RESEARCH PAPER International Journal of Agricultural Sciences, Vol. 7 Issue 1 (January, 2011) : 197-208

Direct-seeding and reduced-tillage options in the rice-wheat system of the Western Indo-Gangetic Plains

R.K.NARESH*, RAJ K. GUPTA[1],ASHOK KUMAR[2],B.SINGH[3], SATYA PRAKASH[4],SATISH KUMAR[5] AND R.C.RATHI[6]

Department of Agronomy, Sardar Vallabhbhi Patel University of Agriculture and Technology, MEERUT (U.P.) INDIA

ABSTRACT

With the introduction of new, improved shorter duration wheat and rice varieties in South Asia in the mid-1960s, double cropping of these two cereals became possible. Rice is grown in the wet, monsoon summer months and wheat follows in the dry, cool winter in one calendar year. More than 13 million ha are grown to rice and wheat in India, Bangladesh, Nepal, and Pakistan. Another 10 million ha are grown in China. This rice-wheat system is one of the most important cropping systems for cereal production and food security in the region. Most of the rice in this system is managed by transplanting rice seedlings into puddled soils. This age-old method of planting is used to reduce water percolation. It also helps control weeds ,but puddling also degrades the soil physical condition with resulting difficulties in establishing and growing succeeding upland crops such as wheat. Much of the research in the region looks at the possibility of establishing rice without puddling. Major perceived hurdles include the inability to economically control weeds and increased water use. However, there are situations when water tables are high or soils are fine-textured where puddling is not needed to slow water infiltration and where dry-seeding technology may work. Less research has been done on evaluating this technology on a systems basis. Experiment looked at the effects of various tillage and crop establishment practices on the productivity of both rice and wheat. Rice yield was not adversely affected by direct seeding without puddling. Direct seeding led to greater weed pressure.Rice yield attributes were altered by direct seeding, indicating a need to optimize plant density and spacing parameters for this practice.Soil bulk density was lowered and infiltration rates increased without puddling. This led to a different water management regime for direct-seeded rice and provided a better soil physical condition for the succeeding wheat crop. Wheat yields were affected by various tillage options whether applied in the rice season or in the wheat season. Wheat yields were significantly higher when rice soils were not puddled and zero tillage performed better as compared to conventional tillage but this may have been because of sufficient moisture for good root development in zero-till plots. The best wheat yield was obtained when soil was deep-tilled and unpuddled for rice and not tilled for wheat i.e. wide raised beds. Although rice yields were lower than wheat yields, differences in the latter were most important for overall system productivity. This paper suggests that direct-seeded rice on unpuddled soils is feasible and that zero-till wheat following unpuddled rice soils is cost-effective, conserves resources, and does not reduce yield.

Naresh, R.K., Gupta, Raj K.,Kumar, Ashok, Singh, B., Prakash, Satya,Kumar, Satish and Rathi, R.C. (2011). Direct-seeding and reduced-tillage options in the rice-wheat system of the Western Indo-Gangetic Plains. *Internat. J. agric. Sci.*, **7**(1): 197-208.

Key words : IGP- Indo-Gangetic Plains, Profitability, Water productivity, Sustainability

INTRODUCTION

"Green Revolution" technology introduced into South Asia in the mid-1960s has been the basis for sustained food security, rural development, conservation of natural resources, and poverty alleviation for the past 30 years. The technical change that resulted in the Green Revolution arose from the introduction of improved varieties, fertilizer, irrigation, and other plant protection chemicals. Investments from the public sector were crucial for making these inputs available to farmers. During the past 30 years, agricultural production has been able to keep pace with population demand for food. This came about through significant area and yield growth. Area growth was a result of new lands being farmed and through increases in cropping intensity, from a single crop to double or even triple crops per calendar year.

