oven drying at 80 °C to constant weight for 72 h. Crops from TPR plots were harvested 107 days after sowing, but in other plots it was harvested 7-10 days earlier. Yields were determined by crop-cutting in two diagonally opposite corners of each plot using a 1m X 1m quadrant.

2.4 Measurement of water requirement and water use efficiency

Evaporation was measured using class A pan. Seepage loss and percolation rates were calculated from the daily observed standing water depths in the plots. Evapo-transpiration was calculated from the measured pan evaporation using the equations for lowland rice (Doorenbos and Pruitt, 1977). Water use efficiency was calculated from the following relationship as described by Viets (1962):

Water-use efficiency (WUE) = grain yield (kg)/ water used (ha-mm)

2.5 Data analysis

The data were analysed according to randomized block design by standard ANOVA at $P \leq 0.05$ level of significance. Duncan's multiple range tests at P £0.05 (Gomez and Gomez, 1983) were also carried out.

3. RESULTS

3.1 Identification of suitable cultivars for wet seeding

Ten rice varieties namely Khandagiri, Surendra, Naveen, IR-64, IR-36, Heera, Lalat, Kalinga-3, MW-10, and Konark of eastern India were grown during rabi, 2001 and 2002 by wet seeding broadcasting method to identify their suitability for this method of crop establishment.

Initial crop establishment: Crop establishment is determined not only by percentage of seedling establishment (i.e. survival of seedling) but also by the initial crop growth rate and crop's competitiveness against weed. Data on initial growth, leaf area and root development of ten rice varieties are presented in Table 1. Rice varieties Kalinga-3, Surendra, and Heera showed faster initial growth as evident from greater seedling height (Table 1). Varieties Naveen and Kalinga-3 had higher leaf area due to more number of leaves. The number of seedlings per unit area was more in Naveen, Kalinga-3, and MW-10 indicating better seedling establishment of these varieties. More seedling number of these varieties was due to higher germination percentage. Shoot dry weight of seedling was more in Kalinga-3, Naveen, and Heera suggesting their higher initial growth. This was also evident from their greater seedling height or higher leaf area. Initial root development was found significantly higher in rice varieties IR-64, Heera, Naveen and Khandagiri that provided better crop anchorage (Thakur *et al*., 2004a). In wet seeding, the field remained exposed to air favouring weed germination during initial seven days of crop growth. Similarities in age and morphological features of young grassy weeds and rice seedlings made hand weeding in wet seeded rice more difficult. To overcome this problem, rice cultivars should have faster initial crop growth.

Table 1: Initial crop growth (21 DAS) of ten rice cultivars grown under wet-seeded condition at Deras farm, Orissa during *rabi* season, 2001 and 2002

Varieties	Germination (%)	Seedling height (cm)	Seedling no./m²	Leaf area (cm²) per seedling	Shoot dry wt. (mg)	Root dry wt. (mg)
Khandagiri	63	22.96	72	14.38	80.3	78.0
Surendra	79	24.44	79	11.00	61.0	43.5
Naveen	90	20.50	112	17.52	81.3	79.3
IR-64	82	23.90	89	16.04	79.0	83.5
IR-36	60	21.88	78	11.78	66.8	60.8
Heera	86	24.37	94	16.82	80.4	83.3
Lalat	46	23.17	70	13.14	78.3	49.3
Kalinga-3	94	32.46	109	17.21	83.3	64.0
MW-10	87	22.50	103	14.57	73.5	64.3
Konark	53	23.80	70	16.14	78.6	45.0
CD (P=0.05)	5	2.98	4	3.84	3.2	6.3

***Growth parameters**:* At maturity, plant height of Kalinga-3, Konark, Surendra and Lalat was significantly higher than other varieties (Table 2). But three out of these four varieties (except Kalinga-3) showed poor root development. Due to greater plant height and poor root development, rice varieties like Konark, Surendra and Lalat were prone to lodging. Shorter plant height with better root development is the preferred trait in rice varieties suitable for cultivation under wet seeded condition. Tillering efficiency is another major factor that influences panicle number and finally the grain yield. Out of the ten test varieties, Naveen, Khandagiri, Heera and Lalat showed significantly higher tiller number, more panicle number and greater leaf area compared to the other varieties (Table 2).

