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Sanjeev Kumar
ICAR Research Complex for Eastern Region

Santosh Kumar
ICAR Research Complex for Eastern Region

Surajit Mondal
ICAR Research Complex for Eastern Region

S. S. Singh
Rani Lakshmi Bai Central Agricultural University Jhansi

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Research Paper

Economics and yield response in rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system as influenced by different tillage and sowing methods in Eastern Region

SANJEEV KUMAR[1], SHIVANI[2], SANTOSH KUMAR[3], S. MONDAL[4], S.S. SINGH[5] AND K.M. SINGH[6]

ICAR Research Complex for Eastern Region, Patna, Bihar 800 014

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ABSTRACT

A field experiment was carried out during the rainy (*kharif*) and winter (*rabi*) seasons of 2011 to 2014 at ICAR-Research Complex for Eastern Region, Patna, Bihar to evaluate the performance of rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) cropping system under different tillage practices and sowing methods with economics. Four methods of sowing in rice, viz. zero-tilled rice (ZT), wet sowing through drum seeder, unpuddled mechanical transplanted rice (UT) and puddled transplanting (CT); whereas in wheat 3 methods of sowings, viz. zero-till-sowing (ZT), manual line sowing (CT) and sowing with Turbo Happy seeder (HS), were evaluated and compared. Unpuddled mechanical transplanting of rice followed by manual sowing of wheat recorded the least bulk density (1.52 Mg/m^3), which was statistically at par with puddled transplanting of rice followed by zero/reduced tilled wheat (1.55 Mg/m^3). The CT-HS and CT-ZT practice under rice–wheat cropping system showed higher water-holding capacity (42.34%), mean weight diameter (0.943 mm), water-stable aggregates (32.45%) and higher hydraulic conductivity (3.05 mm/ hr) over ZT-ZT and CT-CT practice at 0–15 cm of soil depth. Grain yield of conventionally transplanted rice (4.56 t/ha) was statistically at par with unpuddled mechanical transplanted rice, however the highest output : input ratio of 2.4 was recorded in unpuddled mechanically transplanted rice. Wheat grown in plots of manually transplanted rice and mechanical transplanted rice, gave significantly higher yield, i.e. 4.54 and 4.4 t/ ha, with an output : input ratio of 2.1 and 2.2 respectively. Wheat sown by Turbo Happy seeder gave significantly higher grain yield (4.38 t/ha) over other methods of sowing. Zero-tilled rice and mechanically transplanted rice saved 81.6 and 72.3% of sowing cost and 97.3 and 95.6% in terms of time taken in sowing/transplanting on hectare basis respectively. Sowing of wheat through zero-till-drill and Turbo Happy Seeder economized the overall cost of cultivation by ₹9,800 and ₹9,110/ha respectively along with 10–12 days earliness in sowing of wheat after harvesting of rice crop. In terms of system productivity, CT-HS and UT-HS practices provided the maximum productivity with higher benefit: cost ratio. From soil health and yield point of view, zero/reduced tillage followed by conventional tillage or conventional tillage followed by zero/reduced tillage in rice–wheat system (CT-ZT scenario) was found most promising tillage practice.

Key words : Cropping system, Economics, Happy seeder, Sowing methods, Soil physical condition, System productivity, Tillage, Yield

Rice–wheat cropping system is the most dominant cropping system in Indo-Gangetic plains and Eastern Region of the country by covering nearly 10.5 million ha area (Shah *et al*., 2015). This system is vital for national food security, contributing more than 70% of total cereal production in our country (Ahmad *et al*., 2013). Both crop component of this system need more water, labour, time, heavy farm machineries and input costs for their successful cultivation. Depleting soil organic carbon status, groundwater, decreasing soil fertility and reduced factor productivity are other issues of concern. From old age, rice is grown by transplanting in puddled soil manually to achieve yields, but in this method a large number of labours is required to accomplish transplanting of rice seedlings and mostly it is delayed due to unavailability of adequate number of labours during peak period of transplanting. At present, timely availability of labour for transplanting is a burning problem in almost all rice-growing