Post-Green Revolution or the present-day situation sees area growth slowing and it is expected that this will not play a major role in future production growth. Yield growth will have to be the mainstay for providing the means for meeting future food demand unless food imports start to play a major role in South Asia. Evidence from some long-term experiments, however, shows that problems of stagnating yields and even yield declines are

* **Author for correspondence.**
[1]CIMMYT India office, NASC complex, Pusa, NEW DELHI, INDIA
[2]Department of Soil Science, Sardar Vallabhbhai Patel University of Agriculture and Technology, MEERUT (U. P.) INDIA
[3] Sardar Vallabhbhi Patel University of Agriculture and Technology, Krishi Vigyan Kendra, Baghra, MUZAFFARNAGAR (U.P.) INDIA
[4]Department of Horticulture, Sardar Vallabhbhai Patel University of Agriculture and Technology, MEERUT (U. P.) INDIA
[5]Sardar Vallabhbhai Patel University of Agriculture and Technology, Krishi Vigyan Kendra, NAGINA (U. P.) INDIA
[6]Sardar Vallabhbhai Patel University of Agriculture and Technology, Krishi Vigyan Kendra, SAHARANPUR (U. P.) INDIA

occurring in the rice-wheat system of South Asia (Dawe *et al.*, 2000; Duxbury *et al.*, 2000). Total factor productivity is declining and farmers have to apply more fertilizer to obtain the same yields (Hobbs and Morris, 1996; Murgai *et al.*, 2001). Soil organic matter is also declining, new weeds, pests, and diseases are creating more problems, and irrigation water is less available. Farmers are complaining about high input costs and low prices for their produce. Marketing of excess production is a burden for farmers and storage is a problem for governments. Therefore, a huge challenge exists in the region to meet future food demand sustainably without damaging the natural resource base on which agriculture depends, producing food at a cost that is affordable by the poor and with incentives to farmers that allow them to improve their livelihoods and ultimately alleviate poverty.

In the IGP, as well as in many other parts of Asia, water is increasingly becoming scarce. Per capita availability of water has declined in many Asian countries by 40 to 60% between 1955 and 1990 (Gleik, 1993). Agriculture's share of freshwater supplies is likely to decline by 8 to 10% because of increasing competition from the urban and industrial sectors (Seckler *et al.*, 1998; Toung and Bhuiyan, 1994). Poor-quality irrigation systems and greater reliance on groundwater have led to water table decline of 0.1 to 1.0 m yr21 in parts of the IGP, resulting in a scarcity and higher cost of pumping water (Gill, 1994; Harrington *et al.*, 1993; Sharma *et al.*, 1994; Sondhi *et al.*, 1994).The growing labor and water shortages are likely to adversely affect the productivity of the rice–wheat system (Ladha *et al.*, 2003). One way to reduce water demand is to grow direct-seeded rice instead of the conventional puddled transplanted rice (Bhuiyan *et al.*, 1995). Dry seeding of rice with subsequent aerobic soil conditions avoids water application for puddling and maintenance of submerged soil conditions, and thus reduces the overall water demand (Bouman, 2001; Sharma *et al.*, 2002). Another way to save water is to grow rice in raised beds, Borrel *et al.* (1997) observed that the raised-bed system saved 16 to 43% water compared with puddled transplanted rice, though at the expense of yield. Similarly, a yield reduction of 15% was reported when rice was grown on raised beds *vis-a' -vis* the puddle transplanted system (Sharma *et al.*, 2003; Vories *et al.*, 2002). Intermittent irrigation and mid-season drying of soil instead of continuous submergence as used in the conventional puddled-transplanted system could be another option for saving water.

Compared with rice, wheat has a much lower water demand. Rice consumes about 80%of the total water applied in the rice–wheat system. Therefore, much water could be saved if tillage and crop establishment practices of wheat were adopted in rice. However, the extension of tillage and crop establishment practices followed in wheat to rice without a yield penalty has always been a major challenge for researchers. Minimum tillage or no tillage is becoming an increasingly accepted management technology in parts of the IGP (Hobbs and Gupta, 2002; Singh and Ladha, 2004). Tillage operations performed and establishment methods followed for growing rice should complement those practiced for growing wheat and vice versa. It is the overall system productivity that should be considered while judging the suitability of a practice, and not just the individual crop productivity. Although it is often claimed that reduced tillage operations with alternative crop establishment methods such as direct seeding on flat land and raised beds can result in significant water savings (Gupta *et al.*,2003), systematic studies evaluating the effects of these practices on yield, soil fertility, and water requirement of the rice–wheat system are lacking. This paper describes various tillage and crop establishment options to attain the goal of raising productivity in the region and meeting food security needs while at the same time efficiently using natural resources, including water, providing environmental benefits and improving the rural livelihoods of farmers.