Productivity: Grain yield of different rice varieties grown under wet seeded condition for two years are presented in Table 3. Results indicated that rice varieties Khandagiri, Naveen, Heera and Kalinga-3 gave significantly higher yield compared to other varieties both in 2001 and 2002. In both the years, variety *Surendra* showed the lowest yield.

Table 2: Growth and development of ten rice cultivars grown under wet-seeded condition at Deras farm, Orissa during *rabi* season, 2001 and 2002

Varieties	Plant height (cm)	Root dry wt.(g)/m²	Tiller no./m²	Leaf area index (LAI)	Panicle no./m²
Khandagiri	96.7	77.11	311.33	1.66	207.67
Surendra	102.3	57.92	237.33	0.99	146.67
Naveen	83.0	84.06	316.67	1.69	226.00
IR-64	86.0	60.89	263.67	1.14	179.67
IR-36	81.0	68.05	276.67	1.32	196.67
Heera	92.0	75.58	304.33	1.43	214.67
Lalat	100.0	62.58	256.33	1.08	179.67
Kalinga-3	107.0	77.18	304.00	1.78	211.00
MW-10	95.3	68.16	287.67	1.22	194.67
Konark	105.3	55.14	218.00	1.03	132.67
CD (P=0.05)	3.2	6.19	17.29	0.09	19.37

Better performance by these varieties was due to better tillering, more panicle number and better canopy development.

It is therefore concluded that ideotypic characters, which made rice varieties suitable for wet seeding, were high seedling emergence, fast seedling growth, better root development, higher tiller/m², greater leaf area, and higher yield.

Table 3: Grain yield of different rice cultivars grown under wet-seeded condition at Deras farm, Orissa during *rabi* season, 2001 and 2002

Varieties	Yield (t ha⁻¹)		Mean
	2001	2002	
Khandagiri	3.00	3.08	3.04
Surendra	2.03	2.33	2.18
Naveen	2.86	3.22	3.04
IR-64	2.29	2.17	2.23
IR-36	2.46	2.54	2.50
Heera	2.91	2.99	2.95
Lalat	2.33	2.35	2.34
Kalinga-3	2.91	3.01	2.96
MW-10	2.54	2.76	2.65
Konark	1.54	1.53	1.54
CD (P=0.05)	0.36	0.68	—

3.2 Physiological changes of germinated rice seeds under anaerobic soil condition

To identify cultivars tolerant to anoxia during establishment, screening was done following the method described by Yamauchi *et al.* (1993). One hundred germinated seeds of each variety were placed in a plastic tray and were covered with 20 mm of sieved soil. The tray was then submerged in 50 mm deep water. The number of germinated seeds (seedling emergence) that came out of soil surface was recorded.

Under anaerobic condition, significant differences in seedling establishment were observed among the ten rice cultivars studied (Fig. 1). Two varieties, viz. Naveen and IR-64 performed significantly better than other varieties and showed 69 and 60% seedling establishment, respectively under soil anoxia condition. Surendra, Heera and MW-10 showed moderate performance with 25-30% seedling establishment. Other cultivars did not perform well under anaerobic condition. The results showed that out of ten cultivars, only two cultivars Naveen and IR-64 performed well under anaerobic condition. Such anaerobic condition in the field arise generally due to two reasons i.e. either when germinated seeds are buried under muddy soil or in small localized depressions in the uneven field with stagnant water.

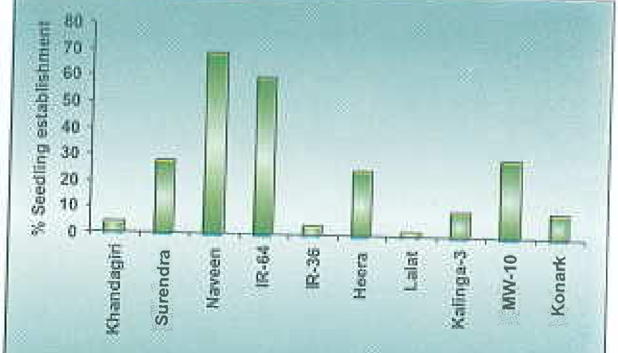

Fig. 1 Percent seedling establishment under anaerobic condition of different rice cultivars