[1]**Corresponding author's Email**: shiv_sanjeev@yahoo.co.in
[1,2]Principal Scientist, Agronomy, [3]Scientist, Plant Breeding, [4]Scientist, Soil Science; [5]Director, ATARI, Kolkata; [6]Head, Division of Socio-economic and Extension, Rajendra Agricultural University, Pusa, Bihar

Asian counties and that too in India. Under these circumstances, it is imperative to develop alternate method of rice and wheat crop cultivation that are more water efficient and less labour intensive to produce higher yield with less cost of production. The land preparation to grow transplanted rice is not only tedious, costly and time consuming but also causes ill-effect on soil health which reduces the yield of succeeding crop, i.e. wheat. Due to conventional puddling and land preparation in rice, a yield decline of 8–9% has been observed in wheat as compared with non-puddled rice due to disturbance in the soil physical structure (Gill *et al.* 2008; Kumar and Ladha, 2011). Besides these, sowing of wheat also get delayed if conventional land preparation is carried out, which requires excessive tillage, thus delays sowing and resulted in linear decline in wheat productivity equivalent to 1.0–1.5% yield loss/ha/day (Gathala *et al.,* 2011). Use of long-duration varieties and delay in transplanting of rice seedlings due to dependency on monsoon rain for puddling are the major reasons for delayed harvesting of rice. In the eastern part of the India, especially in Bihar, rice is harvested up to the second week of December which tends towards late sowing of wheat and a substantial decline in wheat yield. Mishra (2003) reported a decrease of 47 kg/ha/day and 57 kg/ha/day if sowing of wheat is done in the month of December and January, respectively. Delay in wheat sowing can be reduced to some extent by using improved machines. Keeping above facts in view, a study was carried out to evaluate a suitable transplanting/sowing method for rice and wheat crops under different tillage practices in rice–wheat cropping system.

MATERIALS AND METHODS

The field experiment was conducted during the rainy (*kharif*) and winter (*rabi*) seasons of 2011 to 2014 at Main farm of ICAR Research Complex for Eastern Region, Patna, Bihar. The soil of the experimental field was clay loam, having *p*H 6.7 and organic carbon content 0.53%. Randomized block design was used for rice 'Rajendra Sweta' and split plot design for wheat crop 'PBW 373'. The main plot treatments comprised 4 sowing/transplanting methods in rice, viz. (*i*) zero tilled rice, (*ii*) wet sowing through drum seeder, (*iii*) unpuddled transplanting of rice with self-propelled rice transplanter (UT), and (iv) conventional transplanting of rice in puddled condition (CT).

Again, after harvesting rice in the last week of November during all the 3 years, each main plot was divided into 3 sub-plots to facilitate sowing of wheat under three tillage practices viz. (*i*) conventional tillage with manual line sowing (CT), (*ii*) happy seeder (HS) and (*iii*) zero-till drill. Seventeen days old rice seedlings (raised through mat nursery) were used for mechanical transplanting of rice by self-propelled rice transplanter, whereas 24 days old seedlings were used for manual transplanting at a spacing of 20 × 10 cm. Yield assessment of rice and wheat were done on the basis of yield obtained from the net plot area. Recommended doses of fertilizers (100 kg N + 50 kg P_2O5 + 40 kg K_2O) were applied in both the crops. Full dose of P and K and one-third N were applied basal, while remaining N-fertilizer was applied in 2 splits in both the crops (one-third N at active tillering stage + one-third N at panicle-initiation stage) in rice, while in wheat one-third N was applied at crown-root initiation stage and the rest one-third N at booting stage. Intercultural operations like weeding, irrigation and plant protection measures etc. were carried out in both the crop as per standard recommendations. A mean rainfall of 1,157.2 mm (mean over 3 experimental years) was recorded during the years of experimentation. One irrigation of 5 cm depth was applied to rice crop sown by zero till machine, wet-sown drum-seeded rice and manually transplanted rice 10 days after sowing/transplanting due to less soil-moisture in the soil while an irrigation depth of 3 cm was applied in case of unpuddled mechanical transplanted rice during each year of experimentation. However, in winter (*rabi*) season, 4 irrigations were provided to wheat crop to meet out the crop water demand. Bulk density, total porosity, hydraulic conductivity and penetration resistance of soil tilled by different methods were also determined by considering following situations in a cropping system mode, viz. (i) zero tilled rice-Zero tilled wheat (ZT-ZT), (ii) zero tilled rice-happy seeder wheat (ZT-HS), (iii) conventional transplanted rice-zero tilled wheat (CT-ZT), (iv) Unpuddled mechanical transplanted rice- manual line sowing wheat (UT-CT) and (v) Conventional transplanted rice-manual line sowing wheat (CT-CT). Bulk density of the samples was determined by core method (Blake and Hartge, 1986). Cone resistance or soil penetration resistance (PR) was measured by using Hand Penetrometer *Eijkelkamp* for appropriate depth. The base area was also noted because the cone resistance generally expressed in N/cm².