MATERIALS AND METHODS

Two set of experiments on different tillage and crop establishment techniques involving permanent beds were conducted under researcher managed trials at the research farm ($29^0 01'$ N, $77^0 45'$ E, and 237 m above mean sea level) of Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut(Uttar Pradesh), India, and farmer managed trials in Ghaziabad district of Uttar Pradesh in western Gangetic Plain during 2008-09 and 2009-10. The water table depth of the experimental sites is 23 m with very good quality of water. The climate of the area is semiarid, with an average annual rainfall of 805 mm (75–80% of which is received during July to September), minimum temperature of 0 to 4^0C in January, maximum temperature of 41 to 45^0C in June, and relative humidity of 67 to 83% throughout the year. The experimental soil (0–15 cm) was silty loam in texture, with a bulk density of 1.48 Mg m^{-3}, weighted mean diameter of soil aggregates 0.74 mm, pH 7.9, total C 8.4 g kg^{-1}, total N 0.82 g kg^{-1}, Olsen P 28 mg kg^{-1}, and K 127 mg kg^{-1}.

Experiment-I :

The permanent beds and double no till systems in rice-wheat rotation used. A randomized block design (RBD) with three replications was used in the study. A combination of eight tillage and crop establishment techniques. Puddled transplanted rice (TPR) - zero till wheat planted by turbo happy seeder(ZTW), zero tillage direct seeded rice(ZTDSR)-zero till wheat (ZTW), conventional tillage direct seeded rice (CTDSR)-reduced till wheat (RTW), direct seeded rice on narrow raised beds (N Bed DSR)- zero till wheat on permanent narrow raised beds(ZTW NBed), transplanted rice on narrow raised beds(NBedTR)- zero till wheat on permanent narrow raised beds(ZTW NBed), direct seeded rice on wide raised beds (WBed DSR)- zero till wheat on permanent wide raised beds (ZTWWBed), transplanted rice on wide raised beds(WBedTR)-zero till wheat on permanent wide raised beds (ZTWWBed), Conventional puddled transplanted rice (TPR)-conventional tillage wheat(CTW) in RW system was used along with sesbania co-culture (+S) in rice and rice residues (+R) in wheat]. The details of the treatments is as follows-

Transplanted rice after conventional puddling and zero till wheat planted by turbo happy seeder (TPR-ZTW):

Rice (TPR): Conventional puddling (2 dry-harrowing, 3 passes of cultivator followed by 2 wet-tillage and 1 planking) was performed followed by manual transplanting of 21 days seedling at 20 x 20 cm spacing. The plots were kept flooded (5±2 cm submergence) for initial 2 weeks to establish the seedling, and the subsequent irrigations (5±2 cm) were applied at the appearance of hair-line cracks on soil surface.

Wheat (ZTW): Wheat crop was sown in rows 20 cm apart using turbo happy seeder without any preparatory tillage. Five irrigations(5±2 cm) were applied on tensiometer reading (70 milli bar) depending on the winter rainfall at critical stages.

Zero till direct seeded rice and zero-tillage wheat (ZTDSR-ZTW):

Rice (ZTDSR) Rice was direct-seeded in flat plots at 20-cm row spacing using a zero till cum ferti -seed drill with enclined type seed metering devices planter(Fig.1c). The seeding was done on the same day when the nursery sowing for transplanted rice. The irrigation was applied just after seeding, and the plots were irrigated daily for 2 week after germination to maintain saturation. Subsequent irrigations (5 cm) were applied at the appearance of hairline cracks at the soil surface.