3.3 Effects of hydration-dehydration seed treatment on germination and seedling growth

Humid tropical climate causes seed deterioration and loss of vigor, which may lead to poor germination, failure in crop establishment and ultimately results into poor yield. Under such conditions hydration-dehydration pretreatment of seeds may eliminate its damage. A lab experiment was conducted to study the effect of hydration-dehydration treatment of rice seeds on germination and seedling growth during 2003 at WTCER, Bhubaneswar, Orissa. Seeds were soaked in water for 0, 3, 6, 9, 12, 15, 18, and 24 h and then dried in a hot air. β-amylase of dry seeds was measured. Germinated seeds were grown in Petri dishes for 10 days and root and shoot length of 10 seedlings was measured. 10 seedlings harvested at 10 and 20 days after germination grown in Petri dishes for the measurement of CGR. The experiment was laid out in complete randomized block design with four replications and each experiment was repeated three times.

Seeds hydrated for 15 and 18 h showed significantly higher germination % (Table 4), more seedling growth (Fig. 2), and more than double crop growth rate (CGR) compared to other treatments. Duration of hydration up to which embryonic cells may undergo dehydration without incurring cellular damage is critical. Any dehydration, for periods of hydration longer than this (15-18 h), which may even result in pre-germination, would irreversibly damage the germinating axis. β-amylase

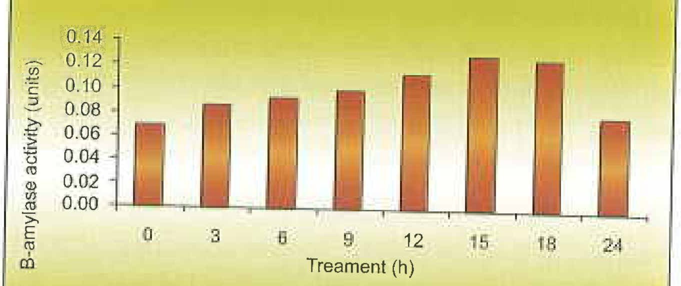

Fig. 2 B-amylase activity of control and dehydtration treated seeds

activity is marker of seedling growth ability (vigor). It was found that seeds hydrated for 15 h and 18 h had higher activity of β-amylase enzyme. More of this hydration period of seeds causes reduced activity of enzyme may be due to impairment of cellular events (Fig. 3).

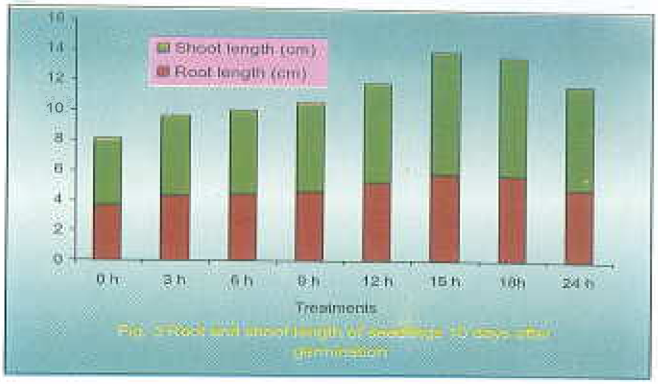

Table 4: Germinationpercentage (after 3 days) and CGR of untreated and treated rice seeds

	0h	3h	6h	9h	12h	15h	18h	24h
Germination %	88.0	89.7	91.7	91.0	93.7	95.3	96.0	91.3
CGR (mg/day)	2.6	3.0	3.5	4.1	5.0	7.7	7.0	4.9

3.4 Rice productivity under different crop establishment methods

3.4.1 Rice growth and yield under different crop establishment methods during *Kharif* season

Field experiments were conducted at the Deras Farm, Mendhasal in Khurda district of Orissa, India, during wet season (July-December) of 2001 and 2002. Rice crop (*Oryza sativa* L.), cv. Gayatri, was established by following six different methods, viz. transplanting of 3 week old seedlings at 20 cm X 15 cm spacing (TPR), dry seeding by broadcast (DSB), wet-seeding by broadcast (WSB), wet-seeding by broadcast followed by beushening (WSBB), wet-seeding in line (WSL) at 20 cm spacing, and wet-seeding in spot (WSS) at 20 cm X 15 cm spacing. The seed rates were 35 kg ha^{-1} for transplanting and 80 kg ha^{-1} for all the direct seeding methods. The experiment was laid out in a randomized block design (RBD) using four replications and plots were of 10 m X 5 m size.

