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Research Paper

Conservation tillage and planting practices in rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system for sustainable agriculture

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ABSTRACT

A field experiment was conducted during the 6 consecutive rice (*Oryza sativa* L.)–wheat [*Triticum aestivum* (L.) emend. Fiori & Paol] crop cycles, starting from rainy (*kharif*) season 2004 to winter (*rabi*) season 2009–10 at the Research Farm, All India Coordinated Research Project on Integrated Farming System (ICAR), SKUAST–Jammu, Jammu and Kashmir, in a clay loam soil, with *p*H 8.1, soil organic carbon 0.55% and available N, P and K of 247.7, 22.0 and 103.3 kg/ha, respectively, to evaluate four rice (*Oryza sativa*)-establishment methods, viz. direct dry seeding, direct seeding of sprouted rice by drum seeder, manual transplanting and transplanting by hand transplanter and 4 wheat establishment methods in succeeding wheat crop, viz. bed planting by bed planter, conventional sowing by seed drill , strip till drilling by strip till drill and zero-till drilling by zero till drill for sustainability, productivity, profitability and energetics of rice–wheat system under sub-tropical irrigated conditions. The experiment was laidout in stripplot design with 3 replications. Keeping 4 rice and 4 wheat establishment methods in the strip resulted significantly higher overall yield attributes and average grain yield of rice (4.80 t/ha) under manual transplanting, whereas lower yield of 3.81 t/ha was obtained under direct dry seeding rice. Succeeding wheat crop sown with bed planter showed significantly higher number of tillers, grain/panicles and grain yield of 3.72 t/ha over other methods but at par with conventionally sown (3.63 t/ha). System productivity (8.44 t/ha) and sustainable yield index (0.75) of rice under conventional practices and wheat (0.79) under conventional sowing were the highest. Net return and benefit: cost ratio of the system was higher in the manual transplanting of rice (₹47.85 × 10^3/ha and 1.81) and bed planting of wheat (₹46.40 × 10^3/ha and 1.73). Manual transplanting reduced weed biomass by 26.7, 36.4 and 56.6% over hand transplanter drum seeding, and direct sowing of rice respectively. Among wheat establishment methods lower weed biomass (6.90 g/m^2) was noticed under bed planting which was at par with conventional sowing of wheat (7.09 g/m^2). Organic carbon content was slightly (up to 5%) build up in all the tillage and planting methods over initial level, but available N,P,K varied considerably from the initial status. Soil-bulk density was improved under manual transplanting (1.19 g/cm^3) of rice and bed planting of wheat treatment (1.19 g/cm^3). In fuel consumption, 18.6% and 44.1% savings were achieved with direct seeding in rice and zero till drilling in wheat establishment methods over conventional methods. In term of system energy-use efficiency and energy productivity was higher under manual transplanting of rice (10.79% and 0.19 kg/MJ) and bed planting for wheat (10.81% and 0.18 kg/MJ), whereas higher water productivity was noticed in paddy established through manual transplanting method (0.49 kg grain/m^3) and wheat established through strip till drill (0.45 kg grain/m^3).

Key word: Direct seeding, Drum seeder, Energy-use efficiency, Paddy transplanter, Strip planting, Zero tillage

Rice–wheat is the most prevalent cropping system in irrigated conditions of Jammu region of Northern India, comprises about 112.04 and 208.20 thousand hectare of area under rice and wheat, respectively, with average yield of both rice and wheat is realized about 2.0 and 1.68 t/ha respectively (DES, 2011–12). The continuous cereal–cereal cropping practices without adequate resource conservation had posed manifold threats not only to sustainability but also had negatively affected the vertical

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productivity. The decrease in yield of rice was due to increased weed pressure and declining soil-nutrient availability, whereas productivity of wheat crop in a system is quite low due to delayed sowing of wheat by 15–20 days under conventional tillage practices which ultimately limit the total productivity. The intensive conventional tillage operations and methods of planting practices in rice and wheat are not only labour and energy intensive but also show increase cost of production besides imbalancing our natural resources. This in turn, leads to nutrient loss through leaching and deep ploughing. The direct sowing in rice and zero tillage in wheat could be a valid option (Gangwar and Singh, 2010). The delayed wheat sowing beyond November reduces grain yield by 140–150 kg/ha (Gill *et. al.,* 2008). In heavy-texture soils, it takes about 12–15 days to reach the optimum moisture content after rice harvesting and causes delay in field operation and timely sowing of wheat. Zero-till drill facilitates timely sowing of wheat on residual soil moisture after the rice harvesting.