Wheat (ZTW): Wheat crop was sown in rows 20 cm apart using zero till cum ferti- seed drill with enclined plate metering system without any preparatory tillage. Five irrigations ((5±2 cm) were applied on tensiometer reading (70 milli bar) depending on the winter rainfall at critical stages.

Direct seeded rice after conventional tillage and reduced-tillage wheat (CTDSR-RTW):

Rice (CTDSR): Tillage operations in rice were restricted to dry tillage (2 dry-harrowing followed 2 cultivator and 1 planking) and rice seeding was done in dry soil in rows 20 cm apart on the same day of nursery sowing for transplanted rice using zero till cum ferti- seed drill with cup type seed metering devices planter(Fig.1c). The irrigation was applied just after sowing following second irrigation 3 days after first irrigation and the subsequent irrigations (5 cm) were applied at the appearance of hairline cracks at the soil surface.

Wheat (RTW): After rice harvest for wheat crop soil was tilled by one harrowing followed by one field leveling with a wooden plank and crop was sown in rows 20 cm apart using zero till cum ferti- seed drill with cup type seed metering devices planter. Five irrigations (5±2 m) were applied on tensiometer reading (70 milli bar) depending on the winter rainfall at critical stages.

Direct Seeded rice on narrow raised beds and wheat on permanent narrow raised beds (NBedDSR-ZTW NBed):

Rice(NBedDSR): At the beginning of the experiment soil was tilled by three harrowings and three plowings followed by one field leveling with a wooden plank, and raised beds were made using a tractor-drawn multi crop zero till cum raised bed planter with enclined plate seed metering devices.

The dimension of the narrow beds were 37 cm wide (top of the bed) x 15 cm height x 30 cm furrow width (at

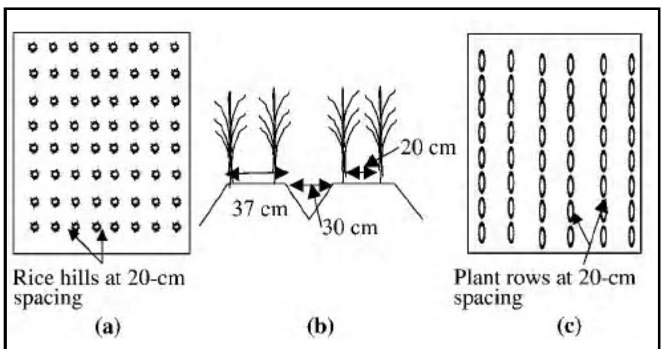

Fig. 1 : Method of rice establishment in (a) transplanted on flat bed in puddled and no tillage conditions. (b) narrow raised bed system and (c) till /no till direct seeded conditions

top) and the spacing from centre of the furrow to another centre of the furrow was kept at 67 cm(Fig.1b). Two rows of rice were direct-seeded on each raised bed at 20-cm row-to-row spacing. The raised beds were seeded using a bed planter, which placed seeds and fertilizer simultaneously. The first irrigation was applied at 1 day after seeding (DAS), followed by daily irrigations for 2 week after germination to maintain soil saturation. The irrigations were applied to completely fill the furrows. Subsequent irrigations (completely filling the furrows) were given at the appearance of hair-line cracks at the soil surface and at the bottom of the furrow.

Wheat (ZTWNBed): After rice,two rows of wheat were seeded directly after reshaping the beds using a multi crop zero till cum raised bed planter with enclined plate seed metering devices. Five irrigations ((5±2 cm) were applied on tensiometer reading (70 milli bar) depending on the winter rainfall at critical stages.

Transplanted rice on narrow raised beds and wheat on permanent narrow raised beds(NBedTR-ZTW NBed):

Rice(NBedTR): At the beginning of the experiment soil was tilled by three harrowings and three plowings followed by one field leveling with a wooden plank, and raised beds were made using a tractor-drawn multi crop zero till cum raised bed planter with enclined plate seed metering devices . The dimension of the narrow beds were 37 cm wide (top of the bed) x 15 cm height x 30 cm furrow width (at top) and the spacing from centre of the furrow to another centre of the furrow was kept at 67 cm (Fig.1b). Transplanting of one 21-day old seedling per hill in two rows at 20 cm spacing on the narrow raised beds. Plant-to-plant spacing was 12 cm to maintain the population equal to that of the conventional transplanted method. The plots were kept flooded for 2 week after seeding and subsequent irrigations were applied to completely fill the furrows at the appearance of hair-line cracks at the soil surface at the bottom of the furrow.