$$\text{Penetration resistance} = \frac{\text{Manometer reading (N)}}{\text{Base area of cone (cm}^2\text{)}}$$

Soil samples were prepared in the laboratory by carefully breaking larger clods (field moist soil) by hand into smaller segments along natural cleavage and then air-dried. Air-dried samples were then passed through an 8-mm sieve and retained on a 6-mm sieve. The aggregates were then wet-sieved following the procedure as laid out by Yoder (1936). The mean weight diameter (MWD) was calculated as an index of aggregation. Particle density was taken as 2.65 g/cm³. Water-holding capacity of soil was determined by the Keen-Raczkowski Box Method (Keen and Raczkowski, 1921) *In-situ* saturated hydraulic conductivity was measured by Guelph permeameter method. Agronomical data were statistically analysed by using standard methods in M-Stat C programme.

RESULTS AND DISCUSSION

Effect of tillage on bulk density and soil strength

A significant different value of bulk density in upper 0–15 cm soil layer was recorded and it was observed that differences were reduced down the profile (Fig. 1). The treatment that received zero tillage in both the season (ZT-ZT) recorded more bulk density values (1.58 Mg/m^3) followed by ZT-HS. The UT-CT treatment recorded the least bulk density (1.52 g/cm^3) and it was at par with CT-CT (1.52 Mg/m^3) and CT-ZT (1.55 Mg/m^3). The ZT practice had the highest bulk density at 0–15 cm depth, which could be attributed primarily to the lack of seasonal loosening from tillage machinery coupled with no residues on the soil surface, contrary to lower bulk density found in CT as also reported by Alvarez and Steinbach (2009). In the lower layers (15–30 and 30–45 cm), the differences among the treatments in bulk density values were reduced, while at 30–45 cm of soil depth, no difference was observed in bulk density. All the treatments showed higher bulk density values than upper layer. The highest bulk density value (1.63 g/cm^3) was recorded in CT-CT-treated plot at 15–30 cm soil depth. Residue incorporation or retention in respective tillage treatments, viz. Happy seeder

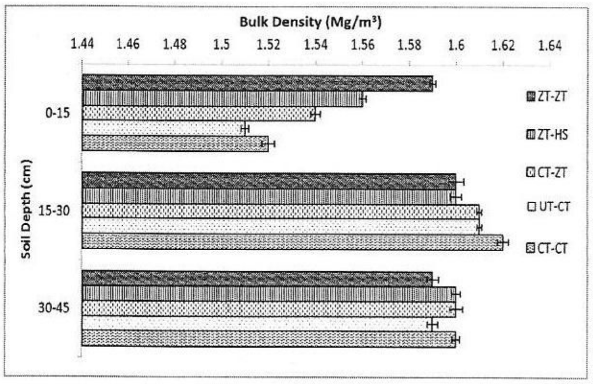

Fig. 1. Bulk density under different tillage conditions

ZT, Zero-tillage; HS, Happy seeder; CT, conventional transplanting; UT, unpuddled transplanting

in wheat significantly affected bulk density at 0–15 cm depth. For rest of the depths, no significant effect was observed. A low bulk density in ZT-HS treatments in comparison to ZT-ZT was due to significant amount of residue incorporation resulting in improvement in organic matter content and physical health of soil. Consistent levels of compaction were noticed in 15–30 and 30–45 cm layers irrespective of tillage or residue management practices, advocating very limited effect of residue management to the deeper layer of soil.