The conservation tillage therefore represents a broad spectrum of farming methods which are based on establishing crops in the previous crop residues purposely left on soil surface. Excessive increase in fuel cost and public environment concerns (Benites *et al.,* 2002) have a combined effect on the reduction of ploughing the field for sowing of crop. This practice only increases the productivity of crop under specific situation (Yaduvanshi and Sharma, 2008) and cropping system, but also improves the soil fertility in respect of its physical, chemical and biological properties (Gan *et al.*, 2007). Thus in present situation, the only option left is to shift towards eco-friendly technology, which advances and efficiently utilizes production resources especially soil, water and nutrients. In the recent years, bed planting has proved to be one of the important components of low-cost sustainable production system.

Keeping this in view, the present investigation was undertaken to identify and quantify the suitable tillage and planting management for rice and wheat in a system which can minimize the consumption of time, energy and labour and cost of cultivation with higher productivity and sustainability under rice–wheat system in sub-tropical conditions.

MATERIALS AND METHODS

The field experiment was conducted during 6 consecutive rice–wheat crop cycles, starting from the rainy (*kharif*) season 2004 to winter (*rabi*) season 2009–10 at the Research Farm, FSR Centre SKUAST–Jammu, (32°–40' North latitude and 74°–50' East longitudes and an 356 meters above mean sea-level), India. The climate at the site was hot and humid rainy season, hot dry summer, warm autumn and cool winter. The maximum temperature during summer rises to about 40 to 44°C and minimum temperature during the winter fall to 6 to 3 °C. Average annual rainfall of the study area was 900 to 1,100 mm, major part of which was received during July–September, the rice- growing period. The soil was clay loam with 42% sand, 26% silt and 34% clay in the surface (0–15 cm) soil. The surface soil was alkaline (*p*H 8.1), having 0.55% organic carbon and 247.7, 22.0 and 103.37 kg/ha available N, P and K respectively. The experiment was laid out in strip-plot design, comprising 16 treatment combinations, i.e 4 rice-establishment methods, viz. direct dry seeding by zero-till drill (P_1), direct seeding of sprouted rice by 8-row drum seeder (P_2), manual transplanting (conventional method) (P_3) and transplanting by hand transplanter (P_4), and 4 wheat-establishment methods, viz. bed planting by bed planter (T_1), conventional sowing by seed drill (T_2), strip till drilling by strip till drill (T_3) and zero till drilling by zero till drill (T_4). Adopted planting techniques for rice in rows (80 m × 5 m) and wheat treatments in columns (20 m × 20 m) with 3 replications. Rice 'Jaya' maintained with spacing of 20 cm × 20 cm and wheat 'PBW 343' with 20 cm row-to-row spacing were used as test crops in the experiment. Before 15 days of transplanting of rice or at the time of field preparation, 5 t FYM/ha on dry-weight basis was applied and full dose of phosphorus (60 kg/ha) and potassium (30 kg/ha) and half dose of nitrogen (60 kg/ha) was applied at the time of direct-sown rice or puddling and rest nitrogen applied in 2 split doses (one at tillering and other at panicle-initiation stage). Under direct-sown rice after applied pre-sowing irrigation, the seed @ 70 kg/ha (dry seeding) was applied by zero tillage seed drill between 10 and 13 June every year. However, in direct seeding of sprouted rice by drum seeder the rice was sown through 8 row drum seeder using sprouted seed (the dry seeds @ 60 kg/ha were submerged in water for 24 h and incubated for 12 h) under puddled field (fully saturated) soil condition without standing water during 10–13 June. For manual and mechanical transplanting of rice, the seed @ 40 kg/ha and 15 kg/ha was sown in nursery on the same day and transplanted 25 days after sowing in fully puddled field with 5 cm standing water. Under mechanical transplanting through hand transplanter of 8 rows were used and the mat-type nursery over a polythene using iron frame of 1.5 m × 1.0 m size were sown. After 21 days, the nursery in blocks were lifted and transplanted with paddy transplanter. Weed control was achieved with butachlor 5% a.i. granules (30 kg/ha) 3 days after transplanting of paddy crop with transplanter and conventional methods, whereas in direct seeding and 8-row drum seeder, weed control was achieved by peritalachlor @ 500 g/ha at 4