Wheat (ZTWNBed): After rice, two rows of wheat were seeded directly after reshaping the beds using a multi crop zero till cum raised bed planter with enclined plate seed metering devices without mulch. Five irrigations ((5±2 cm) were applied on tensiometer reading (70 milli bar) depending on the winter rainfall at critical stages.

Direct Seeded rice on wide raised beds and wheat on permanent wide raised beds (WBedDSR-ZTW WBed):

Rice(WBedDSR): At the beginning of the experiment soil was tilled by three harrowings and three plowings followed by one field leveling with a wooden plank, and raised beds were made using a tractor-drawn multi crop zero till cum raised bed planter with enclined plate seed metering devices. The dimension of the wide beds were 120 cm wide (top of the bed) x 12 cm height x 30 cm furrow width (at top) and the spacing from centre of the furrow to another centre of the furrow was kept at 150 cm (Fig. 2). Six rows of rice were direct-seeded on each raised bed at 20 cm row-to-row spacing.

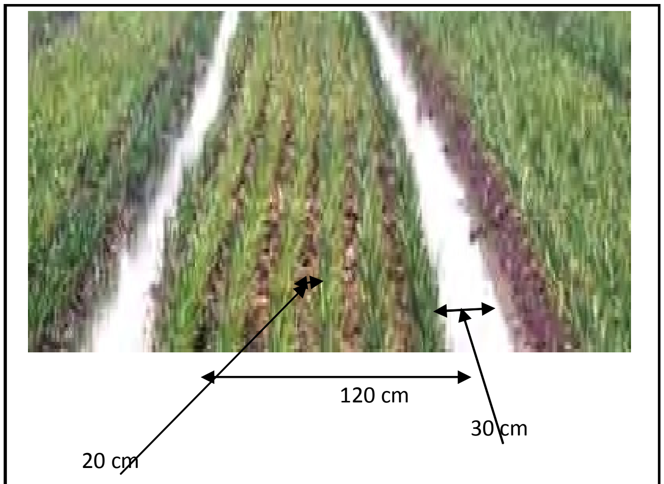

Fig. 2 : Method of rice establishment through wide raised bed system

The raised beds were seeded using a bed planter, which placed seeds and fertilizer simultaneously. The first irrigation was applied at 1 day after seeding(DAS), followed by daily irrigations for 2 week after germination to maintain soil saturation. The irrigations were applied to completely fill the furrows. Subsequent irrigations (completely filling the furrows) were given at the appearance of hair-line cracks at the soil surface and at the bottom of the furrow.

Wheat (ZTW W Bed): After rice, six rows of wheat were seeded directly after reshaping the beds using a multi crop zero till cum raised bed planter with enclined plate seed metering devices. Five irrigations (5±2 cm) were applied on tensiometer reading (70 milli bar) depending on the winter rainfall at critical stages.

Transplanted rice on wide raised beds and wheat on permanent wide raised beds (WBedTR-ZTW WBed):

Rice(WBedTR): At the beginning of the experiment soil was tilled by three harrowings and three plowings followed by one field leveling with a wooden plank, and raised beds were made using a tractor-drawn multi crop zero till cum raised bed planter with enclined plate seed metering devices . The dimension of the wide beds were 120 cm wide (top of the bed) x 12 cm height x 30 cm furrow width (at top) and the spacing from centre of the furrow to another centre of the furrow was kept at 150 cm (Fig. 2). Transplanting of 21 day old seedling per hill was done in six rows at 20 cm spacing on the wide raised beds. Plant-to-plant spacing was 12 cm to maintain the population equal to that of the conventional transplanted method. The plots were kept flooded for 2 week after seeding and subsequent irrigations were applied to completely fill the furrows at the appearance of hair-line cracks at the soil surface at the bottom of the furrow.

