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Research Paper

Assessment of various tillage options in rice (*Oryza sativa*)–wheat (*Triticum aestivum*) system and optimization of nitrogen dose in wheat

S.C. TRIPATHI[1], SUBHASH CHANDER[2] AND R.P. MEENA[3]

ICAR-Indian Institute of Wheat and Barley Research, Karnal, Haryana 132 001

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ABSTRACT

This study was conducted for 4 consecutive years commencing from 2012–13 to 2015–16 at ICAR-Indian Institute of Wheat and Barley Research, Karnal, Haryana, India with the objectives to evaluate tillage options in rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) system and N-levels in wheat for higher productivity and profitability. Combined analysis of 4 years revealed that puddled transplanted rice produced significantly higher grain yield, which was 19.9 and 13.9% higher than yield obtained under zero-till direct seeded rice and zero-till transplanted rice, respectively. Similarly, conventional-till wheat exhibited significantly higher grain and straw yields, which was 10.9 and 22.4% higher than zero-till wheat respectively. Use of leaf colour chart (LCC) in wheat is very handy and cost effective technology, saved 25 kg N/ha and produced grain yield at par with recommended dose of N. Puddled transplanted rice and conventional-till wheat showed maximum total returns, cost of cultivation and net returns.

Key words **:** Agronomic N-use efficiency, Economics, Nitrogen, Rice, Tillage, Wheat

Rice and wheat are the world's 2 most important cereal crops, contributing 45% of the digestible energy and 30% of total protein in the human diet and significant contribution to feeding livestock (Evans, 1993). These are also the major food crops of the Indo-Gangetic Plains of Indian sub-continent. During last 4 decades the growth rates of rice and wheat production (2.5% and 5.2%/year respectively) in South Asia exceeded the population growth rate (2.22%/year), indicating an increase in the per capita availability of these 2 cereals that strengthen the food security, reduced rural poverty and increased affordability of food in the region (Pingali and Shah, 1999). In South Asia, rice–wheat crop sequence is the largest production system and occupies approximately 13.5 million hectares area including 10.3 million hectares in India, extending from Indo-Gangetic plain to Himalayan foothills. In India, approximately 23 and 40% of total rice and wheat area, respectively, is represented by rice–wheat system alone (Timsina and Connor, 2001), which requires contrasting edaphic conditions. Rice is commonly transplanted into puddled soils and gets continued submergence, whereas wheat is grown in upland well drained soils having good tilth. Puddling reduces infiltration of water and destroys soil structure. Farmers generally tilled soil 6–8 times after rice harvest to achieve good seed bed for wheat sowing. This excessive tillage results in delayed planting and thus reduced wheat yields. Delaying wheat sowing beyond November decreases yield by 15.5, 32.0, 27.6, 32.9 and 26.8 kg/ha/day under Northern Hill Zone, North Western Plains Zone, North Eastern Plains Zone, Central Zone and Peninsular Zone, respectively for timely sown varieties with corresponding yield losses of 7.6, 18.5, 17.7, 17.0 and 15.5% (Tripathi *et al*., 2005). The turn-around time between rice and wheat crops is 3–6 weeks. In order to plant wheat timely, many farmers harvest the rice crop with a combine and burn loose residues that lead to greenhouse gas emission and particulate matter in large quantities in sudden spurts and ultimately deteriorating the air quality and loss of nutrients (Sharma and Misra, 2001). Direct seeding of rice (DSR) saves energy, labour and water for rice establishment resulting in earlier maturity of rice, which allows timely wheat sowing.

In zero-till wheat, seed is placed into the soil by a seed drill without prior land preparation. This technology is more relevant in the high yielding regions, more mechanized areas of north-west India and Pakistan, where most of the land preparation is now done with four-wheel tractors (Sheikh *et al.,* 1993). No-till helps to solve the prob-