DAS followed by pyrozosulphuron (sathi) @ 700 g/ha at 15 days of above herbicides during the first and second year, whereas Bispyribac (Nominee Gold) was applied @ 30 g/ha during later years. During the *rabi* season, wheat variety ‘PBW 343’ was sown in the first week of November at seeding rate of 100 kg/ha. Fertilizer particularly N: P_2O_5 : K_2O @ 100 : 50 : 25 kg/ha were supplied as per recommended dose of crop. Full dose of phosphorus and potassium and half dose of nitrogen were applied at the time of ploughing and remaining nitrogen in 2 equal splits, i.e. crown-root initiation and flowering stage of crop. In wheat under bed planting, 2 raised beds (60 cm wide × 30 cm high each) comprising 3 rows of wheat crop in each bed were formed using bed planter. Conventional tillage was done as per the recommended tillage practice using seed drill. In strip till drilling, wheat was sown after reduced tillage with strip till drill and in zero tillage wheat was sown without any seedbed preparation by using zero seed drill. Weed control was achieved through metribuzin 250 g/ha. Yield attributes of rice and wheat were determined by sampling 1 meter of row length from 2 sites of each plot. Soil-bulk density was determined by using core sampler (Blake and Hartge, 1986). Composite surface (0–15 cm) soil samples were collected from each plot after completion of crop cycle and were ground to pass through a 2 mm sieve and were analysed for *p*H in 1 : 2.5 soil : water suspension using glass electrode. Soil organic carbon and available N, P and K were determined by using standard methods. Plant sample (grain and straw) of rice and wheat were also collected, dried, processed, digested and analysed for nutrient concentration by using standard methods (Jackson,1967). Fuel consumption was calculated after operation in each plot of each tillage treatment topping up the fuel tank of tractor with a graduated cylinder. In this study, energy efficiency, specific energy, energy productivity and water productivity were calculated as suggested by (Canakci *et al.*, 2005). Sustainable yield index (SYI) of rice, wheat and system was computed over 6 years using the formula given by Singh *et al.* (1990).

$$\text{Energy efficiency} = \frac{\text{Total energy output (MJ)}}{\text{Total energy input (MJ)}}$$

$$\text{Specific energy} = \frac{\text{Amount of energy applied (MJ)}}{\text{Grain yield (Kg/ha)}}$$

$$\text{Energy productivity} = \frac{\text{Grain yield (Kg/ha)}}{\text{Total energy input (MJ)}}$$

$$\text{Water productivity} = \frac{\text{Grain yield (Kg/ha)}}{\text{Amount of water applied (m}^3\text{)}}$$

Sustainability yield index = (Mean yield–Standard deviation/Maximum yield)

RESULTS AND DISCUSSION

Yield index and yield attributes

Yield attributes and grain yield of rice and wheat were differed significantly by different establishment methods (Table 1). Significantly taller plants were found in manual transplanting of rice and conventional sowing of wheat-establishment methods. The crop-establishment methods influenced the average yield attributes of rice, viz. total tillers/m^2, panicle length and grains/panicle significantly. Maximum number of tillers/m^2 and panicle length were found in manual transplanting, being statistically significant over other methods. However, grains/panicle were the highest through drum seeding rice which was statistically at par with manual transplanting. Yadav and Singh (2000) also reported the maximum grains/panicle under drum seeding, while the lowest yield attributes of rice crop were observed under direct dry seeding method due to less favourable conditions for germination and growth of crop. Average grain yield of rice (6 years) with manual transplanting was the maximum and it increased to the tune of 23.85,11.18 and 9.16% over direct dry seeding, sprouted wet seeds with drum seeding and paddy transplanting with hand transplanter respectively. Similarly, sustainability-yield index (SYI) was statistically higher in manual transplanting (0.75) over hand transplanter (0.71), direct seeding (0.66) but statistically at par with drum seeding (0.74) (Table 1). However, yield attributes and grain yield of rice under wheat-establishment methods were found statistically non-significant with recorded higher grain yield to the tune of 4.34 t/ha and SYI of 0.79 under bed planting of wheat treatment, which was found statically superior to the other methods.

