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Establishment and tillage practices affects crop performance, soil properties, energy generation and economics under rice-wheat cropping system in Central Himalayan *tarai* region

Sumit Chaturvedi, R Singh, AP Singh, B Pramanick, DK Singh and VC Dhyani

Abstract
Different rice establishment and wheat tillage systems were compared for determining its influence on productivity and efficiency. Establishment methods affected the growth of both rice and wheat, with maximum rice and wheat yield found under direct seeded rice and zero tillage wheat. The tillage methods significantly affected the soil properties as bulk density and infiltration rate were improved. Reduced tillage required 7-11% less energy than the conventional rice-wheat system with highest output energy. The maximum net returns and B:C ratio were obtained from direct seeded rice in combination with zero tillage practices with lowest in transplanted rice.

Keywords: Energy, Direct Seeded Rice, Soil properties, Zero tillage Wheat

1. Introduction
Rice (*Oryza sativa*) –wheat (*Triticumaestivum*) cropping system growing intensively in 13.5 mha areas in Indo-Gangetic Plain (IGP) is lifeline for food and livelihood security for millions of poor residents. Green revolution technologies such as high yielding seeds, improved crop management and availability of irrigation water augmented the productivity and stability of rice-wheat system. However, evidence is now appearing from different parts of growing regions that the productivity is plateauing rather factor productivity is also declining because of a fatigued natural resource base and therefore, sustainability of this cropping system is at risk (Ladha *et al*., 2003). Moreover, excessive as well as irresponsible useof agro-chemicals, non-ecological management requirements and lifting more and more ground water threatens the overall ecological balance *vis-à-vis* water availability (Erenstein *et al*., 2007).
Conventionally, rice is taken after intense wet tillage during *kharif* season and wheat during *rabi* season needs well-drained dry soil having good tilth prepared by 6-7 repeated tillage operations. Repeated and continuous puddling in rice and heavy tillage operations in wheat at same soil depth destroys soil structure, creates hard pans at shallow soil depth, which in turn adversely affect the performance of crops (Hobbs and Moris, 1996). Excessive tillage operations can also delay wheat planting which results in yield loss of 35-60 kg $day^{-1}ha^{-1}$ in the IGP (Pathak *et al*., 2003). Moreover, labour scarcity during peak periods is also a serious concern, particularly during labour intensive operations like puddled transplanting. Water scarcity further exaggerates the problem as conventional rice-wheat is very water intensive and inefficient, mostly pulling the water from underground. In *tarai* region of Northern India, rice is also being grown during summer season as puddled transplanting further aggravating the issue of declining water table as it requires as many as 50 irrigations due to very high evaporative demand during summer season.
Direct seeding rice followed by reduced tillage or zero tillage in wheat is one of the good and viable options to combat the problems of conventionally cultivated rice-wheat system. It has been reported that on average wheat yield is reduced by 8% when sown after puddled transplanted rice compared to wheat sown after direct-seeded rice in unpuddled conditions (Kumar *et al*., 2008). There can be several other modifications such as transplanting in unpuddled soil especially in light textured soil. The practice of transplanting on unpuddled soil is a potential technology for those farmers who are doubtful about direct-seeded rice to avoid adverse effect of puddling on succeeding wheat crop. Unpuddled transplanted or dry direct-seeded rice have water-friendly land preparation as compared to puddled transplanted, as puddling (wet tillage) operation takes upto 30% of total irrigation water application in rice in

light textured soils (Aslam *et al*., 2002). However, Saharawat *et al*. (2009) reported similar yield and water application in unpuddled and puddled transplanted rice in farmer participatory trails in Haryana, India. Puddling operation consumes lots of labour and energy also, subsequently, increasing the cost of cultivation making the preposition uneconomic and undesirable. Alternately, Direct seeded rice or reduced tillage system have an advantage of labour as well as energy saving. However, direct seeded rice with alternate wetting and drying cycles is subjected to heavy weed competition and its success lies in effective weed control measures (Rao *et al*., 2007). New innovations in generation of good pre and post emergence herbicidal molecules have made direct seeded rice a practical venture. Reduced tillage practices also promises to be more climate resilient (Pathak *et al*., 2003).

However, the alternative tillage and crop establishment are site specific and therefore evaluations under wider agro-ecological conditions is important to have significant adoption (Ladha *et al*., 2009). Keeping all these in background, a study was conducted in Pantnagar with the focal objective to evaluate the different establishment methods and tillage operations in rice wheat cropping system and its effect on soil fertility of system.

2. Materials and methods

2.1. *Location, climate and soil*

The experiment was conducted at the Norman E. Borlaug Crop Research centre (29ºN, 79ºE and altitude is 244 m above mean sea level), Govind Ballabh Pant University of Agriculture and Technology, Pantnagar during *Kharif* (rainy) and *Rabi* (winter) seasons during 2007–2008 and 2008–2009. The soil was sandy loam (50.4% sand, 33.2% silt and 16.4% clay) in texture having pH (7.8), EC (0.32 dSm^{-1}), organic carbon (0.67%), available N (263 kg ha^{-1}), available P_2O_5 (28 kg ha^{-1}) and available K_2O (206 kg ha^{-1}). Rainfall in areas of Pantnagar occurs from July to November followed by cool to warm period from December to June. During the experimental period the average rainfall in *Kharif* season (June-October) during 2007 and 2008 were 1726.2 and 780 mm respectively and in *Rabi* (November-March) season during 2007 and 2008 were 21.2 and 259 mm, respectively.