The plant height, root growth, leaf area and tiller number were found superior in all other methods of sowing than those under dry-seeding. The TPR and WSS showed significantly better plant growth, root development and leaf area compared to the other methods of WSR cultivation. Tillering efficiency was found better in WSS as compared to other methods of sowing. Compared to WSL or WSB method of sowing, WSS facilitated better tillering due to inter-spot space available leading to overall better plant growth and grain yield. Moreover increasing the seed rate from 35 kg/ha (in case of transplanting) to 80 kg/ha (in case of WSS) increased the tiller number by about 24.68%, finally reflecting in yield increase by 7%. Compared to the broadcasting, WSS helped to maintain optimum plant density avoiding low or high plant density which was often encountered in broadcasted sowing.

Both panicle number and length were significantly higher in transplanted and WSS treatment compared to other methods. Number of grains per panicle and grain filling percent were also found to be higher in crop established by these two methods. In fact main factor affecting the rice yield, i.e. panicle number is directly proportional to tiller number, which is a function of the number of seedlings per unit area. The WSS and WSL not only ensured more seedlings per unit area, it also allowed easier intercultural operations like weeding, etc.

When compared with the traditional transplanting method, 'spot' and 'line' sowing of wet-seeds showed higher yield by improving leaf area development, tillering efficiency, more panicle, better grain filling as well as better dry-matter partitioning. When compared between beushening and non-beushening treatments of wet seeding, the beushening had given additional advantage by increased yield through more rooting, better tillering, more panicle density and better HI over WSR (broadcasted without beushening).

Table 5: Effect of sowing methods of rice (cv. Gayatri) on root development, growth and yield

Crop establishment methods	Root dry wt. (g)/m²	Leaf no./m²	Leaf area index (LAI)	Tiller no./m²	Panicle no./m²	Yield, t/ha
TPR	234.65	1552.7	4.80	392.67	396.3	4.70
DSB	198.53	936.3	2.94	291.33	199.3	2.99
WSB	206.96	1323.7	3.46	313.33	262.7	3.87
WSBB	216.92	1339.0	3.94	327.33	337.3	4.04
WSL	244.09	1775.3	4.57	382.33	354.0	4.66
WSS	276.30	1875.0	5.34	501.67	466.0	5.03
LSD (0.05)	17.36	130.99	0.355	33.403	121.4	0.568

3.4.2 Rice growth and yield under different crop establishment methods during *rabi* season

Field experiments were conducted at the Deras Farm, Mendhasal in Khurda district of Orissa, India during *rabi* season (February-May) of 2002 and 2003. Rice (*Oryza sativa* L. cv. Naveen) was established by six different methods as mentioned earlier. The leaf area was measured using leaf area meter (Li-Cor Model Li-3100). Root samples were collected upto 30 cm depth of the soil at flowering stage because previous report indicated maximum root mass development at this stage in rice (Nabheerong 1995). Root mass density was calculated by ratio of root dry weight and soil volume (Nabheerong 1995). Dry weight was determined after oven drying to constant weight for 72 h at 80 °C.

Results of two consecutive years revealed that canopy development was better in wet seeded spot sowing compared with other methods (Table 6). It was found that the leaf area index (LAI) under wet seeding spot method was significantly higher (70%) than TPR because of more number of leaves. Under dry seeding, the number of leaves present was nearly 50% more than TPR, but the LAI was similar in both the cases. This suggests presence of more number of smaller leaves in dry seeded method. The specific leaf weight (SLW) under different methods showed thicker (higher weight) leaves in TPR, WSR line and WSR spot methods than the leaves of other methods. This was also confirmed by dry weight of single leaf, which was significantly higher in theses methods.

Table 6: Maximum canopy development of rice under different methods of crop establishment in 2002 and 2003 *rabi* season

Crop establishment methods	Leaf no./m²			Leaf area index (LAI)			SLW(mg/cm²)		
	2002	2003	Mean	2002	2003	Mean	2002	2003	Mean
TPR	1302	1064	1183	2.21	2.06	2.14	4.621	4.692	4.657
DSB	1356	1532	1444	1.71	2.08	1.90	4.228	4.196	4.212
WSB	1366	1194	1280	1.72	1.62	1.67	4.332	4.462	4.397
WSBB	1467	1691	1579	1.86	1.85	1.86	4.322	3.972	4.147
WSL	1400	1089	1245	2.13	2.11	2.12	4.675	4.633	4.654
WSS	2024	1824	1924	3.77	3.52	3.65	4.743	4.723	4.733
LSD (0.05)	149.58	125.28	—	0.133	0.085	—	0.065	0.261	—

* In a column, means having a common letter are not significantly different at 5% level by DMRT.