Like rice, number of tillers/m^2 and length of panicles and grains/panicles of wheat crop were found significantly higher when wheat crop was sown with bed planter followed by conventional sowing, strip till drilling and zero till drill. It might be owing to better availability of nutrients as well as water to the crop. Average grain yield of wheat was significantly higher in bed planting over strip till drill and zero tillage and at par with conventional sowing of wheat. The increase in grain yield of wheat with bed planting was 5.50, 9.48 and 13.41% over conventional sowing, zero-till drill and strip till-drill methods respectively (Table 1). This might be owing to improved physical condition of the soil which favourably increased the uptake of nutrients by the crop, competition by lowering the weed population and dry-biomass leading to increase in values of yield-attributing characters. The yield attributes and yield of wheat under rice-establishment methods did not show statistically significant effect. While sustainability yield index of wheat crop was found higher in conventional followed by zero and strip tillage, which was statically at par. However, SYI of wheat crop under rice-establishment methods was varied from 0.69 under hand mechanical transplanted rice to 0.82 under drum seeder rice treatment. Similarly, system productivity was higher under manual transplanted rice and bed planted wheat under rice–wheat cropping system. However, SYI of system was higher, i.e. 0.84 under drum seeding rice and 0.87 under bed planted wheat which was significantly higher than the other methods (Table 2). Kumar *et al.* (2010) also reported that raised bed system leads to more grain yield of wheat owing to better root development and aeration because of more free space available on both sides of bed under furrow irrigated raised bed system.

Weed biomass

Major weeds observed during the *kharif* season were *Echinochloa colonum,* L. *Echinochloa cruss-galli*, *Cyprus rotundus* and *Cyperus iria,* while *Angallis arvensis, Medicago denticulata, Lathyrus aphaca, Phalaris minor, Argemone Mexicana, Cynodon dactylon* were observed during the *rabi* season. Weed biomass was significantly affected with different establishment methods for rice and wheat crop (Table 1). In rice-establishment methods, direct sowing resulted in significantly higher average weed biomass over all the other establishment methods and there was no significant difference between rice establishment through drum seeding and hand transplanter. While manual transplanting reduced weed biomass by 26.73, 36.41 and 56.61% compared to hand transplanter drum seeding, and direct sowing respectively. Saito *et al.* (2010) also reported that weed biomass was lower in manual tillage than in non-tillage in southern Benin conditions. Direct-seeded and manual transplanting resulted in the highest and lowest weed dry matter as compared to other methods (Gangwar and Singh, 2010), which is attributed to

Table 1. Average yield attributes and yield of rice and wheat in a system under resource-conservation technology (2004–05 to 2009–10)