2.2 *Experimental details*

The experiment consisted of four methods of different crop establishment in rice *viz.,* i. direct dry seeded rice; ii. Puddled direct seeded rice /sprouted rice method; iii. Hand transplanting; iv. Machine transplanted rice by self- propelled rice transplanter and four different methods of tillage in wheat crop *viz.,* i. conventional tillage (two ploughing with tiller + one disking + two tilling followed by planking in rice-wheat crop sequence., CT); ii. bed planting (two ploughing with tiller + one tilling followed by planking, 30cm high beds were constructed manually 60cm apart); iii. Strip till drilling; iv. zero till drilling (No till drill). The trial was laid out in strip plot design with three replications. The dimensions of individual plots were 10m×3.6 m. Rice establishment method treatments were placed in the main strip and wheat tillage treatments in the sub-strip. Rice crop was taken during *Kharif* season while wheat was sown in *Rabi* season. A recommended fertilizer dose of 150–60–40 kg $NPKha^{-1}$ was applied in both rice and wheat as urea, single super phosphate and muriate of potash respectively in all treatments. Application of fertilizers was done as per recommended package and practices. Spacing of 20cm×10cm was maintained in rice by thinning and gap filling and wheat rows were spaced 22.5cm apart. Rice variety 'Narendra-359' and wheat variety 'PBW 343' were sown. Seed was treated with Captan@3 g kg^{-1} of seed before sowing to avoid the diseases problems. Except for the soil tillage, all the other technological sequence of sowing, fertilizing, weed control are identical in all the variants. The plots were kept weed-free throughout the growing season by using pre-emergence or post-emergence herbicides and hand-weeding.The weed control for rice was accomplished by a pre-emergent treatment with the Pendimethalin @1.0 kg a.i. ha^{-1} in 500–600 L of water ha^{-1} within 48 hrs of sowing in dry direct seeded rice and butachlor @ 1.5 kg a.i. ha^{-1} after 2 days in puddled transplanted rice. Application of Isoproturon 0.75 kg a.i. ha^{-1} in 500–600 L of water ha^{-1} sprayed at 30 days after sowing in wheat. Additionally, need based hand-weeding was done to keep the plots weed-free.

2.3 *Growth, Yield and Soil Observations*

Crop growth parameters and yields were recorded for both rice and wheat. Yield attributing parameters, i.e. total number of tillers was recorded using $1m^2$quadrate (33 hills in transplanting and 108 plants in direct seeding) from three places in each plot. At maturity, rice and wheat were harvested manually 15-cm above ground level from the net plot area measuring 5 m × 2 m leaving the border rows all around. Thresher was used for threshing the plants after sun drying. Moisture was determined using grain moisture meter immediately after thresing and grain yields of rice and wheat were reported at 14 and 12% moisture content, respectively.

The soil samples were collected from three sites of each plot before the experiment and after harvest of each crop at 0-30 cm from a soil auger. The samples were crushed to pass through a 2 mm sieve after air drying. The soil organic carbon was estimated by chromic acid wet oxidation method (Walkley and Black, 1934). Oxidisable matter in the soil is oxidised by 1 N $K_2Cr_2O_7$ solution. The reaction is assisted by H_2SO_4. The remaining dichromate is titrated with ferrous sulphate. The titre is inversely related to the amount of C present in the soil sample. The undisturbed soil cores of 100 cm^3, 5 cm diameter (three replicates) were taken between rows from 0–30 cm soil depth by a core sampler to measure soil bulk density (Fabrizzi *et al*., 2005).The infiltration rate was measured as quasi steady infiltration by using the double ring infiltrometer at harvest of the crop in both the seasons.

Energy calculations were done recording machine and human labour uses in both rice and wheat from each treatment for each field operation, viz. tillage, seeding, irrigation, fertilizer and pesticide application, weeding, harvesting, and threshing. For human labour, 8 hrs were considered equivalent to 1 person day, whereas, for tractor-drawn machines, time taken to complete a field operation such as tillage, seeding, fertilizer application and harvesting was recorded and expressed on an ha basis. Time (hrs) required to irrigate a particular plot and consumption of diesel (h^{-1}) by the pump was also recorded. The groundwater was pumped from a depth of 1 m and irrigation was given by surface-flooding method.

Manual energy (Em) expended was determined using formula: Em= 1.96*Nm*Tm*GMJ, where Nm= Number of labour spent on a farm activity; Tm= Useful time spent by a labour on a farm activity (hours) (Chaudhary *et al*., 2006). Mechanical energy input was evaluated by quantifying the amount of diesel fuel consumed (Umar, 2003). The diesel fuel energy input was determined by: Ef = 56.31D MJ, where 56.31 = unit energy value of diesel, MJ L^{-1}, D= amount of diesel consumed.

2.4 *Statistical analyses*

The data were subjected to analysis of variance for strip-plot design keeping rice establishment methods in primary strips and wheat establishment methods practices in secondary strips as per the procedure given by Little and Hills (1978). The data were analyzed with STPR statistical programme of G. B. Pant University of Agriculture and Technology. All treatments were compared by computing the ‘‘F-test’’. The significant differences between treatments were compared pair wise by critical difference at 5% level of probability. The interaction table was given separately only for those attributes which were shown significant and described accordingly.

3. Results and Discussion

3.1. *Impact of different planting methods and tillage practices on growth of rice and wheat*