Root growth is a genetic characteristic, but it is strongly affected by the crop management practices. Greater root growth (root dry weight and root mass density) was found in the WSS as compared to the other methods of crop establishment (Table 7). The least root mass was in dry seeding grown under unpuddled soil condition. WSL also showed better root development compared to TPR and WSB. The significantly higher root development in WSS than that of TPR was due to greater tiller number. Also, uprooting from the seedling nursery damaged roots in TPR. In dry seeding poor root development

Table 7: Root dry weight (g/m²) and root mass density (mg/cm³) under different crop establishment methods in 2002 and 2003 *rabi* season

Crop establishment methods	Root dry wt.(g/m²)			Root mass density(mg/cm³)		
	2002	2003	Mean	2002	2003	Mean
TPR	94.89	88.29	91.59	0.316	0.294	0.305
DSB	69.34	63.93	66.64	0.231	0.213	0.222
WSB	77.56	75.46	76.51	0.258	0.252	0.255
WSBB	85.86	83.44	84.65	0.286	0.278	0.282
WSL	96.28	95.30	95.79	0.321	0.318	0.320
WSS	121.35	112.29	116.82	0.405	0.374	0.390
LSD (0.05)	6.368	7.017	—	0.021	0.023	—

* In a column, means having a common letter are not significantly different at 5% level by DMRT.

may be due to lack of puddling and least tillering. Previous report indicates puddling improves the root length density in rice (Singh *et al.* 1991). Nabheerong (1995) also reported root length or root length density of WSR at flowering was significantly higher than TPR. It is already well documented in the literature that root growth significantly affects rice grain yield (Katare and Upadhyay, 1981, Sharma and De Datta, 1986, Singh *et al.* 1997).

Tillering efficiency was found better in WSS as compared to other methods of crop establishment (Table 8). Thus among all the treatments involving sowing of pre-germinated seeds (wet seeding), the spot seeding was found superior. Wet-seeding in spot facilitated better tillering and grain yield compared to the WSL or WSB methods. Tiller number under WSS increased by about 9% and finally reflecting in approx. 12% yield increase compared to TPR.

Panicle number and length was found significantly higher in transplanted and WSS treatment compared to other methods (Table 8). The number of grains per panicle and grain filling percent were also found higher in these two methods. In fact main factor affecting the rice yield, i.e. panicle number is directly proportional to tiller number, which is function of the number of seedlings per unit area.

Table 8: Yield components of rice under different crop establishment methods

Crop establishment methods	Tiller number m^{-2}	Panicle number m^{-2}	Panicle length (cm)	Grains number/ panicle	Filled grains/ panicle	Yield (t ha^{-1})
TPR	378.0b	329.7b	23.57ab	109.2a	90.0b	3.26b
DSB	293.7d	205.8e	20.57c	87.0c	71.7d	2.28e
WSB	310.2d	261.3d	21.38bc	91.7bc	76.0cd	2.65d
WSBB	330.8c	266.0d	20.25c	91.8bc	77.2c	3.05c
WSL	345.3c	308.8c	22.25abc	94.2b	79.7c	3.22b
WSS	413.0a	392.8a	24.60a	108.8a	95.3a	3.64a

*Each value is mean of two year data. In a column, means having a common letter are not significantly different at 5% level by DMRT.

As grain yield among different method of cultivation showed close relationship with number of tillers (r=0.90**), panicle number (r=0.89**) and number of filled grains per panicle (r=0.87**) (Table 9). This increase in yield in WSS appeared due to improvement in tillering efficiency, more panicle, better grain filling as well as better dry matter partitioning. Previous reports also showed that WSR gave similar (Mohammed Ali and Sankaran 1975, Reddy *et al.* 1995) or higher (Rao *et al.* 1973, Shekar and Singh 1991, Bhuiyan *et al.* 1995) grain yield compared to transplanted rice.

