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Effect of crop establishment methods on growth, productivity and soil fertility of rice (*Oryza sativa*)-based cropping systems

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ABSTRACT

A field study was undertaken during 2003-04 to 2005-06 at Modipuram to develop appropriate establishment technique of rice (*Oryza sativa* L.) and to improve the growth, yield, profitability and soil fertility of rice-based cropping systems. The mean yield of hybrid rice was higher (8.52 t/ha) with drum seeding and remained on a par with that of direct seeding and mechanical transplanting (puddled) compared with manual transplanting (puddled) and mechanical transplanting (unpuddled). Direct seeding (dry bed, unpuddled) adopted in the previous rice crop gave higher mean yield of the succeeding wheat (5.70 t/ha), chickpea (2.20 t/ha) and Indian mustard (1.86 t/ha). Drum seeding recorded the highest mean net returns (Rs 47,040 /ha) in rice-wheat system, followed by rice-chickpea (Rs 42,336 /ha) and rice-Indian mustard system (Rs. 39,774 /ha), and benefit : cast ratio (1.24) in rice-chickpea followed by rice-wheat (1.21) and rice-Indian mustard system (1.12). The system-wise soil analysis undertaken after three crop cycles indicated that organic carbon increased positively over initial status in rice-chickpea system; however, the magnitude of increase was largest under mechanical transplanting (puddled), and negative balances were found in rice-wheat system. Available P and K balance was generally positive in rice-wheat, rice-chickpea and rice-Indian mustard crop sequences except for P in rice-wheat and rice-mustard crop sequences under direct seeding. The drum or direct-seeded rice-based cropping system not only produced higher grain yield of hybrid rice but also resulted in greater productivity of the subsequent crops.

Key words: Crop establishment, Direct seeding, Economics, Grain yield, Soil fertility, Transplanting

Traditionally rice (*Oryza sativa* L.) is followed generally by wheat (*Triticum aestivum* L. emend. Fiori & Paol.) and especially legumes or oilseeds in Indo-Gangetic plains region of India. This is primarily due to difficulty in speedy seed-bed preparation in compact soil after transplanted rice, as the optimum time of sowing of most of the other winter crops is earlier than that of wheat. But continuously following the same system has adverse effect on soil conditions, ultimately reducing its productivity. Evolution of a large number of high-yielding, short-duration varieties along with the advent of efficient tools and implements for tillage has paved the way to substitute wheat with a number of other crops. Inclusion of pulses and oilseeds in the system is more beneficial than cereals after cereals (Kumpawat, 2001; Raskar and Bhoi, 2001). In addition, the legumes have favourable impact on the soil fertility and help in increasing the yield of the succeeding rice crop (Quayyam and Maniruzzaman, 1996). Besides, non-availability of irrigation water, shortage of labour during peak period of farm operations increase the labour wages and makes transplanting and manual weeding costly, invariably leading to delay in farm operations. Moreover, puddling a pre-requisite for transplanting, deteriorates the soil structure. Therefore land preparation for the succeeding crop becomes difficult and requires more energy to attain proper soil tilth. To mitigate this problem many farmers are switching to direct seeding, which can reduce the labour requirement, shorten the duration of crop by 10 days and provide comparable grain yield as that of transplanted rice. Keeping these points in view, an investigation was undertaken to develop appropriate rice-establishment methods to improve the productivity, profitability and soil fertility in the rice-based cropping systems.

MATERIALS AND METHODS

A field study was conducted for 3 years (2003 to 2006) at Project Directorate for Cropping Systems Research, Modipuram, (29° 4'N and 77° 46'E, 237 m above mean sea-level). The climate of Modipuram is semi-arid subtropical, characterized by very hot summers and cold winters. The hottest months are May and June (maximum temperature 45-46°C), whereas during December and January

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the minimum temperature often goes below 5°C. The average annual rainfall is 863 mm, 75-80% of which is received through the southwest monsoon during July-September. The soil was sandy loam (64.2% sand, 18.5% silt and 17.3% clay) in texture (Typic Ustochrept), pH 8.1, electrical conductivity 0.42 dS/m., organic C 0.49%, nitrate N 74 mg/kg, Olsen's P 12.6 mg/ kg, and soil-available K 69.1 mg/kg. There were five treatments of rice-establishment methods, viz. direct seeding (dry bed, unpuddled), drum seeding (wet bed-unpuddled), mechanical transplanting (puddled), mechanical transplanting (unpuddled) and manual transplanting (puddled) in rice-wheat, rice-chickpea and rice-mustard crop sequences. A randomized block design was followed with three replications. The hybrid rice 'PHB 71' was sown 20 cm apart with seeding rate 40 kg/ha. Crop cultivars used were: wheat, 'PBW 243' chickpea 'Avrodhi' and Indian mustard 'Varuna'; these were grown at 20, 30 and 45 cm apart, at 100, 75 and 6 kg seed rate/ha, respectively. The gross plot size was 33 m x 4 m for rice and 10 m x 4 m for wheat, chickpea and Indian mustard throughout the study.