Various planting methods influenced the shoot height, number of tillers m^{-2} and dry matter accumulation of rice and wheat during both the years of experimentation. The rice planting methods were significantly influenced rice shoot height than wheat tillage methods during 2007-08 while shoot height of wheat was significantly controlled by different tillage method employed in wheat during 2008-09 (Table 1). The maximum values of rice shoot height was observed under direct seeded rice during both the years amongst other rice planting methods and this was 18.07 and 5.06% higher over hand transplanting (usually followed by the farmers) in 1st and 2nd year respectively. Comparing other wheat tillage methods on the shoot height of rice, zero tillage resulted in the superior growth and it registered 4.88 and 3.00% higher shoot height of rice in the respective years of study than conventional method of tillage. Direct seeded rice could be growing more height than transplanted rice due the root vicinity zone has receiving sufficient air to facilitate oxidized root zone. This finding is in the agreement with Yomauchi *et al*. (1995). Similarly, Naklang *et al*. (1996) were also reported that increased plant height of rice from 8.21 to 13.46% was observed in various treatment of direct seeded rice. Wheat also was responded similar as rice accorded to rice planting and wheat tillage methods. During both the year’s rice and wheat planting systems was not significantly influenced plant height except during 2008-09 in wheat establishment method (Table 1). The maximum plant height of wheat was observed under DSR (82.1 and 89.5 cm during 2007-08 and 2008-09, respectively) and zero till drill methods (83.3 and 89.8 cm). Zero till drill wheat showed 5.04 and 2.86% higher shoot height of wheat during 2007-08 and 2008-09 respectively over conventional tillage method. Another interesting findings, observed that conventional wheat after machine transplanted rice showed the maximum height of wheat (Table 7). ZT-wheat exhibited the maximum plant height after DSR in rice. But ZT was not found to increase the shoot height in wheat when done after hand transplanted rice field. Increment in tiller number in rice and wheat under DSR and zero till drill over other methods of planting and tillage were also observed during both the years. 8.89 and 27.36% higher tillers m^{-2} in rice and 4.83 and 4.67% more no. of tillers m^{-2} in wheat was recorded under DSR over hand transplanting method in 2007-08 and 2008-09 correspondingly. Minimum number of tillers m^{-2} of both rice and wheat were observed under machine transplanting. The more tillers under direct seeded rice method represents more effective plant arrangement and intensity that cause the increase of land area in direct seeded rice method and more population under direct seeded rice method also could proved more tillers per unit area. Moreover, minimum population and more spacing area between plants and rows lead to fewer tillers per unit area under machine transplanted rice than DSR. Biswas and Yamouchi (1997) also confirmed with same results. Simultaneously, more tillers m^{-2} of wheat was observed in zero till drill wheat due to more plant population in the system. Besides, this system improves the soil physical and nutrient content and build up more organic matter. Due to this, more shoot height and more tillers m^{-2} are observed. Variation in the dry matter accumulation in rice and wheat due to rice establishment methods was significant in both years of experiment. During 2007-08, dry matter accumulation under direct seeded rice (526.2 and 431.8 g/m^2 during 2007-08 and 2008-09, respectively) was at par with sprouted rice (500.2 and 397.7 during 2007-08 and 2008-09, respectively) but significantly higher than that of hand and machine transplanted rice in both years. However, it was not significant under wheat establishment methods. The more dry matter accumulation was observed in zero tillage followed by strip drill method. The higher dry matter accumulation in DSR and zero till drill methods could be confirmed with Pandey and Valesco (1999) that higher total biomass due to more tillers and higher plant height and more plant population could be obtained more total dry matter accumulation in these system. Wheat after DSR resulted in 8.25 and 7.91% more dry mater accumulation in 2007-08 and 2008-09 respectively than wheat after hand transplanted rice, while, ZT wheat showed the maximum dry matter accumulation in wheat than other tillage methods and it accounted for 11.65 and 11.92% higher dry matter than conventional tillage in respective years of study. Comparing rice establishment methods at same or different wheat establishment methods, direct seeded rice produced significantly more dry matter accumulation under all the wheat establishment methods followed by sprouted rice and hand transplanted rice and minimum value was recorded in machine transplanted rice might be due to minimum plant population and more spacing between plants (Table 7). Comparing wheat establishment methods, both zero till drill and strip till drill had produced higher dry matter than conventional and bed planting methods under all the rice establishment methods and synergistic effect were found between zero till drill and DSR methods.

2.3 *Impact of different planting methods and tillage practices on yield of rice and wheat*

Grain and straw yield of rice was influenced significantly by rice planting methods and different tillage systems in wheat (Table 2). Direct seeded rice produced 18% and 19% higher overall mean yield than hand transplanting during 2007-08 and 2008-09 respectively. ZT in wheat also increase the rice yield to the tune of 8-11% over conventional tillage during the experiment. Bed planting method showed the lowest rice grain yield (3617 and 3083 kg/ha during 2007-08 and 2008-09, respectively) during both years than other methods. This was because of low soil moisture, lack of seed cover and seed damage by birds causing lowest value of yield contributing characters and lower grain yield. Studies have shown that shallow hard pan caused by repeated puddling generally reduces root growth (Oussible *et al*., 1992; Aggarwal *et al*., 1995) resulting in lower tillering and ultimately grain yield. Similar trend of results were found regarding straw yield of rice too. DSR and zero till drill method registered more straw yield of rice due to more production of biomass dry matter, more tiller and shoot height. In case of wheat the highest average grain yield was observed under DSR and ZT amongst all rice planting and wheat-tillage methods. ZT wheat showed 19 and 12% higher grain yield over conventional tillage during 2007-08 and 2008-09 respectively. The higher grain yield in DSR and zero till drill might be associated with higher nutrient content in soil and more uptake of nutrient by crops, more plant population and tillers per unit area leads to could be obtained maximum grain yield than conventional methods. These results are in agreement with Arshad and Gill (1997) who found the greatest wheat yield in zero tillage followed by reduced tillage and lowest in conventional tillage. Moreno *et al*. (1997) reported of higher winter wheat yield under conservation tillage than traditional tillage but difference was not significant. The yield increase was correlated with increase in water contents in the soil due to reduced evaporation. Loss of soil organic matter (SOM) is less under reduced tillage relative to conventional tillage, influences the soil physical, chemical and biological properties and creates a favourable medium for biological reactions. Ghuman and Sur (2001) observed in sub-humid sub-tropical climate that zero tillage in wheat conjunction with direct seeded rice in rice crop practices improved and sustained the higher wheat yield. The maximum straw yield of wheat was observed in DSR and zero till drill planting method followed by sprouted rice and strip till drill methods. The total system productivity was calculated for rice- wheat system as a whole manner and higher total system productivity was observed in DSR were 7.86 and 8.93 t ha^{-1} during 2007-08 and 2008-09, respectively followed by sprouted rice methods. In wheat planting methods, system productivity was observed the maximum in zero till drill followed by strip drill till and the minimum was under bed planting methods due to grain yield of rice and wheat crops had been recorded lesser yield with bed planting during both years.

2.4 *Impact of different planting methods and tillage practices on soil physical and chemical property*