In the upper layer (0–15 cm) the ZT-ZT treated plots recorded the highest cone index (CI) values, followed by ZT-HS and CT-ZT, whereas the 2 treatments (UT-CT and CT-CT) with conventional tillage recorded lower CI values (Table 1). In the lower layer (15–30 cm) the highest CI value was recorded by CT-CT treated plots. In 30–45 cm soil layer, no difference in CI values was observed among the treatments. The higher CI value under CT-CT plots obstructed deep penetration of roots into the deeper layer resulting into more energy consumption.

Effect of tillage on water-holding capacity, mean weight diameter, water stable aggregates, hydraulic conductivity and organic carbon

Different values of mean weight diameter were observed in different tillage practices. The highest mean weight diameter was recorded in ZT-HS system, followed by ZT-ZT, CT-ZT and UT-CT, while the lowest MWD value was recorded in CT-CT. Similar type of observation was also recorded for water stable aggregate (Table 2). The highest and lowest amount of water-stable aggregates were recorded in ZT-ZT and CT-CT, respectively. Higher mean weight diameter and water-stable aggregates in treatments that received zero tillage were due to the omission of tillage and incorporation of crop residues in the soil (Mondal *et al.*, 2013). Zero tillage practice and organic matter addition improve the aggregation in comparison to conventional tillage. For the same reason, hydraulic conductivity was also higher in zero tillage. Infiltration rate was the highest in CT-ZT followed by ZT-HS, ZT-ZT, CT-CT and the lowest hydraulic conductivity was recorded in MT-CT. Lower hydraulic conductivity in conventional tillage could be attributed to the destruction of soil aggre-

Table 1. Cone index (penetration resistance) as in MPa (pooled data of 2011–14)

Tillage practices	ZT-ZT	ZT-HS	CT-ZT	UT-CT	CT-CT
0–15 cm	1.78	1.75	1.74	1.72	1.71
15–30 cm	1.73	1.73	1.73	1.73	1.76
30–45 cm	1.72	1.72	1.72	1.72	1.72

ZT, Zero-tillage; HS, Happy seeder; CT, conventional transplanting; UT, unpuddled transplanting gates due to intensive tillage practices and removal of crop residues. Poor aggregation results quick dispersion of aggregates and clogging of macro-pores by finer soil particles. In case of porosity and water-holding capacity, higher value was observed in treatments that received conventional tillage than zero tillage practice. Tillage practices improve the porosity and water-holding capacity of the soil.

The soil organic carbon content is a function of soil management, and change in management can alter soil organic carbon content. It is an important factor affecting soil quality, and an important source of plant nutrients. The soil organic carbon after harvesting of rice and wheat were analysed and higher organic carbon (7%) was found in zero tillage and Happy seeder than conventional tillage. The organic matter stratification differs between conventional and no-tillage soil, mainly due to the remaining plant residue cover on the soil surface which favours the accumulation of organic matter near the soil surface. The conversion efficiency of residue carbon on soil organic carbon was lower for plough till (8%) than for no-till (10%). Higher soil organic carbon sequestration was observed by adopting zero tillage (Chandrapala *et al.*, 2010).