The fertilizers for hybrid rice were applied @ 150 kg N, 34.9 kg P, 50 kg K and 5.5 kg Zn/ha. Phosphorus, K and Zn were applied basal, whereas N was applied in 4 splits (1/4 basal dressing, 1/4 at mid-tillering, 1/4 at active tillering and 1/4 at panicle initiation). Two sprays of $FeSO_4$ at 0.2% solution at 30 and 40 days after planting were also given in direct seeding and drum seeding rice to correct iron deficiency, whereas 120 kg N/ha to wheat and Indian mustard, and 20 kg N/ha to chickpea along with 60 kg P/ha and 60 kg K/ha to each succeeding crop were applied. P and K were applied basal whereas N was applied in three splits to wheat (1/2 basal dressing, 1/4 at first irrigation, 1/4 at spike emergence); in three splits to Indian mustard (1/3 basal dressing, 1/3 at first irrigation and 1/3 at flowering) and total N to chickpea as basal dressing. All the crops were grown under assured irrigated conditions. In hybrid rice, 12 irrigations were applied. In each irrigation 5 cm standing water was maintained and the interval between two irrigations depended on the disappearance of the standing water. Indian mustard received two irrigations at 30 and 60 days after sowing, whereas chickpea received one irrigation at pod-formation stage. In the direct and drum-seeding treatments, seeding was done on 15 June and on 7 July in the mechanical and manual transplanting methods respectively, whereas succeeding crops were sown on 22 October in direct and drum-seeding treatments and on 30 October in mechanical and manual transplanting. In hybrid rice, to control weeds pendimethalin 1.25 kg/ha in 800 litres water was sprayed at 1-4 days after sowing (DAS) in direct seeding (dry bed) and butachlor was applied 1.5 kg/ha at 3 DAS in drum seeding (wet bed) and mechanical and manual transplanting; thereafter one hand-weeding was also done at 30 DAS. In wheat isoproturon 1.25 kg/ha in 600 litres water was applied at 30 DAS to control *Phalaris minor*, whereas in Indian mustard and chickpea weeds were controlled by one hand-weeding at 30 DAS for providing weed-free environment to these crops. Hybrid rice was harvested on 15 October (direct and drum seeding) and on 25 October (mechanical and manual transplanting), whereas the succeeding crops were harvested in the first week of April.

Soil samples were drawn from the 0-15 cm soil layer by a core sampler, from 80 mm diameter at five places in the experimental field. These five samples were mixed and bulked, and a representative sample drawn for determining the organic carbon, total N (modified macro-Kjeldahl method), 0.5 M $NaHCO_3$ (pH 8.5) extractable P and IN NH_4OAc extractable K were determined by standard procedures. The post-harvest soil samples were also drawn from 0-15 cm soil layer in each plot following the same procedure, after competition of rice-wheat, rice-chickpea and rice-Indian mustard crop sequences.

RESULTS AND DISCUSSION

Growth and yield

In rice the dry biomass production of shoot and root and leaf-area index (LAI) were affected significantly due to different crop-establishment methods. Significantly higher of shoot and root biomass and LAI were recorded in drum seeding (wet bed, unpuddled), which was statistically on a par with that of direct-seeding (dry bed, unpuddled) and mechanical transplanting (puddled) but significantly higher than mechanical transplanting (unpuddled) and manual transplanting (puddled) in the succeeding crops like wheat, chickpea and Indian mustard. Direct seeding (dry bed, unpuddled) recorded significantly greater dry biomass of shoot and root and leaf-area index, similar to that of drum seeding (wet bed, unpuddled) and mechanical transplanting (unpuddled), but significantly higher than of than of compared with mechanical and manual transplanting (puddled). Different growth parameters, i.e. dry biomass of shoot, LAI and dry biomass of root, were affected significantly by various methods of rice seeding. The rice plants grown in drum seeding (wet bed, unpuddled) had higher accumulation of dry biomass of shoot and root than the plants grown in manual and mechanical transplanting (puddled). Similarly, wheat, chickpea and Indian mustard crops recorded higher dry-matter accumulation in shoot and root when direct seeding (dry bed, unpuddled) was adopted in the preceding rice crop compared with the other methods, probably because a fine seed-bed was prepared under unpuddled soil than with the puddled soil. Soon after rice cropping, puddled