Wheat (ZTWWBed): After rice, six rows of wheat were seeded directly after reshaping the beds using a multi crop zero till cum raised bed planter with enclined plate seed metering devices. Five irrigations (5±2 cm) were applied on tensiometer reading (70 milli bar) depending on the winter rainfall at critical stages.

Conventional puddled transplanted rice and conventional tillage wheat (TPR- CTW):

Rice(TPR): Conventional puddling involving 2 dry-harrowings,2 passes of cultivator followed by2 wet-tillage operations and one field leveling with a wooden plank was done after that water was imponded, followed by manual transplanting of 21 day old seedlings at 20 by 20cm spacing (Fig.1a). The plots were kept flooded (5-cm submergence) for an initial 2 week, and in subsequent irrigations, which were applied at the appearance of hair-line cracks at the soil surface, the field was flooded up to the point where 5 cm water was standing. Farmers in the study area commonly use the appearance of hairline cracks at the soil surface as an indicator to initiate irrigation. In the soil used in present study, the hair-line cracks appear at field capacity moisture regime.

Wheat (CTW): Tillage operations in wheat were restricted to dry tillage (2 dry-harrowing followed 3 cultivator and planking) and wheat sowing was done in rows 20 cm apart using zero till cum ferti- seed drill with enclined type seed metering devices. wheat was irrigated at the crown root initiation, tillering, jointing, and dough growth stages. Each field was flooded up to the point where 5 cm water was standing in the field.

Management of sesbania:

In direct seeded rice, Sesbania @ 15 kg ha^{-1} was broadcasted on the same day of rice seeding and was managed with rice without any additional inputs (fertilizer, water). After 30 days of seeding, the sesbania was knock down with 2,4-D ester @ 400 g a.i. ha^{-1}. In transplanted rice, sesbania was grown *ex-situ* on the same day of direct seeding and was applied in the transplanted rice on the day when it was knock down under DSR plots.

Crop residue management:

The rice residue was managed at 6.0 t ha^{-1} (partially anchored and partially loose).

Seeding and seed rate:

Pusa Sugandha- 4 (1121) rice variety was seeded on 1st and 3rd June in direct-seeded plots, where as transplanting was done on 22nd and 24thJune in 2008 and 2009, respectively. Rice was seeded in flat beds as well as in raised beds after seed priming (soaking seeds in water for 12 hr's followed by air drying). A seed rate of 25 kg and 20 kg ha^{-1} was used for direct-seeded rice on flat and raised beds, respectively. 'PBW 343' wheat was seeded on 7th and 9th Nov. 2008 and 2009, respectively. A seed rate of 80 kg ha^{-1} was used in treatments where wheat was seeded on beds, and 100 kg ha^{-1} was used in the rest of the treatments. The multi crop zero till cum raised bed planter with enclined plate seed metering device machine was calibrated every time before seeding to adjust the seeding rate.

Fertilizer application:

For rice, 120 kg N, 60 kg P_2O_5, 40 kg K_2O, and 20 kg $ZnSO_4$ ha^{-1} and for wheat 150 kg N, 60P_2O_5, 40 kg K_2O ha^{-1} was applied. Half dose of N and full doses of P, K, Zn were applied as basal and remaining N was applied in two equal splits in rice and in wheat, 80 per cent N was applied as basal and remaining N was applied at full bloom stage.

Weed management:

The crop was maintained weed free using following practices-

Rice:

Weeds that germinate prior to seeding of rice and wheat in zero till plots were killed by spraying glyphosate @ 900 g a.i. ha^{-1}. The plots were then kept weed-free throughout the growing season. Butachlor @ 1300 g a.i. ha^{-1} at 2 days after transplanting (DAT) in case of transplanted rice followed by a spray application of bispyribac sodium(Nomne gold) @ 25 g a.i. ha^{-1} at 25-30 DAT for narrow and broad leaf weeds, and pendimethalin @ 1000 g a.i. ha^{-1} at 2 DAS in direct seeded rice were applied for controlling grassy weeds followed by a spray application of bispyribac sodium(Nomne gold) @ 25 g a.i. ha^{-1} at 25-30 DAS for narrow and broad leaf weeds.