Response to sowing/transplanting methods and tillage

Yield and yield attributes: Yield in unpuddled mechanical transplanting (UT) of rice was statistically at par with the conventional transplanting. Significantly higher number of effective tillers/m^2 over zero tilled (ZT) rice and other methods of seeding was observed under unpuddled mechanical transplanting (Table 3). Manually transplanted and mechanically transplanted rice performed equally better in respect of yield/ha over zero tilled and direct wet sown rice. Filled grains/panicle and 1,000-grains weight were also found higher in transplanted rice by both methods (manual and mechanically transplanted rice) than direct wet-sown and zero-tilled rice. Similar trend was also observed for grain and straw yields (Table 3).

Sowing methods of wheat under different tillage practices revealed that sowing by Happy seeder resulted in significantly higher number of effective tillers/m^2, grains/ear as well as grain and straw yield over zero-till drill and manual line sowing, (Table 4). The beneficial effect of Happy seeder on yield and other growth characters in wheat may be owing to incorporation of rice residues (about 30 cm) which facilitated the crop with slow release of nutrients up to later stages and earliness in sowing of wheat crop. Sidhu *et al.* (2007) also reported that Turbo Happy seeder leaves the sowing lines exposed which enable successful establishment and production of wheat into heavy rice stubbles, facilitating with sufficient organic carbon at later stages. However, different sowing methods remained statistically at par with regard to 1,000-grain weight. Zero-tilled wheat and conventional line sowing of wheat were found statistically at par in respect of all yield attributes and grain as well as straw yields. Poor perfor-

Table 2. Soil physical parameters as affected by different tillage practices in 0–15 cm soil layer (pooled data of 2011–14)

Treatment	Porosity (%)	Water-holding capacity (%)	Mean weight diameter (mm)	WSA (%)	Hydraulic conductivity (mm/hr)
ZT-ZT	40.00	39.65	0.956	34.65	2.62
ZT-HS	41.13	40.98	0.984	33.56	2.94
CT-ZT	41.89	42.34	0.943	32.45	3.05
UT-CT	43.02	42.42	0.905	30.32	2.5
CT-CT	42.64	42.92	0.856	28.56	2.54

ZT, Zero-tillage; HS, Happy seeder; CT, conventional transplanting; UT, unpuddled transplanting; WSA, water soluble aggregates.

Table 3. Yield and yield attributes, output: input ratio of rice as influenced by various sowing/ transplanting methods (pooled data of 2011–14)

Treatment	Effective tillers/m^2	Filled grains/panicle	1,000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Output: input ratio#
ZT rice	167.5	115.0	15.1	4.81	5.02	1.9
Direct wet sowing	163.2	114.8	15.6	3.82	5.10	1.7
Conventional transplanting	212.4	139.0	17.9	5.21	5.85	1.8
Mechanical Transplanting	215.3	135.2	17.1	5.02	5.63	2.5
SEm±	3.55	3.82	0.26	0.155	0.16	-
CD (P= 0.05)	11.7	12.2	0.89	0.51	0.49	-

#Output: input ratio= gross returns/cost of inputs mance of wheat under manual line sowing may be attributed to its delayed sowing by 2 weeks. Wheat grown after harvesting of conventionally transplanted rice plots resulted in the maximum grain and straw yields (Table 4). Optimum performance of wheat grown in conventionally transplanted rice crop and unpuddled mechanical transplanted rice can be attributed to its effect on providing ideal seedbed and soil environments for wheat which resulted in better growth and yield of wheat crop (Erenstein and Laxmi, 2008; Singh *et al.*, 2012).

System productivity

Higher system productivity of 9.77 t/ha was obtained from conventional transplating of rice (CT)-Happy seeder-sown wheat (HS) and was found statistically at par with unpudled mechanical transplanting of rice (UT)-Happy seeder-sown wheat and was followed by conventional transplanted rice (CT)-zero-tilled sown wheat (Table 4). Higher yield under CT rice-HS wheat or UT rice-HS wheat may be attributed to higher number of tillers/hill due to transplanting of rice and getting optimum soil-physical condition in wheat. Lower system productivity of ZT rice-Manual sown wheat (MS) was probably because of adverse soil condition for rice seed germination and heavy weed infestation. In-spite of judicious use of pre- and post-emergence herbicides, weed infestation was more pronounced in direct-seeded rice than other methods of transplanting at active tillering and primordial emergence stages which ultimately leads to lower grain yield. Higher weed infestation in wet season in direct-seeded rice is due to alternate wetting and dry situation which favours heavy weed infestation in rice crop (Singh, and Rao, 2012).