Table 1. Grain yield (t/ha) of rice, wheat, chickpea and Indian mustard as influenced by different methods of rice-crop establishment

Treatment	2003-04				2004-05				2005-06				Pooled			
	Rice	Wheat	Chick-pea	Indian mustard	Rice	Wheat	Chick-pea	Indian mustard	Rice	Wheat	Chick-pea	Indian mustard	Rice	Wheat Indian	Chick-pea	Indian mustard
Direct-seeding (dry bed, unpuddled)	7.84	5.62	2.21	1.75	8.53	5.76	2.33	1.89	8.55	5.72	2.06	1.93	8.31	5.70	2.20	1.86
Drum-seeding (wet bed, unpuddled)	8.11	5.50	2.18	1.69	8.71	5.63	2.28	1.74	8.74	5.60	2.02	1.78	8.52	5.58	2.16	1.74
Mechanical transplanting (puddled)	7.75	4.74	1.52	1.33	8.45	4.90	1.66	1.43	8.46	4.86	1.44	1.47	8.22	4.83	1.54	1.41
Mechanical transplanting (unpuddled)	7.33	5.48	2.10	1.66	7.73	5.59	2.11	1.70	7.86	5.55	1.92	1.74	7.64	5.54	2.04	1.70
Manual transplanting (puddled)	7.46	4.85	1.55	1.36	7.84	5.06	1.70	1.47	7.89	5.02	1.52	1.51	7.73	4.98	1.59	1.45
SE m±	0.13	0.06	0.04	0.03	0.06	0.08	0.09	0.06	0.14	0.08	0.12	0.07	0.12	0.06	0.08	0.06
CD (P=0.05)	0.38	0.17	0.12	0.11	0.19	0.25	0.29	0.18	0.41	0.24	0.34	0.21	0. 33	0.22	0.25	0.17

soil conditions impaired soil structure, and a hard pan are the major impediments to the establishment and growth of the wheat and other subsequent crops (Gill *et al.*, 2006).

Pooled analysis indicated that the grain yield of hybrid rice and the succeeding crops (wheat, chickpea and Indian mustard) was influenced significantly by different methods of rice seeding (Table 1). The mean yield of hybrid rice was higher (8.52 t/ha) with drum seeding (wet bed, unpuddled), followed by direct seeding (in dry bed, unpuddled) (8.31 t/ha) and mechanical transplanting (in puddled) (8.22 t/ha) compared with manual transplanting (in puddled) (7.73 t/ha) and mechanical transplanting (in unpuddled condition) (7.64 t/ha). The higher grain yield under direct-seeded rice was mainly due to greater leaf area, dry-matter accumulation and effective tillers/m^2. Similarly, higher values of yield-contributing characters were recorded in succeeding crops under direct seeded-dry bed such as number of panicles/m^2, number of grains/panicles and 1,000-grain weight in rice under drum seeding (wet bed); number of ears/m^2, number of grains/ear, 1,000-grain weight in wheat; pods/plant, seeds/pod and 1,000-grain weight in chickpea; and siliquae/plant, seeds/siliqua and 1,000-grain weight in Indian mustard. Direct seeding (dry bed, unpuddled) adopted in the preceding rice crop resulted in higher mean yield of wheat (5.70 t/ha), chickpea (2.20 t/ha) and Indian mustard (1.86 t/ha), whereas the lowest mean yield of wheat, chickpea and Indian mustard was recorded in mechanical transplanting (puddled). This was mainly attributable to relatively greater compaction of puddled soil under manual and mechanical transplanting (puddled) and its carryover effect on the succeeding crops, i.e. wheat, Indian mustard and chickpea, which demonstrated the disadvantage of puddling and transplanting on the succeeding crops (Tripathi *et al.*, 1999).