The grain yield also was found closely associated with root development characteristics like root dry weight (RDW) and root mass density (RMD) as evidenced by significant and positive correlation coefficients (Table 9). Thus better root development under wet seeding in spot method compared to transplanting method might have favoured more nutrient uptake leading to higher grain yield. However, increased root biomass under spot sowing and associated changes in internal concentration of plant hormones like ABA and cytokinins warrant further investigation to corroborate the view of altered translocation efficiency in wet seeding.

Table 9: Correlation coefficient among various yield components in rice as influenced by crop establishment methods (n=12)

	Leaf no.	LAI	SLW	RDW	Tiller number	Panicle number	Panicle length	Filled grains	Grains/ panicle	Yield
Leaf no.	1									
LAI	0.776**	1								
SLW	0.021	0.599*	1							
RDW	0.54	0.858**	0.742**	1						
Tiller number	0.519	0.847**	0.734**	0.919**	1					
Panicle number	0.433	0.804**	0.784**	0.937**	0.952**	1				
Panicle length	0.332	0.749**	0.823**	0.801**	0.896**	0.842**	1			
Filled grains	0.452	0.783**	0.760**	0.867**	0.953**	0.938**	0.902**	1		
Grains/ panicle	-0.01	0.333	0.576*	0.499	0.684*	0.593*	0.801**	0.758**	1	
Yield	0.421	0.701*	0.674*	0.939**	0.908**	0.892**	0.808**	0.871**	0.677*	1

* and ** significant at P= 0.05 and 0.01, respectively.
LAI: Leaf area index, SLW: Specific leaf weight, RDW: Root dry weight

3.5 Water requirements and WUE under different crop establishment methods of rice

Water requirements for different operations in rice cultivation under three crop establishment systems are presented in Table 7. Total water required for growing rice crop by transplanting, wet seeding and dry seeding methods were 1041.15, 941.53 and 915.03 ha-mm, respectively (Thakur *et al.,* 2004a). Evapotranspiration values were 3.7-7.2 mm day^{-1} during the crop growth period from last week of January to first week of May. A seepage and percolation loss combined (SP) was 4 mm day^{-1} in transplanted and wet seeded plots. But in dry seeded plots, SP was as high as 6 mm day^{-1}. Higher SP under dry seeding was due to unpuddled field. Maximum water consuming system was transplanting and the least water was required in dry seeding system. Water saving in wet seeding was 10% compared to the traditional transplanting system. It was found that water saving in wet seeding compared to TPR was mainly in the land preparation. Water requirement for land preparation in wet seeding was less by about 30% compared to transplanting system, as it took just 7 days to complete all land preparation activities, like land soaking, ploughing and leveling while, in transplanting system these operations took 21-25 days. The reason is that in transplanting, traditionally farmers start water use in the main field for land soaking at the same time or soon after they start to prepare nursery for the raising seedlings. They continue to use water in the main field until the seedlings are ready for the transplanting. Thus, large amount of water is lost from the main field through evaporation, seepage and percolation, and surface runoff. Contrary to this, wet seeding required only 3-4 days of land soaking and incubation of seeds before seeding into main field. More demand of water in transplanting was also due to requirement of nursery preparation and more crop duration (7 days).

Bhuiyan *et al.*, (1995) reported that the amount of water needed to complete land preparation and crop irrigation for TPR is 40% and 10% more as compared to WSR and total water consumed is 21% more for TPR compared with WSR. With continuous standing water, wet-seeded rice requires 19% less water during the crop growth period (Tabbal *et al.*, 2002).

The comparison of water use efficiency (WUE) for the different crop establishment methods of rice showed lowest WUE for dry seeding and highest for wet seeding in spots (Fig. 4). Wet seeding in line (WSL) and spots (WSS) showed 9.7 and 24.0% higher WUE, respectively, over the traditional TPR method. Commonly adopted wet seeding method, i.e. wet seeding broadcast (WSB) showed 10% less water use efficiency than TPR.