The interaction effect of tillage and sowing methods was found insignificant. However, the effect of tillage and sowing methods were found significant in individual crop separately.

*Output: input ratio:*Mechanical transplanted rice showed the highest output : input ratio and marked its utility in terms of remunerativeness than the other methods of transplanting/sowing (Table 3), followed by drum seeder. Higher Output : input ratio was attained due to heavy reduction in labour hiring costs and timely sowing/transplanting (Singh and Rao 2012; Sidhu *et al.*, 2007). However, sowing by conventional method resulted in the lowest output : input ratio (1.9), whereas in terms of yield it superseded all direct-sown methods. Different sowing and transplanting methods of rice also influenced the output : input ratio of succeeding wheat crop (Table 4). Manually transplanting of rice revealed significantly maximum output : input ratio and was closely followed by mechanically transplanted rice plots, which were found statistically at par with each other.

Turbo Happy seeder resulted in the highest output : input ratio and was followed by zero till drill method of sowing. This may be due to incorporation of straw of previous crop (rice) in the field which acted as mulch and provided better soil moisture and optimum temperature to the crop throughout whole crop cycle resulting higher grain and straw yield besides reducing the cost of cultivation by ₹ 8,500/ha. Higher economics of mechanical transplanted/sowing crops in the system is due to less labour requirement for carrying out transplanting/sowing operation, lesser water requirement (210–240 mm), escaping puddling operation and more yield due to timely establishment of rice and wheat crop. Gathala *et al.* (2011) and Ahmad *et al.* (2013) also reported higher profitability in case of

Table 4. Effect of different sowing methods and tillage practices on yield attributes, yield, output : input ratio in wheat along with system productivity and economics of the system (pooled data of 2011–14)

Treatment	Effective tillers/m^2	Grains/ panicle	1,000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Output: input ratio	System productivity (t/ha)	Net returns (×10^3 /ha)	Benefit: cost ratio
Sowing/transplanting method in rice									
ZT rice	241.0	40.3	42.7	3.41	5.02	1.7	8.22	64.2	2.2
Direct wet sowing	223.6	34.7	42.4	3.31	5.10	1.5	7.13	62.2	2.1
Conventional transplanting	251.2	35.7	42.0	4.56	5.85	2.2	9.77	81.4	2.3
Unpuddled mechanical transplanting	250.5	34.8	43.2	4.40	5.63	2.1	9.42	89.4	2.8
SEm±	2.77	1.04	0.75	0.040	0.089	-	0.12	2.3	0.1
CD (P=0.05)	8.8	3.33	NS	0.126	NS	-	0.41	7.2	0.4
Sowing of wheat									
Manual line sowing	223.0	32.1	41.6	3.75	5.24	1.5	8.16	62.1	2.1
Happy Seeder	248.3	38.7	42.1	4.25	5.65	2.2	9.15	87.2	2.9
Zero-till-drill	235.8	35.2	41.9	3.84	5.24	1.9	8.62	82.8	3.0
SEm±	4.09	0.97	0.28	0.095	0.104	-	0.16	3.1	0.2
CD (P=0.05)	12.1	2.9	NS	0.28	0.31	-	0.52	10.3	0.5

ZT rice and unpuddled mechanical transplanted rice. Manual line sowing was found to be the most uneconomical (1.5), due to producing lesser yield (late sown) and higher cost of cultivation (Table 4).