[1]**Corresponding author's Email:** subhtripathi@gmail.com
[1,2]Principal Scientist, [3]Senior Scientist, ICAR-IIWBR, Karnal, Haryana 132 001

lem of late planting and excessive costs of wheat production, but if rice can be grown without puddling, the total system productivity and profitability would be even greater. Earlier works showed 14.3% higher grain yield in zero-till wheat under direct seeded rice unpuddled condition compared to conventional wheat crop in puddled transplanted rice conditions. In contrast, for rice, it is just reverse resulting in similar rice–wheat productivity (Tripathi *et al.,* 1999). However, this requirement will depend upon the soil type and prevailing agro-climatic conditions. Changing from transplanted, puddled rice to direct seeded aerobic rice would also significantly reduce the emissions of methane, a green house gas that is 21 times more effective than carbon dioxide (Grace *et al.,* 2003). Reduction of methane will ultimately reduce the global warming. Combinations of tillage options in rice–wheat system, preferably no-till in rice as well as in wheat, will enhance the productivity and profitability to a great extent. Rice–wheat cropping sequence having productivity of 7 t/ha of rice and 5 t/ha of wheat removes more than 300 kg nitrogen from the soil. Keeping these facts in mind, the present hypothesis was studied with the objectives of optimizing of tillage requirement in rice-wheat system and nitrogen saving in wheat crop for harnessing the maximum productivity and profitability on sustainable basis.

MATERIALS AND METHODS

A field study was conducted for 4 consecutive years commencing from 2012–13 to 2015–16 at ICAR-Indian Institute of Wheat and Barley Research, Karnal (Latitude 29^{o} 43' N, longitude 76^{o} 58' E and altitude 245 m above mean sea level). The experimental soil was sandy clay loam in texture (15% clay), low in organic carbon (0.36 %) and available N (143 kg/ha), medium in available P (16.7 kg/ha) and available K (168 kg/ha) content having pH 8.1. Experiment was conducted in split-plot design with 3 main plots, viz. direct seeding in ZT, zero-till transplanted rice in non puddled soil and puddled transplanted rice and 4 subplots in wheat i.e. 0, 75, 150 N kg/ha and leaf colour chart (LCC)-based N application after first top dressing with 3 replications. Recommended 60 kg P_2O_5/ha (in the form of DAP), 40 kg K_2O /ha (through MOP) and 1/3 nitrogen (through urea) was applied at the time of sowing as basal dose, 1/3 N was applied at first node stage i.e. DC 31 (Zadoks *et al.,* 1974) and remaining 1/3 N was applied at late jointing (65 days after sowing, DAS) as per treatments. Rice variety 'Gobind' and wheat variety 'DPW 621–50' was grown. Rice was seeded @ 80 kg/ha under direct seed condition in 1st week of June, whereas transplanting was done with 25 days old seedlings in other two main plots in first week of July. Transplanting under zero-tillage condition was done by irrigating the field 24 hours earlier. Wheat was seeded @ 100 kg/ha, after adjusting the 1,000-grain weight at 38 g, during first week of November in each year of the study. Wheat under zero-tillage condition was sown about 3–4 days earlier than conventional-tillage condition. Irrigations were applied as per need of the crop. Weeds in zero-till rice were controlled with the application of pendimethalin @ 1.0 kg/ha just after seeding, whereas in transplanted rice weeds were controlled with the application of butachlor @ 1.0 kg/ha in 400 liter of water at 3–4 days after rice transplanting. Similarly weeds in wheat were controlled with the application of sulfosulfuron 25 g/ha in 400 liters of water at 35 DAS. All the other recommended package and practices were adopted in rice as well as in wheat. Observations were recorded on yield and its component characters. Cost of cultivation was calculated by taking into account the prevailing price of inputs like fertilizer, seed, herbicides, irrigations, tillage operations, transportation charges, management charges, rental value of land and depreciation cost of implements. Returns were calculated by taking minimum support price of rice and wheat grain and market price of rice and wheat straw on pooled yield basis. Agronomic efficiency (kg grain/kg nitrogen applied) was calculated as per standard procedure. Production efficiency was calculated as wheat equivalent yield in a cropping sequence divided by duration of that cropping sequence (Tomar and Tiwari, 1990). Grain yield from control plot was subtracted from the treated plot and then divided by added nitrogen for calculating agronomic N-use efficiency. Standard statistical methods of analysis were followed for the yield and yield attributing parameters (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Rice

All the parameters of rice under study were significantly influenced by year due to climate variations year to year. Significantly the highest rice grain yield (8.14 t/ha) was recorded in 2014 as compared to 2012, 2013 and 2015. Similarly straw yield was significantly highest in 2013 as compared to other years of study. This grain yield increase was probably due to the highest number of panicles/m^2 and grains/panicle in 2014. On the other hand, the lowest rice grain yield was in 2015 and straw yield was in 2012. Significantly the lowest harvest index (HI) in 2013 was due to the highest straw yield and higher lodging in that year (Table 1).