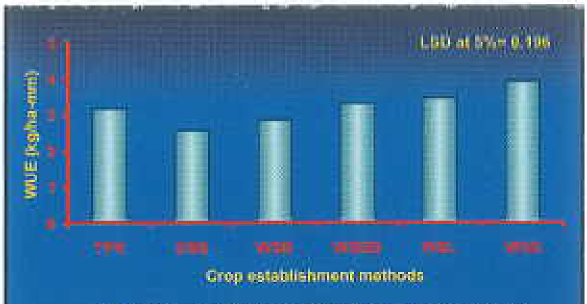

Fig. 4 Water use efficiency (kg/ha-mm) under different crop establishment methods during dry season (each value is mean of two year data)

Table 10: Water requirements (ha-mm) under different methods of rice crop establishment on sandy clay-loam soil during 2002 and 2003 at Bhubaneswar, India

Items	Transplanting		Wet-seeding		Dry seeding	
	2002	2003	2002	2003	2002	2003
Nursery preparation	19.9	19.9	—	—	—	—
Crop demand for nursery (20 days)	13.8	14.86	—	—	—	—
Land soaking (Tillage)	150	150	150	150	20	20
Land preparation	140.0	148.6	40.0	49.0		
Crop demand						
Evapo-transpiration	405	430.25	396	428.05	396	428.05
Seepage & Percolation	270	320.0	310	360.0	468	498
TOTAL	998.7	1083.6	896.0	987.05	884.0	946.05
Mean	1041.15		941.53		915.03	
Relative (%)	100		90.4		87.9	

3.6 Weed growth under different methods of rice crop establishment

Hand weeding is the most widely used weed control method in rice production system and is cost-effective, but labour intensive. Under different methods of crop establishment of rice it was found that maximum weed infestation occurred under dry seeding followed by WSB and weed growth was minimum under transplanting method both the year. As compared to TPR, approximately 400%, 300%, and 100% more weeds were found in dry seeding, WSB and WSL or WSS methods, respectively (Fig.5). In comparison to wet seeding by broadcast method, line or spot seeding showed significantly less weed growth, i.e. nearly half. It is evident from the figures that during first weeding (15 DAS) there were more weeds in WSL and WSS compared to WSB. However, during second and third weeding, lesser weed population was present under WSS and WSL than that under broadcasting. This happened because during early stage of seedlings it was difficult to recognize and uproot all the weeds in the broadcasted field. However, in line and spot seeding plots weeds present in inter-spaces of hills or lines could be easily removed. Thus, in wet seeded broadcasting most of the weeds was removed during second and third weeding and less weeds were left in line or spot sowing plots. As a result, in spot and line seeding weed competition was less compared to wet seeding broadcasting and dry seeding.

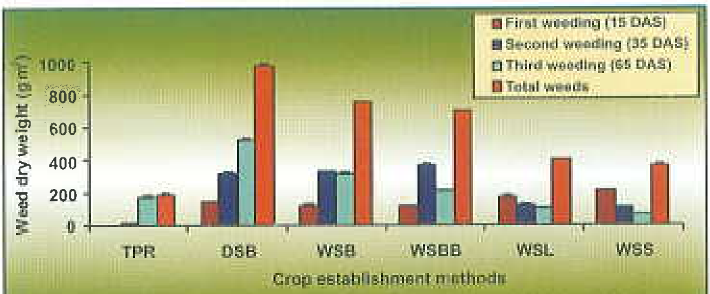

Fig. 5 Weed dry weight at three dates after sowing and total weeds dry dry weight as affected by different crop establishment methods

3.7 Labour requirements under different methods of rice crop establishment

Weeding is no doubt a major labour-intensive operation of rice crop production system. Wet seeding reduced the labour requirement for growing a rice crop compared to TPR (Table 11). It varied from 5% to 20% depending upon the methods of crop establishment. Wet seeding in spots (WSS) and line (WSL) saved maximum labour. Wet seeding eliminates the use of seedlings and related operations such as seedling nursery preparation care of seedling, pulling, bundling, transporting, and transplanting. In line and spot seeding more labour was required for the sowing, but weeding operation was easier and less labour intensive. Weeding is a major operation in which labour requirements were more in dry-seeding (45% of total) and WSB (42% of total). The labour requirement of wet-seeded and dry-seeded rice cultivation was less during the period of peak demand in the locality.