Planting method and tillage management practices significantly influenced the bulk density and infiltration rate (Table 3). Soil bulk density decreased with the increase in level of tillage after rice and wheat harvest. Amongst the different rice planting methods, the highest value of mean bulk density after harvesting of rice was recorded under machine transplanting in 2007-08 and under sprouted rice was in the next year. Comparing rice establishment methods, hand transplanted rice under all wheat tillage methods being at par with machine transplanted and spouted rice and found significantly higher bulk density than DSR, while, comparing wheat establishment methods, all wheat establishment methods were observed similar and at par in bulk density with DSR, hand and machine transplanted rice (Table 7). However, zero till drill wheat was at par with strip till drill and showed significantly higher bulk density under sprouted rice than conventional and bed planted wheat. Whereas, after wheat harvest, higher bulk density was found in machine and hand transplanting methods in rice planting methods and zero tillage under wheat tillage. This may be due to settling of soil particles, which increased bulk density to a great extent under zero tillage system (Cassel and Nelson, 1985). However, soil bulk density was not significantly influenced by tillage and planting methods except wheat tillage practices during 2008-09. The infiltration rate increased with the increase in tillage operations. The highest and lowest values of mean infiltration rate were recorded in DSR and zero tillage, respectively. Minimum infiltration rate in puddled field of transplanted rice due to impervious layer of puddled soil restrict the movement of water in to below the soil. The lower value of bulk density and higher infiltration rate under conventional tillage clearly revealed the quality of seed bed preparation which allowed more amount of water to penetrate into the field and the wheat crop to grow vigorously (Meelu *et al*., 1994). Regarding organic carbon % after completion of the crop cycle, it was found that ZT in wheat increased 7-8% organic carbon in soil over conventional method of tillage. Amongst rice established methods DSR showed the better result (Table 4). The higher organic carbon in zero till drill might be due to less oxidation of organic matter. In untilled system the organic carbon tends to accumulate near surface where in tilled field it mixes the soil and oxidizes more rapidly resulting in low organic carbon in the top soil (Campbell *et al.,* 1988 and Rath, 1999). However, in contrast to more organic carbon percentage in direct seeded rice, machine transplanted rice combination with zero till drill had recorded higher soil available phosphorus and potassium and lower value was recorded under direct seeded rice during both the years. This was 14 and 8% higher phosphorus and 5 and 2% increased under machine transplanted rice during 2007-08 and 2008-09, respectively than direct seeded rice. This maximum available phosphorus and potassium under machine transplanted rice field due to puddled field improved available nutrient status over direct seeded rice and favourable condition viz. hydrolysis/reducing conditions (Ponnanperuma, 1972; Sharma and De Dutta, 1985).Comparing all wheat establishment methods, zero till drill wheat plots showed higher available phosphorus under all rice methods (Table 7). Our results obviously showing that zero till wheat combined with direct seeded rice could be available more phosphorus than or equally conventional methods of transplanted rice with other methods of wheat. Higher phosphorus might be due to receded phosphorus by crops which contained in straw are back to soil when straw had been incorporated into soil under zero tillage.

2.5 *Impact of different planting methods and tillage practices on nutrient uptake*

Comparing different rice and wheat established methods DSR and ZT registered the highest nutrient uptake during both the years (Fig. 1a to 2b). Higher nutrient uptake from DSR and ZT due to higher nutrient concentration in the tissue and dry matter yield and direct seeded rice and zero tillage facilitates to develop more root biomass and biological yield and took up more nutrients from deeper soil layer. Sharma and De Dutta (1985) and Gangwar *et al*. (2004) also observed higher nutrient uptake under direct seeded rice and zero tillage wheat. The beneficial effect of zero tillage and mulching on nutrient uptake could be attributed to that change in soil properties. Higher total porosity and better soil moisture conservation favoured the more root growth and nutrient uptake (Sharma *et al*., 2011). Potash uptake by both rice and wheat crops was higher than nitrogen and phosphorus nutrient. In general, cereal crops such as rice and wheat having less cation exchange capacity in roots zone and it prefers to uptake more monovalent ions such as K^+ than divalent ion. Hence, it resulted in more uptake of K^+ ion than nitrogen and phosphorus.

2.6 *Impact of different planting methods and tillage practices on energy production (input-output ratio) pattern*

Conventional tillage system was the greatest energy consumer

(Table 5). Hand transplanted rice consumed the highest amount of total energy (22.77 and 21.82 GJ ha^{-1} during 2007-08 and 2008-09, respectively) followed by machine transplanted rice, while, DSR consumed the minimum energy (20.46 and 20.01 GJ ha^{-1} during 2007-08 and 2008-09, respectively). This was 11 and 9% less energy required as compared to hand transplanting and 7% in both years in direct seeded rice methods. This might be due to tillage and puddling requires greater part of energy in conventional planting and tillage operation. Therefore, more energy was required for hand transplanting and machine transplanting method as compared to direct seeded rice. The puddling was curtailed under DSR method reasons to obtain minimum energy value. Similarly, strip till drill and zero till drill operation there was restricted level of tillage operation. Less energy required with these method of wheat planting. The energy requirement for the rice-wheat cropping system was the maximum when conventional wheat was taken after hand transplanting over the other treatments in both the years. The minimum energy input might be due to more irrigation water, labour requirement and prolonged period for field operation. Similarly, total input energy for zero till wheat was 24.02 and 25.42% less than that of conventional wheat. These results supported the conclusion of several earlier investigations that the energy input requirement can be reduced with no tillage (Boerma *et al*., 1980). The use of minimum tillage management practices for wheat production is increasing because it reduces time, fuel as well as labour requirements and also reduces soil erosion on slopes. Chauhan *et al*. (2003) also reported low energy in zero till wheat from conventional wheat. Sharma *et al*. (2011) reported no tillage saving 80% energy and minimum tillage saving 60% in comparison to the conventional tillage. The total energy output from the rice-wheat cropping system as a whole in zero till wheat system after DSR was the maximum being 272.41 and 302.25 GJ ha^{-1} during 2007-08 and 2008-09, respectively, whereas, bed planted wheat after machine transplanted rice yielded the minimum energy being 218.3 and 238.33 GJ ha^{-1} during two seasons, respectively (Table 4). The maximum energy output in DSR was due to more biological yield. The energy output from wheat after DSR was higher than that of wheat after puddled rice. The energy output-input ratio from the rice-wheat system as a whole was the maximum from zero tillage wheat after DSR (14.04 and 16.12 GJ ha^{-1} in 2007-08 and 2008-09, respectively). Bed planted method after machine transplanted rice in 2007-08 and conventional wheat after machine transplanted rice in 2008-09 recorded minimum output-input ratio. The maximum output-input ratio in DSR and zero till drill wheat had been exhibited findings are in agreement with the results of Singh *et al*. (2005).