Economics

Tillage and crop establishment (direct seeding or transplanting) account for a major part of total crop production costs (Erenstein and Laxmi, 2008). Rice crop sown by zero till drill covered the maximum area (2,200 m^2), followed by unpuddled mechanical transplanter (1,350 m^2) on hourly basis. Labour utilization was very poor under manual transplanting, i.e. consumed largest number of man-hours (524 man-hours/ha) in performing transplanting activity (Table 5). In comparison to manual transplanting, zero-till drill-sown rice saved 97.3% time and 81.6% cost of transplanting. Likewise, mechanical rice transplanter also saved 95.6% time and 72.3% of cost which was followed by direct wet seeding (87.5% time and 64.4% of cost) over manual transplanting. The higher profits from mechanical transplanter, drum seeder and zero-tilled rice was ascribed to their low cost of transplanting or sowing along with saving of irrigation water by 30–35% (Kumar *et al.*, 2012).

Though system productivity was more under CT rice-HS wheat, but benefit: cost ratio was found higher under UT rice-HS wheat (3.0) due to lesser production cost of UT rice and HS wheat (2.9) than CT rice-MS wheat (2.1) and was followed by CT rice-HS wheat and CT rice-ZT wheat (2.8).

Temporal and power requirement with different methods of sowing

Zero tillage covered the maximum area (2,550 m^2/labour/hour), followed by Happy seeder (1,700 m^2/labour/hour), while manual line sowing of wheat proved in least efficient method (35 m^2/labour/hour) as indicated in Table 6. In comparison to line sowing by manual, zero seed drill and Happy seeder saved about 98.4 and 97.6% time as well as 56.2% and 34.3% cost of cultivation respectively. Conventional tillage (manual line sowing), as it involved repeated ploughing and also resulted in delayed sowing by 2 weeks as compared to zero seed drill and Turbo Happy Seeder, proved as least efficient and uneconomical method of wheat sowing due to lesser returns and more cost of cultivation.

Based on the experimental findings, it can be concluded that zero tillage/reduced tillage- conventional tillage scenario (CT-ZT/HS) or vice-versa provides better soil physical condition in terms of bulk density, penetration

Table 5. Comparison between different sowing/transplanting methods in rice (pooled data of 2011–14)

Particular	ZT rice	Direct wet sowing	Conventional transplanting	Unpuddled mechanical transplanting
Man-power for raising nursery (hours/ha)	-	-	90	70
Man-power for sowing/transplanting (hour/ha)	14	65	524	23
Saving (%) in time by use of different transplanter/seeder over conventional transplanting	97.3	87.5	-	95.6
Cost of sowing/transplanting including cost of nursery raising (₹/ha)#	2450	4460	13,300	3680
Saving (%) in cultivation cost due to use of ZT, drum seeder, MT over conventional transplanting	81.6	66.4	-	72.3

#Based upon fuel consumption and man-hours required
ZT, Zero tillage; UT, unpuddled mechanical transplanter/ing

Table 6. Saving in time and cost of sowing in wheat under different tillage practices (pooled data of 2011–14)

Treatment	Manual line sowing	Happy seeder	Zero-till-drill
Man-power required for sowing	32	4	4
Capacity (m^2/hour/ha)	35	1,690	2,500
Earliness in sowing through HS and ZTD over MLS	-	14	14
Time Saving (%) by HS	-	98.8	99.2
Cost of sowing (₹/ha)	4,800	3,000	2,000
Saving (%) in seeding cost over MLS	-	56.2	66.6
Overall cost of cultivation	22,300	13,500	12,500

MLS, Manual line sowing; HS, Happy seeder; ZTD, Zero-till-drill resistance, water-holding capacity, soil organic carbon, etc. under rice-wheat cropping system which facilitates optimum growth and development of the plant and subsequently high yield and optimum returns. Conservation tillage in wheat either by Happy seeder or Zero-till-drill provides better returns by reducing the cost of cultivation by ₹7,500–9,000/ha. In a nut shell, conventional tillage followed by conservation tillage system is an ecological approach to soil surface management and seedbed preparation which can be implemented as a science-based technique; conversion from conventional to conservational tillage system may increase soil organic carbon, improve soil structure, and enhance soil quality and its environmental regulatory capacity.

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