System productivity and net returns

The systems productivity measured as rice equivalent yield (REY) and net returns were influenced by different methods of rice-crop establishment (Table 2). The REY of different cropping sequences showed that the maximum productivity (15.26 t/ha) was obtained from drum seeding (wet bed), followed by direct seeding (15.20 t/ha) under rice-wheat system. The higher REY in this cropping system was due to higher yield of both the crop and higher price of the produce. The highest net returns (Rs 47,040 / ha) were obtained under drum seeding (wet bed unpuddled), closely followed by direct seeding (dry bed, unpuddled) and mechanical transplanting (unpuddled) in rice-wheat, rice-chickpea, rice-Indian mustard crop sequences respectively; but higher than the rest of the two methods of rice-crop establishment under puddled conditions. Similar results were also obtained in benefit : cost ratio.

Soil fertility

Soil-organic C content was 12.3% more under mechanical transplanting (puddled) in rice - chickpea sequence than the initial content (Table 4). The organic matter of the soil increased in all the rice-planting methods, but rice - wheat sequence showed a decrease in organic C of the soil, and this decrease (8.2%) was observed over initial content in direct seeding (dry bed-unpuddled). In rice-Indian mustard sequence, the soil-organic carbon increased up to 4% in puddled soil, i.e. mechanical transplanting (puddled) but it decreased by 2-4% under unpuddled soil. Flooding of rice fields causes major chemical changes in the soil that affect the transformation and availability of nutrient, organic-carbon dynamics and growth of rice as well as of the subsequent crops. Puddling creates anaerobiosis in soil, which is helpful in relative proliferation of anaerobic micro-flora, which in turn is responsible for slow degradation of soil-organic matter in contrast to aerobic soil under direct seeding (dry bed) where the aerobic microflora predominates and causes rapid degradation of the soil-organic matter (Takahasi *et al.*, 2003). But irrespective of the method of rice seeding, soil-organic matter increased under rice – chickpea sequence due to inclusion of grain-legume crop. Similarly, when compared with the initial value, the available P content of the soil decreased by 2.2-6.3% in rice – wheat sequence and 1.2-3.9% in rice – Indian mustard sequence under unpuddled soil, whereas in these two crop sequences P content of the soil increased in other treatments. In the sequence having chickpea, the P content increased by 0.6-11.2% over the initial content irrespective of the unpuddled or puddled nature of the soil. In contrast, the available K content increased over the initial value in all the treatments in these three crop sequences, but the highest increase (15.9%) was recorded in rice – chickpea sequence, whereas in the standard rice – wheat crop sequence it increased by 13.6% and in rice – Indian mustard by 13.8% under puddled condition. Rice - wheat and rice – Indian mustard sequences resulted in negative P balance over the initial P content of the soil under unpuddled condition, whereas positive P balance in puddled soil except in rice – chickpea crop sequence in all the methods of rice seeding when each component crop received the recommended rate, the apparent P balances were positive in most growing situation (Swarup and Wanjari, 2000). The positive P balance computed in the present investigation was accompanied with an increase in available P content

Table 2. System productivity, net returns and benefit : cost ratio as influenced by different methods of rice crop establishment (pooled data of 3 years)

Treatment	System productivity in terms of rice equivalent yield (t/ha)			Net returns ($\times 10^3$ Rs/ha)			Benefit : cost ratio		
	Rice-wheat	Rice chickpea	Rice-Indian mustard	Rice-wheat	Rice chickpea	Rice-Indian mustard	Rice-wheat	Rice chickpea	Rice-Indian mustard
Direct-seeding (dry bed, unpuddled)	15.20	13.88	13.58	45.99	40.87	36.98	1.17	1.19	1.06
Drum-seeding (wet bed, unpuddled)	15.26	13.99	13.45	47.04	42.34	39.77	1.21	1.24	1.12
Mechanical transplanting (puddled)	14.06	12.12	12.22	39.02	30.83	31.08	1.05	0.96	0.93
Mechanical transplanting (unpuddled)	14.33	12.81	12.46	41.92	36.29	34.31	1.12	1.13	1.00
Manual transplanting (puddled)	13.75	11.76	11.84	38.39	29.78	30.16	1.03	0.91	0.89
SEm±	0.24	0.26	0.20	1.42	2.47	2.02	0.06	0.10	0.07
CD (P=0.05)	0.70	0.76	0.58	4.11	7.16	5.86	0.17	0.28	0.21

Sale price of rice (Rs/t) 5,310; wheat 6,300; chickpea, 13,995; Indian mustard 17,010

Table 3. Physical parameters of soil and nutrient uptake (kg/ha) as influenced by different methods of rice-crop establishment after 3 crop cycles