Treatment	Plant height (cm)	No. of tillers/m^2	Panicles/ ear length (cm)	Grains/ panicle	Test weight (g)	Grain yield (t/ha)	Sustainable yield index	Weed biomass (60 DAS/ g/m^2)
				Rice				
Rice-establishment methods								
Direct seeding	82.0	246.7	21.5	177.8	20.0	3.81	0.66	28.37
Drum seeding	86.5	259.4	23.3	204.5	18.5	4.21	0.74	19.36
Manual transplanting (conventional)	91.2	293.3	26.3	199.4	19.2	4.80	0.75	12.31
Hand transplanter	88.8	283.0	25.1	189.8	18.7	4.41	0.71	16.80
SEm±	1.3	3.1	0.34	4.1	0.80	0.06	0.01	1.43
CD (P=0.05)	3.8	9.1	1.03	13.3	N.S	0.2	0.02	4.39
Wheat-establishment methods								
Bed planting	87.6	269.6	23.9	195.9	18.54	4.34	0.79	19.22
Conventional sowing	87.6	264.0	24.4	183.1	18.54	4.22	0.72	20.20
Strip-till dril	86.4	269.7	23.9	200.2	18.54	4.34	0.67	21.00
Zero-till dril	87.2	279.0	24.0	192.3	18.54	4.31	0.74	21.20
SEm±	1.15	2.2	0.28	2.2	0.56	0.10	0.01	1.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.02	NS
				Wheat				
Rice establishment methods								
Direct seeding	87.7	338.8	9.4	41.4	40.9	3.53	0.79	7.93
Drum seeding	87.0	314.0	9.7	41.5	38.3	3.52	0.82	7.23
Manual transplanting (conventional)	87.8	304.0	8.9	42.6	41.5	3.63	0.77	7.03
Hand transplanter	88.0	298.2	9.9	47.2	40.4	3.61	0.69	7.20
SEm±	0.98	2.5	0.26	1.9	0.58	0.75	0.01	0.29
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Wheat-establishment methods								
Bed planting	88.7	365.4	9.9	44.0	40.1	3.72	0.74	6.90
Conventional sowing	88.9	315.1	9.2	41.5	41.4	3.63	0.79	7.09
Strip-till dril	87.0	297.6	9.1	40.8	40.4	3.59	0.77	8.25
Zero-till dril	85.8	248.4	9.7	41.2	41.9	3.34	0.77	9.48
SEm±	1.9	3.1	0.39	0.3	0.61	0.04	0.01	0.42
CD (P=0.05)	3.4	10.6	NS	1.0	NS	0.12	0.03	1.25

greater weed competition than crop plants. Weeds come up vigorously under direct seeding than in puddle conditions because puddling avoided burial of weed seeds and preserve inside the soil. However, weed biomass in rice crop under wheat-establishment methods was non-significant but reduced from 21.2 g/m^2 in zero till drill plots to 19.22 g/m^2 in bed planting wheat. Among the wheat-establishment methods, weed biomass in wheat crop under bed planting and conventional sowing was statistically at par, but significantly lower than zero tillage and strip till drill, which though was found at par with each other. Yau *et al.* (2010) also reported that the minimum tillage had more weed infestation than conventional tillage and no-till under Bekka valley of Lebanon.

Soil properties

Physico-chemical changes of soil under different tillage and planting methods of rice and wheat are presented in Table 3. After 6 years of experimentation, soil *p*H did not change noticeably due to continuous cropping. Initially the soil *p*H was alkaline (8.03) and after completion of 6 cropping cycles, the pH range varied from 8.05 to 8.13. However, organic carbon content of the soil was slightly build up (up to 5%) to all the tillage and planting methods of rice and wheat plots. Initially soil organic content was 0.55% which was increased to 0.58% under hand transplanter rice treatment, strip till-drill and zero till-drill of wheat treatment owing to large amount of plant residues left on the soil surface and slow rate in the breakdown of organic matter under conservation tillage practices (Lal *et al.*, 2004). No-till with stubble retention increases crop root mass and contributes positively to the surface of soil organic carbon. Moreover, higher temperature in the top soil of the ploughed plots might have promoted metabolic

Table 2. System productivity, sustainable yield index and economics of rice–wheat in a system as affected by different tillage and planting methods

Treatments	System Productivity (t/ha)	Sustainable yield index	System cost of cultivation (×₹10^3/ha)	Net return (×₹10^3/ha)	Benefit: cost ratio
Rice-establishment methods					
Direct seeding	7.37	0.83	24.50	41.75	1.70
Drum seeding	7.75	0.84	24.95	44.35	1.78
Manual transplanting (conventional)	8.44	0.79	26.45	47.85	1.81
Hand transplanter	8.01	0.76	25.43	45.05	1.78
SEm±	0.08	0.01	-	0.49	0.03
CD (P=0.05)	0.29	0.03	-	1.68	N.S
Wheat-establishment methods					
Bed planting	8.14	0.87	26.81	46.40	1.73
Conventional sowing	7.87	0.80	27.09	45.50	1.68
Strip-till dril	7.89	0.75	22.45	44.60	1.99
Zero-till dril	7.66	0.79	24.99	42.50	1.71
SEm±	0.12	0.01	-	0.54	0.04
CD (P=0.05)	NS	0.02	-	1.59	0.10