Additionally, 1 hand-weeding in transplanted rice and 2 hand- weeding in direct seeded rice were done to keep the plots weed-free.

Wheat:

grassy weeds were controlled by spraying of sulfosulfuron @ 35 g a.i. ha^{-1} at 30-45 DAS, and broad leaf weeds using 2,4-D @ 500 g a.i. ha^{-1} at 35 DAS.

Harvesting:

At maturity, rice and wheat were harvested and the grain and straw yields were determined from an area of 71.4 m^2 in flat beds and 75.04m^2 in raised beds located in the center of each plot out of 120 m^2 gross plot area. The grains were threshed using a plot thresher, dried in a batch grain dryer, and weighed. Grain moisture was determined immediately after weighing. Grain yields of rice and wheat were reported at 14 and 12 per cent moisture content, respectively. Straw weight was determined after oven-drying at 70^{0}C to constant weight and expressed on an oven dry-weight basis.

Economic analysis:

The cost of cultivation was calculated by taking into account costs of seed, fertilizers, biocide, and the hiring charges of labour and machines for land preparation, irrigation, fertilizer application, plant protection, harvesting, and threshing, and the time required per hectare to complete an individual field operation. Cost of irrigation was calculated by multiplying time (h) required to irrigate a particular plot, consumption of diesel by the pump (1 h^{-1}) and cost of diesel. The prices of human and machine labour, and diesel are their current prices in north India collected by market survey. Gross income was the minimum support price offered by the Government of India for rice and wheat.Net income was calculated as the difference between gross income and total cost. System productivity was calculated by adding the grain yield of rice and wheat.

Experiment-II:

The farmers' participatory trials on tillage and crop establishment techniques were carried out at five locations (one farmer at each location) in Ghaziabad and Saharanpur district for two years. Five tillage and crop establishment techniques [1. puddled transplanted rice (TPR) –conventional till wheat (CTW), 2. zero-till direct seeded rice (ZTDSR)-zero till wheat,(ZTW) 3. conventional till direct seeded rice (CTDSR)- reduced till wheat (RTW) using rotary till drill, 4. direct seeded rice on permanent narrow raised beds (NBed DSR)-wheat on permanent raised beds(NBed ZTW),5. direct seeded rice on permanent wide raised beds (WBed DSR)-wheat on permanent raised beds(WBed ZTW)] in RW system was used. The permanent beds were reshaped during each season with minimum tillage (zero harrowing). The seed rate for rice and wheat was kept at 25 and 100 kg ha^{-1}. Rice variety Pusa Sugandha-4 and wheat variety PBW-343 were used for the trial purpose. Multi crop raised bed planter and zero till cum ferti- seed drill with enclined type seed metering devices were used for seeding. The soil samples were taken at 0-15 cm soil layer from top of the beds in permanent beds and within the row in flats. The details of the soil physical properties measured are as follows:

Bulk density:

The bulk density was determined with the core sampler at the 5 cm intervals up to 20 cm soil depth. The samples were collected and oven dried at 105^{0}C for 24 hrs and bulk density was determined on the basis of oven dried soil.

Soil aggregation:

The large clods were collected from the each plot after harvest of the crop and oven dried. Large clods were broken to small pieces ranged >4.75 to >8mm size. Water stable soil aggregates were determined by using the wet sieve procedure (Ejik make method).

Infiltration rate:

Infiltration rate was measured using double ring infiltrometers in each plot after harvest of the crop. The initial infiltration rate was measured after 5, 15, 30, 60 minutes interval and steady state infiltration was measured after 24 hrs.

Soil resistance:

Soil resistance was measured almost near to field capacity with the help of manual cone Penetrometer by using the 2 cm^2 cone. Soil resistance readings were recorded at the interval of every 5 cm up to 45 cm soil depth and in a replication of three in each plot after harvest of the crop.