Treatment	Infiltration rate (cm/hr)	Bulk density (Mg/m^3)	Rice-wheat			Rice-chickpea			Rice-Indian mustard		
			N	P	K	N	P	K	N	P	K
Direct-seeding (dry bed)	1.32	1.46	184.8	31.0	179.2	171.2	23.6	131.9	181.7	26.6	150.3
Drum-seeding (wet bed)	1.11	1.46	186.8	32.3	178.3	173.4	24.7	132.5	181.5	27.5	151.9
Mechanical transplanting (puddled)	0.70	1.49	193.1	35.2	184.6	180.6	28.9	138.3	191.2	31.8	158.5
Mechanical transplanting (un uddled)	1.01	1.47	188.5	33.5	180.3	174.5	25.8	135.2	184.2	28.3	154.3
Manual transplanting (puddled)	0.82	1.48	191.7	34.7	182.4	179.0	27.1	136.8	187.6	29.9	156.2
SEm±	0.10	0.01	1.2	0.8	1.3	2.2	1.4	1.4	1.5	1.1	1.8
CD (P=0.05)	0.28	0.03	3.4	2.4	3.8	6.3	4.1	3.9	4.2	3.1	5.1

Table 4. Changes in soil organic C, available P and K under different crop sequences after 3 crop cycles

Treatment	Change over initial content (%)								
	Rice - wheat			Rice - chickpea			Rice - Indian mustard		
	Organic C	Available P	Available K	Organic C	Available P	Available K	Organic C	Available P	Available K
Direct-seeding (dry bed, unpuddled)	- 8.16	- 6.30	+ 2.45	+ 4.08	+ 0.61	+ 4.70	- 4.08	- 3.86	+ 3.95
Drum-seeding (wet bed, unpuddled)	- 6.12	- 3.04	+ 4.02	+ 6.02	+ 3.04	+ 6.20	- 2.04	- 1.20	+ 5.25
Mechanical transplanting (puddled)	0.00	+ 4.47	+ 13.58	+ 12.24	+ 11.17	+ 15.90	+ 4.08	+ 6.91	+ 9.69
Mechanical transplanting (unpuddled)	- 4.08	+ 2.23	+ 7.37	+ 8.16	+ 3.25	+ 8.94	0.00	+ 1.62	+ 8.46
Manual transplanting (puddled)	- 2.04	+ 2.13	+ 12.08	+ 10.20	+ 1.60	+ 14.54	+ 2.04	+ 4.26	+ 13.98

Initial content: Organic C, 0.49; available P, 21.5; available K, 146.5 kg/ha

of the soil after 3 years of cropping. Positive K balance in all the crop sequence was observed under each method of rice seeding. The physical parameters of the soil and nutrient uptake were affected significantly by different rice crop-establishment methods (Table 3) after 3 crop cycles. The lowest and highest values of bulk density (1.46 and 1.49 Mg/m^3) were recorded under direct seeding (dry bed) and mechanical transplanting (puddle). This may be due to settling of soil particles, which increased the bulk density greatly under puddled condition (Gangwar *et al.*, 2006). The infiltration rate increased under direct seeding (dry bed) and a highest value of infiltration rate (1.32 cm/hr) was recorded under unpuddled soil condition. The higher values of infiltration rate was recorded under direct seeding (dry bed), which revealed the quality of seed-bed preparations that allowed greater amount of water to penetrate into the field and allowed the subsequent crops to grow vigorously. Among the methods of crop establishment, mechanical transplanting (puddle) resulted in higher total nutrient uptake (413 kg/ha) in rice- wheat sequence compared with that in rice – Indian mustard sequence (382 kg/ha) and rice–chickpea sequence (348 kg/ha), indicating that total nutrient uptake was maximum in rice-wheat sequence probably due to higher biomass production. Similarly, the highest uptake of nutrients was recorded with mechanical transplanting (puddle) because of increased nutrient availability under puddle conditions. However, the lowest total nutrient uptake by rice- chickpea sequence was recorded in direct seeding (dry, unpuddled) condition.

It was concluded that drum seeding (wet bed, unpuddeld) resulted in higher grain yield of hybrid rice, whereas direct seeding (dry bed, unpuddeld) adopted in the preceding rice crop produced greater yield of wheat, chickpea and Indian mustard. Direct seeding (dry bed, unpuddeld) also increased the net returns and benefit : cost ratio.

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