Combined analysis of 4 years revealed that puddled transplanted rice produced significantly higher grain yield (8.1 t/ha), which was 19.9 and 13.9% higher than yield obtained under zero-till direct-seeded rice and zero-till transplanted rice, respectively. Similar was the case for straw yield, however, direct-seeded rice recorded significantly higher straw yield than zero-till transplanted rice. Significantly lower straw yield was obtained under zero-till transplanted rice as compared to other two methods of rice seedings. Zero-till direct-seeded rice and zero-till transplanted rice exhibited the significantly lowest HI (35.3%) and panicles/m^2 (386), respectively as compared to other methods of rice transplanting (Tables 1). Puddled transplanted rice exhibited significantly higher number of grains/panicle (80.4) than zero-till direct seeded rice. Lowest grains/panicle in zero-till direct-seeded rice resulted in significantly higher 1,000-grain weight (23.8 g) than other two methods of rice transplanting. Higher rice grain yield in conventionally-tilled puddled transplanted rice was owing to the highest panicles/m^2 and grains/panicle than other rice seeding methods (Table 1). There was non-significant effect of different N doses applied in wheat on rice grain and straw yields, HI and yield attributes of rice (Tables 1). Generally researchers advocate the direct-seeded rice over puddled transplanted rice to save water, drudgery for transplanting and manual labour. However, in this case direct seeded rice with no till produced significantly lower yield over puddled transplanted. These findings are in agreement with observations of Tripathi *et al.* (2015), where they mentioned that direct seeded rice in zero-till and bed-planting conditions produced significantly lesser grain and straw yields and yield attributes than puddled transplanted conditions. Similarly Bhattacharya *et al.* (2006) and Kumar *et al.* (2015) reported that direct-seeded rice produced lower yield than puddled transplanted rice. Therefore, direct-seeded rice practices may not perform better than puddled transplanted in all agro ecological conditions and savings, especially in term of irrigation water, depends on rainfall.

Wheat

Wheat grain and straw yield and yield attributing parameters were significantly influenced by year due to climate variations year to year. The highest grain yield (4.45 t/ha) was obtained in 2015–16, which was significantly higher as compared to other years. Maximum straw yield (7.19 t/ha) was exhibited in 2014–15 and HI in 2015–16. In year 2012–13 and 2014–15, number of earheads/m^2 was higher and lower grains/earhead and 1,000-grain weight, whereas reverse trend was observed in 2013-14 and 2015-16 (Table 2).

On pooled analysis, conventionally till wheat exhibited significantly higher grain and straw yields, which was 10.9 and 22.4% higher than zero-till wheat, respectively. Earheads/m^2 and grains/earhead was significantly higher in conventional wheat than zero-till wheat. In contrast, HI and 1,000-grain weight was significantly higher in zero-till wheat than conventional wheat. Higher grain yield in conventional wheat was mainly attributed by higher earheads/