2.7 *Impact of different planting methods and tillage practices on economics*

Two years experiment showed that direct seeded rice and zero tillage gave remarkably higher net monetary returns (Rs. 39,948 and 52,267 ha^{-1}during 2007-08 and 2008-09 respectively) and benefit: cost ratio (1.35 and 1.73 during 2007-08 and 2008-09 respectively) followed by sprouted rice and lowest net return and B: C ratio were recorded in hand transplanted rice (Table 6). DSR registered 34% and 45% increase in net returns during 2007-08 and 2008-09 respectively over conventional tillage. Zero tillage method of wheat fetched the highest net monetary returns and B: C ratio followed by strip till drill treatment. Further, tillage and strip till drill were almost equally economic. The findings indicate that the direct seeded rice with zero tillage was beneficial in rice-wheat rotation in these areas. Direct seeded rice in combination with zero tillage found beneficial in terms of soil quality improvement, crop yield and economics of rice-wheat cropping system. Bonciarelli and Archetti (2000) concluded that reducing soil tillage always resulted in notable savings of fuel consumption and working time. Verch *et al*. (2009) in four years trial observed that reduced tillage proved to be more profitable than conventional tillage.

Table 1: Growth attributes of rice and wheat crops as influenced by different planting methods under rice-wheat cropping system

Planting and tillage methods	Rice						Wheat					
	Shoot height (cm)		Tillers (No. m^{-2})		Dry matter accumulation (g m^{-2})		Shoot height (cm)		Tillers (No. m^{-2})		Dry matter accumulation (g m^{-2})	
	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
Rice												
Direct seeded rice	78.4^{a}	76.8^{a}	245^{a}	270^{a}	526.2^{a}	431.8^{a}	82.1^{a}	89.5^{a}	432^{a}	426^{a}	1032.7^{a}	999.6^{a}
Sprouted rice	74.1^{a}	74.3^{a}	231^{a}	213^{a}	500.2^{a}	397.7^{a}	80.7^{a}	89.1^{a}	417^{a}	416^{a}	987.9^{b}	959.5^{b}
Hand transplanting	66.4^{b}	73.7^{a}	225^{a}	212^{a}	466.2^{b}	302.4^{b}	80.5^{a}	87.3^{a}	412^{a}	407^{a}	954.0^{c}	926.3^{c}
Machine transplanting	65.2^{b}	71.7^{a}	206^{a}	200^{a}	343.0^{c}	270.4^{b}	78.9^{a}	86.8^{a}	385^{a}	400^{a}	930.6^{c}	901.8^{c}
Wheat												
Conventional	69.7^{a}	73.3^{a}	219^{a}	217^{a}	438.3^{a}	344.2^{a}	79.3^{a}	87.3^{b}	401^{a}	397^{a}	951.2^{c}	923.4^{c}
Bed planting	69.5^{a}	72.7^{a}	212^{a}	213^{a}	418.9^{a}	338.6^{a}	74.9^{a}	86.9^{b}	393^{a}	389^{a}	885.0^{d}	856.2^{d}
Strip till drill	71.7^{a}	74.9^{a}	234^{a}	226^{a}	471.6^{a}	352.0^{a}	79.7^{a}	88.7^{ab}	402^{a}	418^{a}	1006.9^{b}	974.1^{b}
Zero till drill	73.1^{a}	75.5^{a}	243^{a}	229^{a}	507.0^{a}	367.4^{a}	83.3^{a}	89.8^{a}	450^{a}	445^{a}	1062.0^{a}	1033.5^{a}

Within column, value represented with different letter indicate significant difference (P = 0.05).

Table 2: Yield and their attributes of rice and wheat crops as influenced by different planting methods under rice-wheat cropping system

Planting methods	Rice				Wheat				Total system productivity (t ha^{-1})	
	Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})		Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})			
	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
Rice										
Direct seeded rice	4356^{a}	3725^{a}	6147^{a}	5475^{a}	3408^{a}	5065^{a}	5075^{a}	7394^{a}	7.86	8.93
Sprouted rice	4053^{a}	3517^{ab}	5940^{a}	5192^{ab}	3384^{a}	4979^{a}	4875^{a}	7202^{a}	7.53	8.64
Hand transplanting	3933^{a}	3125^{bc}	5908^{a}	4723^{bc}	3375^{a}	4885^{a}	4816^{a}	6888^{a}	7.40	8.15
Machine transplanting	3667^{a}	3017^{c}	5519^{a}	4556^{c}	3154^{a}	4576^{a}	4650^{a}	6589^{a}	6.91	7.72
Wheat										
Conventional	3954^{ab}	3325^{bc}	5858^{a}	4887^{a}	3175^{b}	4745^{b}	4650^{bc}	6817^{b}	7.22	8.20
Bed planting	3617^{b}	3083^{c}	5454^{a}	4745^{a}	3000^{b}	4062^{c}	4467^{c}	6692^{b}	6.70	7.26
Strip till drill	4062^{a}	3383^{ab}	5950^{a}	5104^{a}	3367^{b}	4806^{b}	4992^{ab}	7026^{b}	7.52	8.32
Zero till drill	4375^{a}	3592^{a}	6228^{a}	5209^{a}	3779^{a}	5291^{a}	5308^{a}	7538^{a}	8.26	9.03

Within column, value represented with different letter indicate significant difference (P = 0.05).

Table 3: Effect of different establishment methods on soil physical properties of soil under rice wheat cropping system

Planting methods	Bulk density (g cc^{-1}) at 0- 30cm depth				Infiltration rate (mm hr^{-1})			
	After rice harvest		After wheat harvest		After rice harvest		After wheat harvest	
	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
Rice								
Direct seeded rice	1.54^{b}	1.58^{b}	1.41^{a}	1.45^{a}	1.79^{a}	1.96^{a}	5.73^{a}	6.18^{a}
Sprouted rice	1.60^{ab}	1.65^{a}	1.41^{a}	1.50^{a}	1.69^{a}	1.67^{b}	5.71^{a}	6.01^{ab}
Hand transplanting	1.64^{a}	1.64^{ab}	1.42^{a}	1.55^{a}	1.69^{a}	1.75^{b}	5.49^{a}	5.86^{b}
Machine transplanting	1.65^{a}	1.60^{ab}	1.48^{a}	1.48^{a}	1.67^{a}	1.62^{b}	5.60^{a}	5.81^{b}
Wheat								
Conventional	1.57^{b}	1.57^{c}	1.42^{a}	1.44^{b}	2.05^{a}	2.31^{a}	5.96^{a}	6.25^{a}
Bed planting	1.58^{b}	1.60^{bc}	1.47^{a}	1.50^{ab}	1.90^{ab}	1.77^{b}	5.68^{b}	6.00^{b}
Strip till drill	1.63^{ab}	1.63^{ab}	1.44^{a}	1.49^{ab}	1.54^{bc}	1.55^{bc}	5.55^{c}	5.87^{c}
Zero till drill	1.66^{a}	1.68^{a}	1.46^{a}	1.55^{a}	1.35^{c}	1.35^{c}	5.35^{d}	5.73^{d}

Within column, value represented with different letter indicate significant difference (P = 0.05).