Table 3. Soil physico-chemical properties as affected by different tillage and planting methods in rice–wheat cropping system (after completion of 6 years)

Treatment	Soil *p*H (1 : 2.5)	Organic carbon (%)	Bulk density (g/cm^3)	Available nutrient (kg/ha)		
				N	P	K
Rice-establishment methods						
Direct seeding	8.06	0.56	1.29	226.8	19.4	108.2
Drum seeding	8.13	0.57	1.20	225.2	20.1	111.7
Manual transplanting (conventional)	8.05	0.56	1.19	219.2	19.9	116.0
Hand transplanter	8.10	0.58	1.20	215.8	19.4	110.7
Wheat-establishment methods						
Bed planting	8.02	0.55	1.19	226.9	19.5	111.8
Conventional sowing	8.01	0.56	1.23	220.9	19.8	118.1
Strip-till dril	8.10	0.58	1.30	219.3	19.8	111.0
Zero-till dril	8.05	0.58	1.32	219.8	19.8	110.2
Initial value	8.03	0.55	–	247.7	22.0	103.3

processes and enhances degradation of the soil organic carbon (Gan *et al.,* 2007) and thus, lower organic carbon content was found under conventional (0.56%) sowing. The available N and P status of soil was decreased from initial values in all the rice-and wheat-establishment methods. However, there was an increase in available K, ranged from 108 to 118.1 kg/ha in the soil after crop harvesting as compared to initial status (103.3 kg/ha) under all the methods of rice and wheat establishment. In case of rice-establishment methods, the lowest value of K was recorded under direct dry seeding, while in case of wheat-establishment methods, minimum value for available K was recorded under zero till drilling. Similar results were reported by Brar *et al.* (1983). Values of bulk density differed treatment-wise after completion of 6 rice–wheat cropping systems under different tillage and planting methods (Table 3). Direct seeded rice and zero till drill wheat showed higher soil bulk density than the other treatments. Bulk density is the combination of solid and pore space of soil under zero tillage was subjected to certain amount of compaction which resulted in less pore space and higher bulk density. Soil compaction develops when aeration pores (macro pores) are destroyed and soil volume is reduced (Blank, 2007). No-till system forms a surface combination with high bulk density, low volume of macropores (Lindstorm and Onstead, 1984). Similarly, under puddled condition (conventional method) in rice the bulk density was obviously reduced to 1.19 g/cm^3 compared to the treatments where the rice was sown through direct seeding (1.29 g/cm^3), whereas under wheat-establishment methods, the higher bulk density value of 1.32 g/cm^3 was observed under zero till-drill practices due to the fact that reduced tillage resulted less pore space in soil (Lindstorm and Onstead, 1984) and reduced to 1.19 g/cm^3 under bed planted wheat.

Nutrient uptake

Nutrient uptake by plants is dynamic in nature and is greatly affected by different factors. It is a function of climate, soil properties, amount and method of fertilizer application and cultural practices adopted. Nutrient uptake by paddy indicated that rice establishment methods had positive effect on nutrient uptake (Table 4). The maximum uptake of N, P and K by paddy was recorded under manual transplanting treatment which was statistically significant over the other methods, whereas the minimum uptake of N, P and K was recorded in direct dry seeding methods, as uptake of nutrients is known to governed by the dry-matter production, lower yield led to lower N P K uptake (Bazaya *et al.,* 2009). Similarly, N P and K uptake by rice under wheat-establishment methods was also significantly higher under bed planting wheat treatment owing to better soil environment for nutrient availability (Yaduvanshi and Sharma, 2008). Among the wheat-establishment methods, bed planting accounted for the maximum uptake of N, P and K by wheat crop which was statistically significantly higher than the other methods, might be owing to reduction in the state of crop–weed competition and favourable physic-chemical conditions of soil. Minimum uptake of N, P and K by wheat was under zero-till drilling, might be due to reduced root growth and nutrient absorption by wheat due to compacted soil layers (Chitale *et al.*, 2007). Among the rice-establishment methods, higher N, P, K uptake and by wheat crop was re-