Table 11: Labour requirements (per hectare) for various operations under different methods of rice crop establishment

Items	TPR	DSB	WSB	WSBB	WSL	WSS
Nursery raising	5±2	-	-	-	-	-
Seed germination	-	-	2	2	2	2
Sowing	-	2±1	3±1	3±1	20±3	25±3
Transplanting	75±5	-	-	-	-	-
Gap filling	-	13±3	-	13±3	5±2	5±2
Weeding	30±5	100±7	90±6	75±5	40±5	40±5
Beushening	-	5±2	-	5±2	-	-
Other operations*	119±10	100±10	119±10	119±10	119±10	119±10
TOTAL	229±22	220±23	214±17	217±21	186±20	191±20

*Other operations: Land preparation, Bunding, Ferilizers/FYM/Pesticides application, Irrigation and drainage, and harvesting

3.8 Transfer of technology

3.8.1 On farm Demonstration: Cultivar 'Gayatri' was grown by following methods of wet-seeding by broadcast, wet-seeding in line, wet-seeding in spot and transplanting at Deras farm of WTCER in 3,200 sq. meter area (800 sq.m. each plot). Wet-seeding in spot gave highest yield (4.92 t/ha) followed by transplanted (4.52 t/ha) and wet-seeding in line (4.46 t/ha).

During *kharif* 2003, four rice varieties, viz. Surendra, Lalat, Swarna and Naveen were grown following wet seeded spot method at Deras Research Farm and compared with transplanting method of crop establishment. It was found that all the four rice variety showed better tillering, higher yield, less labour requirement under spot seeding compared to transplanting method.

During *kharif* 2004, spot seeding method of rice crop establishment were demonstrated and compared with the existing transplanting method at Deras farm (Variety: Surendra). It was found that crops with spot seeding method had more tiller number, better canopy development and higher yield compared to the transplanting method. At Deras farm, spot seeding gave 3.2-3.6 t/ha while transplanted rice gave 2.8-3.1 t/ha yield.

3.8.2 Transfer of technology at farmers field: At Balipatna Block of Khurda district, the spot seeding method of rice crop establishment were demonstrated and compared with the existing transplanting method at farmers field during *rabi* 2004 (Variety: Lalat). It was found that crops with spot seeding method had more tiller number, better canopy development compared to the transplanting method. Grain yield under transplanting and spot seeding methods were 3.88 and 4.69 t/ha, respectively. Thus, wet seeding spot method gave 21% higher yield compared to traditional method of transplanting. Root study revealed that maximum roots were present in 1-15 cm soil layer. At 15-30 cm soil layer, transplanting method had more roots as compared to spot seeding. During *Kharif* 2004 also (Variety: Lalat) spot seeding method gave better production compared to the transplanting method. Grain yield under transplanting and spot seeding methods were 3.54 and 4.13 t/ha, respectively.

4. CONCLUSIONS

- Ideotypic characters suitable for wet seeding are better germination, better initial growth, shorter plant stature, longer roots, more tillers for better anchorage, more canopy development and higher yield. Rice varieties like Naveen, Khandagiri, Heera and Kalinga-3 had maximum ideotypic characters suited for wet-seeding.
- Naveen and IR-64 showed better germination and seedling establishment (60-69%) under anaerobic condition.
- 15-18 h hydration and then dehydration of rice seeds improved germination, enzyme activity and seedling growth.
- As compared to the traditional transplanting method, wet seeding in spot (WSS) showed higher yield (7-21%) by improving leaf area, tillering efficiency, more panicle, better grain filling as well as better dry matter partitioning.
- Root length and root mass density was found highest under spot seeding. In wet seeding methods, maximum root occurs in 1-15 cm soil layer; however in case of transplanting method maximum root density was found between 15-30 cm soil layers.
- 5% to 20% labour saving was achieved under WSR compared to TPR (depending upon the methods of crop establishment). WS eliminates the use of seedlings and related operations such as nursery preparation, care of seedling, pulling, bundling, transporting, and transplanting. In line and spot seeding more labour were required for the sowing, but weeding operation is easier and less labour intensive. The labour requirement of wet-seeded and dry-seeded rice cultivation was less during the period of peak demand in the locality.
- As compared to TPR, about 400%, 300%, and 100% more weeds were found in dry seeding, WSB and WSL or WSS methods, respectively. In line or spot seeding, weeding was found easier.
- In wet-seeding, about 10% less water was required for crop production compared to the transplanting method. Wet seeding in spots (WSS) showed 24.0% higher WUE over the traditional TPR method.

It can be concluded that wet seeding in spot is a promising rice production technology and it may be the alternative method of rice cultivation over transplanting method in the future.

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