Table 4: Effect of establishment method and tillage on after end of crop cycle soil fertility in rice - wheat cropping system

Establishment methods	Organic carbon %		Available Phosphorus (kg ha^{-1})		Available potash (kg ha^{-1})	
	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
Rice						
Direct seeded rice	0.72^{a}	0.73^{a}	21.73^{c}	23.52^{c}	150.00^{b}	144.42^{c}
Sprouted rice	0.71^{a}	0.72^{a}	23.37^{b}	24.12^{b}	152.41^{b}	145.19^{bc}
Hand transplanting	0.71^{a}	0.71^{a}	23.09^{b}	24.67^{b}	155.37^{a}	145.89^{b}
Machine transplanting	0.70^{a}	0.71^{a}	24.86^{a}	25.51^{a}	157.07^{a}	147.42^{a}
Wheat						
Conventional	0.69^{b}	0.69^{c}	22.00^{d}	23.07^{d}	149.40^{c}	141.74^{c}
Bed planting	0.70^{b}	0.70^{c}	22.80^{c}	24.25^{c}	152.09^{bc}	143.74^{bc}
Strip till drill	0.72^{a}	0.72^{b}	23.56^{b}	24.83^{b}	154.47^{b}	146.47^{b}
Zero till drill	0.73^{a}	0.74^{a}	24.70^{a}	25.68^{a}	158.88^{a}	151.04^{a}

Within column, value represented with different letter indicate significant difference (P = 0.05).

Table 5: Energy input: output ratio of rice wheat cropping system as influenced by different establishment methods

Treatments	Energy input (GJ ha^{-1})		Energy output (GJ ha^{-1})		Energy input-output	
	2007-08	2008-09	2007-08	2008-09	2007-08	2008-09
Direct seeded rice						
Conventional	21.67	21.30	244.54	285.41	11.29	13.59
Bed planting	21.42	21.45	242.66	281.52	11.33	13.12
Strip till drill	19.34	18.54	257.91	291.59	13.34	15.73
Zero till drill	19.40	18.75	272.41	302.25	14.04	16.12
Mean	20.46	20.01	254.38	290.19	12.43	14.50
Sprouted rice						
Conventional	21.97	21.50	243.56	278.59	11.09	12.96
Bed planting	21.80	21.36	234.77	277.89	10.77	13.01
Strip till drill	19.70	19.09	244.74	275.16	12.42	14.41
Zero till drill	19.81	19.36	253.96	287.59	12.82	14.86
Mean	20.83	20.33	244.26	279.81	11.73	13.76
Hand transplanting						
Conventional	24.35	23.67	234.60	260.32	9.63	10.99
Bed planting	24.21	23.40	233.01	257.04	9.63	10.99
Strip till drill	21.21	20.05	244.94	257.04	11.55	12.82
Zero till drill	21.31	20.16	253.43	277.16	11.89	13.75
Mean	22.77	21.82	241.5	262.89	11.33	12.05
Machine transplanting						
Conventional	23.41	23.44	225.49	242.07	9.63	10.33
Bed planting	23.43	22.51	218.30	238.33	9.32	10.59
Strip till drill	20.52	20.02	228.96	256.18	11.16	12.80
Zero till drill	20.54	20.04	236.84	267.10	11.53	13.33
Mean	21.98	21.50	227.40	250.92	10.35	11.67

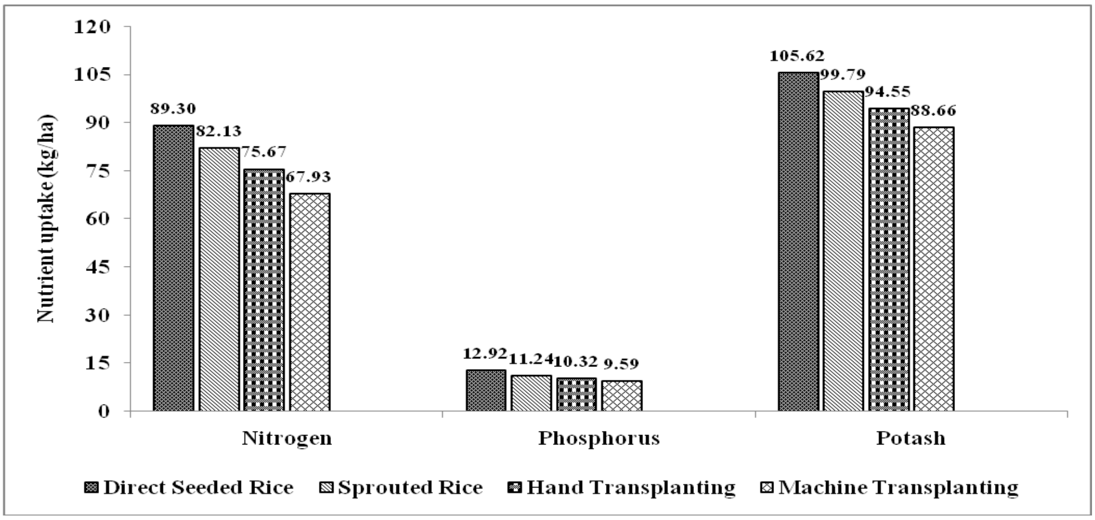
Table 6: System economic analysis of rice and wheat under different crop establishment methods of rice-wheat system