Table 4. Effect of different tillage and planting methods of rice and wheat cropping system on nutrient uptake by crops (average data of the 6 years)

Treatment	Nutrient uptake by rice (kg/ha)			Nutrient uptake by wheat (kg/ha)		
	N	P	K	N	P	K
Rice-establishment methods						
Direct seeding	57.1	12.8	92.2	57.3	13.7	69.8
Drum seeding	64.9	16.3	88.6	59.6	13.9	79.9
Manual transplanting (conventional)	70.7	17.3	117.5	64.4	14.4	86.8
Hand transplanter	63.7	17.2	111.8	55.7	13.1	75.8
SEm±	1.1	0.5	1.4	1.1	0.26	1.3
CD (P=0.05)	3.2	1.6	4.3	3.2	0.8	3.2
Wheat-establishment methods						
Bed planting	68.2	15.4	117.0	69.2	16.4	99.2
Conventional sowing	59.6	14.6	104.7	62.2	14.3	89.1
Strip-till dril	60.3	15.2	101.6	55.1	14.0	76.5
Zero-till dril	67.7	18.0	109.3	53.0	12.9	74.7
SEm±	0.87	0.31	1.2	0.8	0.36	0.8
CD (P=0.05)	2.6	0.9	3.6	2.2	1.1	2.5

corded under manual transplanting rice (conventional treatment) which was statistically significant over the other rice-establishment method. It might be owing better soil condition created in conventional methods for nutrient availability to the crop.

Fuel consumed and labour efficiency

A considerable saving was recorded in fuel and labour under rice–wheat establishment methods (Table 5). Average maximum fuel of 40.3 *l*/ha in rice–wheat system was utilized manual transplanting of rice and drum-seeding treatments, minimum of 32.8 *l*/ha was utilized in rice and wheat under direct rice seeding plots, which showed 18.6% saving over manual transplanting (Conventional method). However, under wheat-establishment methods the maximum fuel was utilized under bed planting methods which was 4.8% higher than conventional method in rice–wheat system. Zero-till drill and strip till-drill methods in rice–wheat system saved fuel to the tune of 44.1 and 41.6% over conventional sowing method. Lithourgidis *et. al.* (2006) observed in Greece that fuel consumption under minimum tillage during seed bed preparation was 73.7% less than conventional tillage. The reduced fuel consumption of conservation tillage systems could be attributed to the fewer trips on the field. Similarly, manual transplanting (conventional method) of rice in rice and wheat combined required more labour in a system followed by the treatments mainly direct seeding, hand transplanter and less labour engaged in drum seeding methods which showed 8.7, 12.1 and 15.5% labour saving over the conventional method in rice and wheat crop. However, under wheat-establishment method the highest labour (196 man-days/ha) in combined rice and wheat crop was engaged under conventional sowing method of wheat followed by strip till-drill, zero till-drill and minimum in bed planting, which contributed saving of 5.1, 6.6 and 7.8%, respectively, in system based rice and wheat crop. However, labour efficiency was the highest in drum seeder of rice-establishment method and bed planter of wheat-establishment method.

Energetics and water productivity

The comparison of energy-use pattern (Table 6) in different crop-establishment methods in rice–wheat system revealed that the lowest input energy was utilized in raising rice and wheat crop by drum seeder (45.0×10^3 MJ/ha) with lowest energy-use efficiency of 10.16%, highest specific energy of 5.81 MJ/kg and energy productivity of 0.7 kg/MJ, which was closely followed by other rice-establishments methods. For wheat-establishment methods, amount of energy per hectare needed to produce crop productivity of rice and wheat on raised beds was higher than the other methods of wheat establishment, which was owing to higher use of machinery for pulverizing soils for bed formation. Hussain *et al.* (2010) under semi-arid of Pakistan similarly observed that amount of machinery energy per hectare needed to produce wheat on raised bed was significantly higher than the conventional sown methods. Low energy input of 44.6×10^3 MJ/ha of rice–wheat cropping system was required in zero till drill due to less tillage operations (Jain *et al.,* 2007). Specific energy indicating energy on per kg product was less on bed planting system (5.61). Naresh *et al.* (2013) also observed water savings with zero-till wheat system in rice–wheat cropping system.