Table 1. Effect of different tillage options on grain yield, straw yield, HI and yield attributes of rice (pooled data of 4 years)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Panicles/m^2	Grains/ panicle	1,000-grain weight (g)
Year						
2012	7.16	9.21	43.8	406	76.4	23.4
2013	7.55	17.14	30.5	415	78.0	23.5
2014	8.14	12.39	39.7	448	79.7	23.0
2015	6.44	11.71	35.4	417	64.9	24.0
SEm±	0.07	0.21	0.32	6.81	1.25	0.08
CD (P=0.05)	0.2	0.59	0.9	19	3.5	0.21
Tillage						
ZT Rice–ZT Wheat	6.76	12.68	35.3	440	64.6	23.8
ZTT Rice–CT Wheat	7.11	11.90	38.2	386	79.3	23.5
CT Rice–CT Wheat	8.10	13.25	38.6	438	80.4	23.2
SEm±	0.09	0.21	0.3	2.3	0.79	0.09
CD (P=0.05)	0.33	0.72	1.2	8.0	2.8	0.34
N (kg/ha) in wheat						
0	7.20	12.47	37.4	419	74.5	23.4
75	7.32	12.72	37.2	421	74.7	23.6
150	7.31	12.63	37.2	427	73.5	23.6
LCC based (125)	7.42	12.63	37.6	419	76.3	23.5
SEm±	0.09	0.23	0.3	7.4	1.41	0.07
CD (P=0.05)	NS	NS	NS	NS	NS	NS

ZT, Zero-tillage; ZTT, zero-tillage transplanted; CT, conventional tillage m^2 and grains/earhead as compared to zero-till wheat (Tables 2). Many authors (Hobbs and Gupta 2003; Tripathi *et al*., 1999) have reported that wheat can be planted on time at reduced cost without sacrificing yield, whereas in this experiment cost saving was there but similar yield was not obtained due to no-till in both crops i.e. rice and wheat.

Nitrogen application has resulted in significant differences in grain and straw yields, HI and yield attributes on pooled basis (Tables 2). Application of 75, 125 and 150 kg N/ha has increased wheat grain yield by 96.8, 140.8 and 143.6% over the control respectively. Similarly, straw yield was also increased by 60.8, 101.2 and 104.7% over the control on same N doses. LCC based N application resulted in at par grain and straw yields, HI, earheads/m^2 and grains/earhead as compared with recommended dose (150 kg N/ha). Though, 1,000-grain weight was significantly higher with LCC based N application (37.57g) as compared to recommended rate of N application (36.71g). There was significant increase in wheat yield by increasing N levels up to 125 kg/ha (LCC based application). LCC is a handy tool which can save 25 kg N/ha to wheat crop with similar yield. Sharma and Behera (2016) also reported that wheat productivity increased up to 120 and 160 kg N/ha application under conventional and zero-tillage, respectively. A predetermined dose of N is applied using LCC, when a critical colour shade is obtained. This have provided an excellent opportunity in terms of developing real-time N management strategy but do not take into account photosynthetic rates or the biomass production and expected yields for working out fertilizer N requirements (Bijay Singh *et al.*, 2011).

Agronomic N-use efficiency

Agronomic N-use efficiency (NUE) in wheat was calculated as per different N doses application on pooled basis. Maximum agronomic N-use efficiency was recorded at 75 kg N/ha (27.81 kg grain/kg N) application followed by 125 (24.26 kg grain/kg N) and 150 Kg N /ha (20.61 kg grain/kg N) application. Increasing N doses has resulted in decreasing the agronomic efficiency in wheat, which is thumb rule (Table 2). In such scenario use of leaf colour chart (LCC) in wheat is a very handy and cost effective technology, which can save 25 kg N/ha over recommended rates of N application. Studies have indicated that a decrease in NUE with increasing fertilizer rates is because grain yield rises less than the N supply in soil by fertilizer application (Lopez-Bellido and Lopez-Bellido, 2001). Nitrogen is one of the most important factors for growth and development of plants and most limiting nutri-

Table 2. Effect of different tillage options on grain yield, straw yield, HI, yield attributes and agronomic N use efficiency of wheat (pooled data over 4 years).