Treatments	2007-08				2008-09			
	Total cost of cultivation (Rs ha^{-1})	Gross income (Rs ha^{-1})	Net income (Rs ha^{-1})	Benefit cost ratio	Total cost of cultivation (Rs ha^{-1})	Gross income (Rs ha^{-1})	Net income (Rs ha^{-1})	Benefit cost ratio
Direct seeded rice								
Conventional	30,939	67,142	36,203	1.17	31,596	81,485	49,889	1.58
Bed planting	30,449	66,376	35,927	1.18	31,066	80,710	49,644	1.60
Strip till drill	28,800	70,210	41,410	1.44	29,453	82,648	53,195	1.81
Zero tillage	28,757	75,007	46,250	1.61	29,453	85,792	56,339	1.91
Mean	29,736	69,684	39,948	1.35	30,392	63,354	52,267	1.73
Sprouted rice								
conventional	33,813	66,956	33,143	0.98	34,891	79,292	44,401	1.27
Bed planting	33,338	63,690	30,352	0.91	34,362	79,057	44,695	1.30
Strip till drill	30,292	66,991	36,699	1.21	31,360	82,468	51,108	1.63
Zero tillage	30,249	70,325	40,076	1.33	31,360	82,468	51,108	1.63
Mean	31,923	66,991	35,068	1.11	32,993	79,966	46,973	1.43
Hand transplanting								
conventional	37,792	63,421	25,629	0.68	41,547	74,382	32,835	0.79
Bed planting	37,767	63,325	25,558	0.68	41,547	74,382	32,835	0.79
Strip till drill	34,863	67,559	32,696	0.94	38,158	74,184	36,026	0.94
Zero tillage	34,820	70,153	35,333	1.02	38,158	80,461	42,303	1.11
Mean	36,311	66,115	29,804	0.83	39,722	75,595	35,873	0.91
Machine transplanting								
conventional	35,406	61,322	25,916	0.73	38,700	69,438	30,738	0.91
Bed planting	34,931	59,084	24,153	0.69	38,177	68,067	29,890	0.78
Strip till drill	32,039	62,184	30,145	0.94	35,364	75,154	39,790	1.13
Zero tillage	31,996	65,541	33,545	1.05	35,364	77,608	42,244	1.20
Mean	33,593	62,033	28,440	0.85	36,901	72,567	35,666	0.98

Table 7: Interaction effect of rice-wheat establishment method on various parameters at significant level

Treatments	Wheat shoot height (cm)	Wheat dry matter (g m^{-2})	Soil available P_2O_5 (kg ha^{-1})	Bulk density at rice harvest (g cc^{-1})
	2007-08	2007-08	2008-09	2007-08
Direct seeded rice				
Conventional	73.20 ^{f}	990 ^{de}	20.66 ^{g}	1.51 ^{e}
Bed planting	83.60^{ab}	899^{fg}	20.95 ^{g}	1.51 ^{e}
Strip till drill	80.13^{abcd}	1057 ^{c}	21.94 ^{f}	1.57^{cde}
Zero till drill	85.87 ^{a}	1185 ^{a}	23.37 ^{e}	1.58^{abcde}
Sprouted rice				
Conventional	82.00^{abc}	963 ^{e}	22.26 ^{f}	1.54 ^{de}
Bed planting	78.20^{bcdef}	902^{fg}	23.04 ^{e}	1.57^{cde}
Strip till drill	83.27^{ab}	1014 ^{d}	23.51 ^{e}	1.63^{abcd}
Zero till drill	84.93 ^{a}	1073 ^{b}	24.66 ^{c}	1.67^{ab}
Hand transplanting				
Conventional	75.93^{cdef}	932 ^{f}	21.80 ^{f}	1.62^{abcd}
Bed planting	79.93^{abcde}	883^{gh}	23.02 ^{e}	1.62^{abcd}
Strip till drill	75.73 ^{def}	992 ^{de}	23.32 ^{e}	1.65^{abc}
Zero till drill	73.80^{ef}	1009 ^{d}	24.22 ^{d}	1.69 ^{a}
Machine transplanting				
Conventional	85.97 ^{a}	920 ^{f}	23.26 ^{e}	1.6^{abcde}
Bed planting	77.67^{bcdef}	856 ^{h}	24.17 ^{d}	1.63^{abcd}
Strip till drill	79.80^{abcde}	964 ^{e}	25.47 ^{b}	1.68 ^{a}
Zero till drill	78.73^{bcdef}	982 ^{de}	26.52 ^{a}	1.69 ^{a}

Within column, value represented with different letter indicate significant difference (P = 0.05).