Higher water productivity (0.49 kg grain/m^3) of rice–wheat system was noticed in rice crop established through manual transplanting whereas in case of wheat in a system based rice and wheat, strip till drill had highest water productivity of 0.45 kg grain/m^3 followed by zero till drill (0.44 kg grain/m^3) method (Table 6). Hassan *et al.* (2005) also observed that beds used less amount of irrigation water as compared to conventional which reduced evaporation, less wetted area and to prevent excess irrigation.

Table 5. Fuel and labour saving in different tillage and planting methods under rice–wheat system. (average data of the 6 years)

Treatments	Total fuel consumed in system (Litre/ha)	Fuel saving (%)	Total labour used in system (man days)	Labour saving (%)	Labour efficiency (%)
Rice-establishment methods					
Direct seeding	32.8	18.6	188	8.7	39.2
Drum seeding	40.3	0.0	174	15.5	45.0
Manual transplanting (conventional)	40.3	–	206	–	41.0
Hand transplanter	40.3	0.0	181	12.1	44.4
Wheat-establishment methods					
Bed planting	50.4	–4.8	181	7.8	44.5
Conventional sowing	48.1	–	196	–	40.1
Strip-till dril	28.1	41.6	186	5.1	42.6
Zero-till dril	26.9	44.1	183	6.6	41.8

Table 6. Average system energy pattern, water productivity under rice–wheat system as affected by different tillage and planting methods

Treatment	System energy input (× 10^3 MJ/ha)	System energy output (× 10^3 MJ/ha)	EUE (%)	Specific energy (MJ/kg)	Energy productivity (kg/MJ)	Total water used (cm)	Water productivity (kg grain/m^3)
Rice-establishment methods							
Direct seeding	45.3	472.4	10.43	6.14	0.16	188	0.39
Drum seeding	45.0	457.3	10.16	5.81	0.17	193	0.40
Manual transplanting (conventional)	45.3	488.8	10.79	5.37	0.19	173	0.49
Hand transplanter	45.1	479.8	10.64	5.63	0.18	173	0.46
SEm±	-	-	0.39	0.18	0.01	-	-
CD (P=0.05)	-	-	NS	0.32	0.02	-	-
Wheat-establishment methods							
Bed planting	45.7	493.9	10.81	5.61	0.18	188	0.43
Conventional sowing	45.6	478.3	10.49	5.79	0.17	193	0.41
Strip-till dril	44.8	467.5	10.44	5.68	0.18	173	0.45
Zero-till dril	44.6	458.6	10.28	5.82	0.17	173	0.44
SEm±	-	-	0.20	0.15	0.01	-	-
CD (P=0.05)	-	-	NS	NS	0.02	-	-

EEU, Energy-use efficency

Economics

System cost of cultivation and net returns were more manual transplanting of rice (conventional)-establishment method, with higher benefit: cost ratio, closely followed by hand-transplanted rice. However, the lowest system net return and benefit: cost ratio were observed under direct seeding rice method, which was statically lower (Table 2). Likewise rice-establishment method, conventional sowing of wheat required higher system cost of cultivation. While higher system net returns were realised under bed planting, followed by conventional sowing, strip till-drill and zero till-drill. Whereas system benefit: cost ratio was found higher in strip planting followed by bed planting, zero tillage and conventional tillage. Hussain *et al.* (2010) also reported the net returns of wheat on raised bed was higher than conventional under semi-arid area of Pakistan.

Thus, it may be concluded that among various conservation tillage and planting techniques in rice–wheat cropping system under irrigated ecosystem of clay loam soil though operated manual transplanting followed by hand transplanter and 8- row drum seeder showed higher trend in system productivity and profitability but the sustainable yield index, labour saving was found higher in drum seeding technique and hand operated transplanter in rice crop. However, in wheat bed planting method recorded higher in almost all the parameter, i.e. system productivity, system-sustainable yield index, labour efficiency, and energy productivity. The benefit: cost ratio was found higher in strip-till drill method and followed by zero-till drill.

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