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Ear heads/m^2	Grains/ earhead	1,000-grain weight (g)	Agronomic N-use efficiency (kg grain/kg N)
Year							
2012–13	4.07	6.40	38.5	443	24.8	36.07	–
2013–14	4.16	6.43	38.5	307	32.3	40.92	–
2014–15	4.14	7.19	36.6	423	26.9	36.66	–
2015–16	4.45	6.94	39.0	340	33.6	39.18	–
SEm±	0.05	0.13	0.43	5.91	0.57	0.22	–
CD (P=0.05)	0.13	0.35	1.2	16.5	1.6	0.61	–
Tillage							
ZT Rice–ZT Wheat	3.95	5.88	39.7	371	27.2	38.97	–
ZTT Rice–CT Wheat	4.28	7.14	37.2	377	30.5	37.56	–
CT Rice–CT Wheat	4.39	7.20	37.5	386	30.5	38.07	–
SEm±	0.04	0.11	0.5	1.57	0.37	0.25	–
CD (P=0.05)	0.15	0.42	2.1	5.5	1.3	0.86	–
N (kg/ha) in wheat							
0	2.15	4.04	34.9	322	17.2	39.33	–
75	4.24	6.50	39.7	358	30.8	39.20	27.81
150	5.25	8.28	38.9	423	34.6	36.71	20.61
LCC based (125)	5.19	8.14	39.1	409	34.8	37.57	24.26
SEm ±	0.06	0.18	0.5	8.7	0.51	0.29	–
CD (P=0.05)	0.15	0.44	1.2	22	1.3	0.72	–

ZT, Zero-tillage; ZTT, zero-tillage transplanted; CT, conventional tillage

Table 3. Economics of rice–wheat cropping system, and system productivity under different tillage options.

Treatment	Gross returns (× 10³ ₹/ha)	Cost of cultivation (× 10³ ₹/ha)	Net returns (× 10³ ₹/ha)	Benefit: cost ratio	System productivity (kg/ha/day)
Tillage					
ZT Rice–ZT Wheat	179.1	76.4	102.7	2.35	46.97
ZTT Rice–CT Wheat	194.0	89.9	104.2	2.16	50.90
CT Rice–CT Wheat	209.9	93.6	116.3	2.24	55.05
N (kg/ha) in wheat					
0	150.6	82.5	68.1	1.83	39.50
75	193.9	83.3	110.6	2.33	50.86
150	216.1	84.1	132.0	2.57	56.68
LCC based (125)	216.2	83.8	132.4	2.58	56.71

ZT, Zero-tillage; ZTT, zero-tillage transplanted; CT, conventional tillage

ent in crop production particularly in wheat. Blanket recommendation, most prevailing N management strategy in India could not help in increasing the nutrient-use efficiency beyond a limit (Bijay- Singh, 2008). Moreover, farmers have a tendency to apply N in excess of the requirement of crop to avoid risk of N deficiency. Overall farmers use about 10.5 to 24.5% higher N dose in rice–wheat cropping system of Haryana (Singh *et al.,* 2012; Erenstein *et al.,* 2007), which lower the N recovery efficiency.

Economics of rice–wheat system

Conventional tillage (Puddled transplanted) rice-conventional tillage wheat system exhibited the maximum returns (₹209.9 × 10³/ha), cost of cultivation (₹93.6 × 10³/ha), net returns (₹116.3 × 10³/ha) and system productivity (55.05 kg/ha/day) as compared with other 2 systems of rice–wheat cultivation. Zero-till direct seeded rice–zero-till wheat system recorded the lowest returns (₹179.1 × 10³/ha), cost of cultivation (₹76.4 × 10³/ha) and net returns (₹102.7 × 10³/ha), which were 14.67, 18.38 and 11.69% lower than puddled transplanted rice–conventional wheat cultivation system, respectively. However, benefit: cost ratio was the highest (2.35) in zero-till direct seeded rice-zero till wheat system. In nitrogen application treatments in wheat, the highest gross returns, net returns and benefit: cost ratio as well as system productivity (56.71 kg/ha/day) were found in LCC based N (125 kg/ha) application (Table 3).

Generally direct-seeded rice is advocated by various researchers over puddle-transplanted rice to save irrigation water and drudgery of transplanting. In this situation, direct-seeded zero-till rice recorded significantly lower grain and straw yields than puddled transplanted conditions. This might be one of the reasons that direct-seeded rice is not popular among the farmers of South Asia despite many additional benefits. On the basis of this 4 years study it can be concluded that zero-till direct-seeded rice-zero till wheat system is not profitable, despite saving in cost of cultivation to the tune of 18.37%, as compared to puddle-transplanted rice-conventional tillage wheat system. Use of LCC in wheat is very handy and cost effective technology, which can be practiced by farmers to save 25 kg N/ha (16.67% of recommended N) with similar wheat productivity.

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