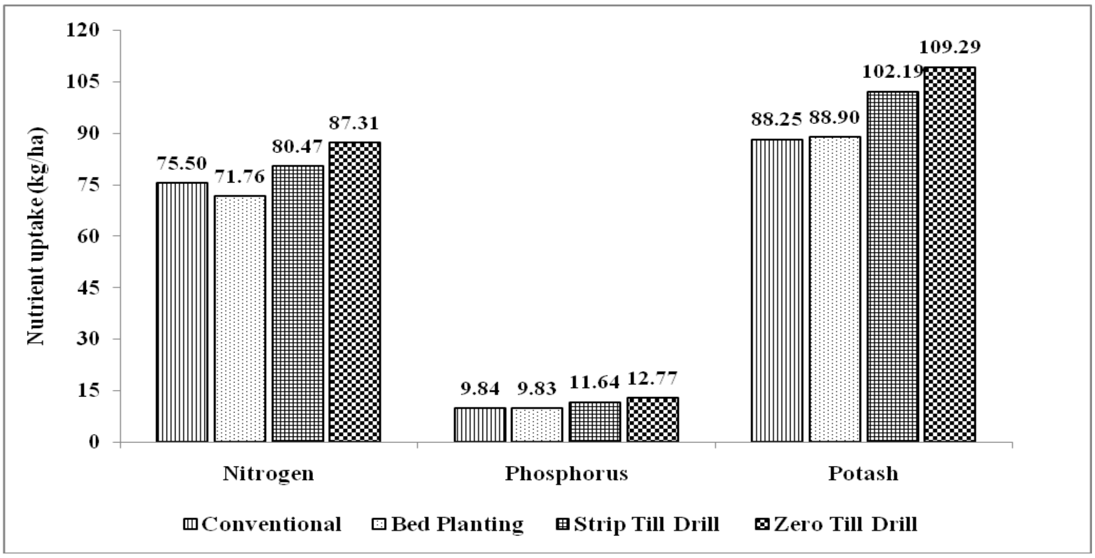
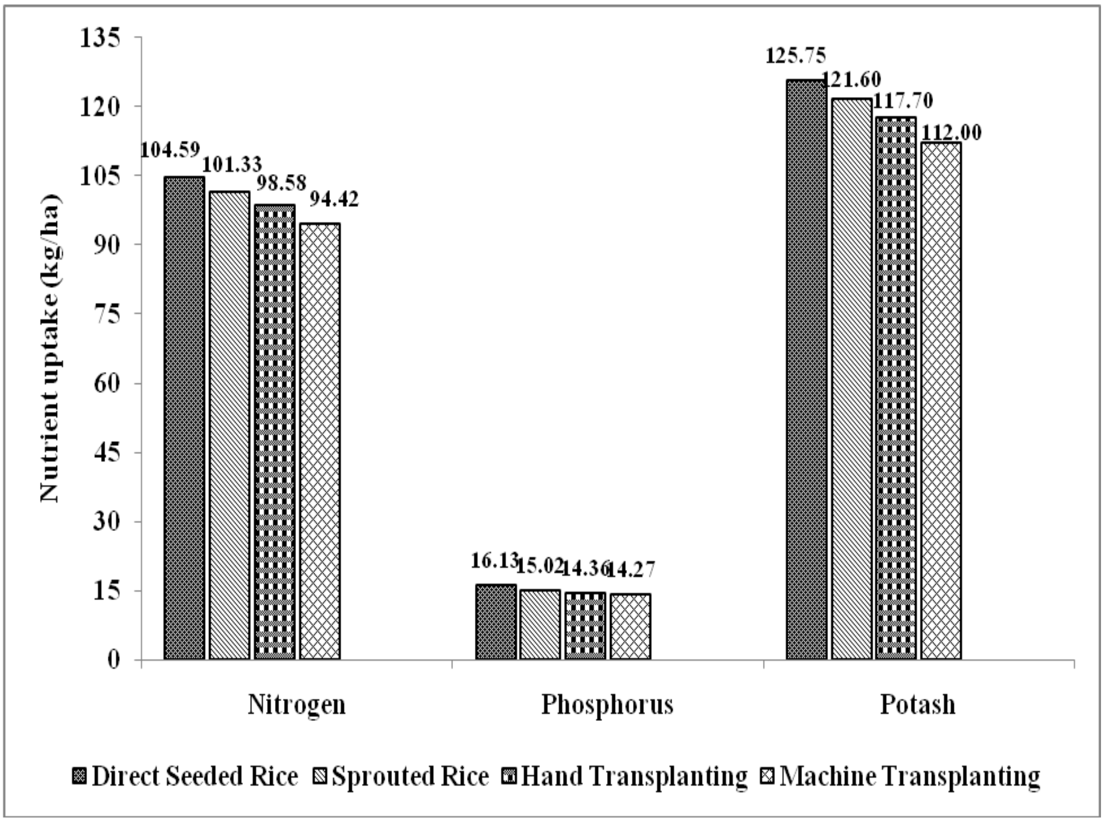


Fig 1: Total mean uptake of Nitrogen, Phosphorus and Potash (kg ha^{-1}) by rice crop as influenced by (a) rice establishment methods and (b) wheat establishment methods



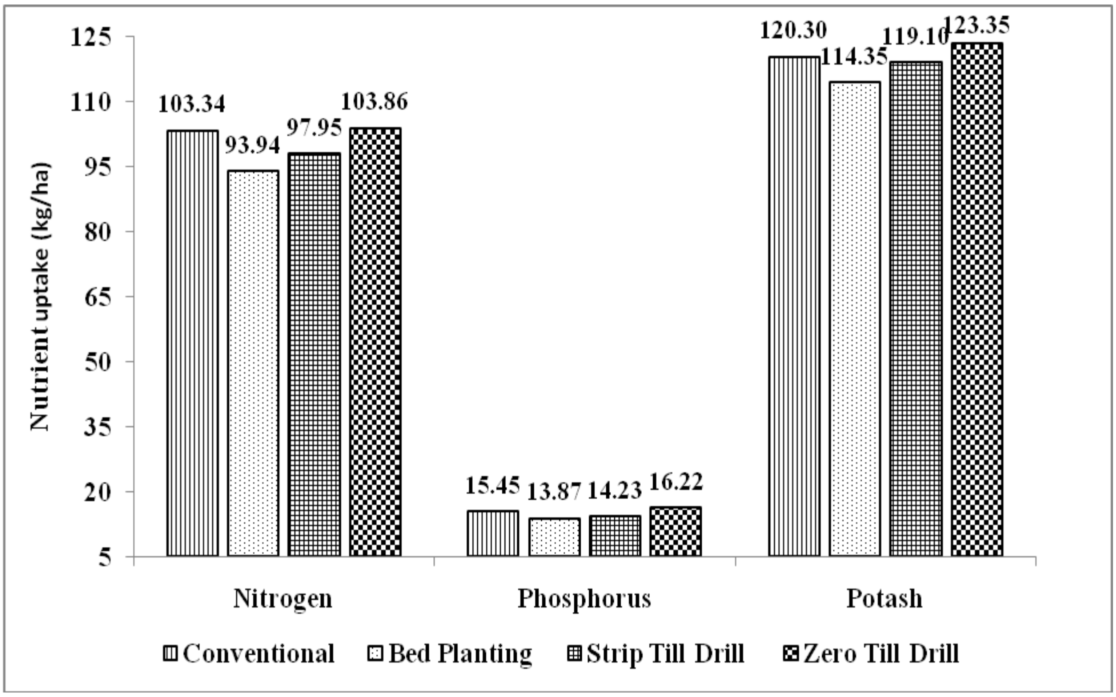


Fig 2: Total mean uptake of Nitrogen, Phosphorus and Potash (kg ha^{-1}) by wheat crop as influenced by (a) rice establishment methods and (b) wheat establishment methods

3. Conclusion

With respect to the energy requirement, economics, soil properties and grain yield, the best results were achieved under direct seeded rice with zero till wheat system. The results of the study show that the yield, energy requirement, economics and soil physical properties of rice and wheat respond to these management strategies. Direct seeded rice in combination with zero tillage followed by strip till drill is advantageous in point of view of the economically (cost reduction), ecologically (soil compaction, improve soil physical chemical properties), and organizationally (reducing soil preparation operations). So using of direct seeded rice with zero tillage could help farmers in this region to increase the total system productivity and to decrease production cost and energy in the rice and wheat production.

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