RESULTS AND DISCUSSION

The findings of the present study as well as relevant discussion have been summarized under following heads:

Experiment-I:

Rice, wheat and system productivity:

Rice:

The various tillage and crop establishment methods had a significant effect on rice yield. Yields were similar when rice was conventionally transplanted(TPR), zero till direct seeded rice(ZTDSR),conventional till direct seeded rice (CTDSR), and transplanted on wide raised beds(WbedTR+S) (Table 1). This indicated that puddling of soil, for which normally a large amount of water and labour are required, can be avoided without any yield penalty in rice. Irrespective of the tillage and crop establishment techniques, the rice + sesbania co-culture did not produce significant yield variation.Treatments ZTDSR and WBedDSR were at par with each other, however,they recorded higher grain yield over CTDSR treatment which recorded lower grain yield(4.45 t ha^{-1}). Rice either direct drill-seeded or transplanted on narrow raised beds yielded 5 to 27% lower than conventional puddled transplanting. Partitioning of treatments using linear contrast showed that conventional tillage treatments gave higher rice yields than the raised bed and no tillage treatments, whereas no tillage treatments gave higher yields than the narrow raised bed treatments regardless of seeding method (Table 1). Transplanted rice on beds apparently suffered from more water stress compared with flat land, resulting in lower yields.

Wheat:

The wheat yield under all tillage and crop establishment techniques, , there was significant yield advantage with surface residue retention compared to removal but the maximum yield was recorded with double no-till practices (Zero till and permanent beds). The crop residues retained as surface mulch (partially anchored and partially loose) @ 6.0 Mg ha^{-1} that helped in regulating the soil temperature and moisture and more response was mainly due the aberration in weather conditions during the crop growth period (winter 2007-08 was abnormal in terms of weather). Green and Lafond (1999) reported the heat advantage of tillage and residue management and highlighted that surface residues with no-till system helped in regulating the soil temperature and they noticed that the soil temperature (5 cm soil depth) with residue removal and conventional till was 0.29^{0}C lower during the winter than that of no-till and surface retained residues whereas the soil temperature during summer was 0.89^0 C higher under conventional till than no-till surface retained residue situation.

Rice- wheat system:

The analysis of system productivity revealed that significant treatment effects on rice+wheat(system) yields were observed (Table 1). The yields of the rice–wheat system were similar in the puddled and nonpuddled systems, but were lower in residue removal treatments. Moreover,residue retained treatments gave higher system yields under both no-tillage and raised bed treatments.The rice plus wheat yields in conventional systems residue removal plots was lower by 12 % in compared with the conventional systems residue retained plots . Partitioning of treatments by linear contrast showed that system yields under no-tillage were higher than those in narrow raised beds but at par with wide raised beds regardless of

Table 1: Productivity of RW under various tillage and crop establishment techniques

Crop establishment		Grain yield (tonnes ha^{-1})		
Rice	Wheat	Rice	Wheat	RW System
TPR+S	ZTW+R	5.72	5.35	11.07
TPR	ZTW	5.78	5.05	10.83
ZTDSR+S	ZTW+R	4.76	5.85	10.61
ZTDSR	ZTW	4.60	5.20	9.80
CTDSR+S	RTW+R	4.45	5.60	10.05
CTDSR	RTW	4.60	5.25	9.85
NBedDSR+S	ZTW+R	4.15	5.30	9.45
NBedDSR	ZTW	4.20	5.05	9.25
NBedTR+S	ZTW+R	4.35	5.35	9.70
NBedTR	ZTW	4.45	5.03	9.48
WBedDSR+S	ZTW+R	4.70	5.70	10.40
WBedDSR	ZTW	4.25	5.55	9.80
WBedTR+S	ZTW+R	5.65	5.80	11.45
WBedTR	ZTW	5.40	5.35	10.75
TPR	CTW	5.70	4.05	9.75
C.D. (P=0.05)		1.53	1.26	1.15

seeding method.The data indicated that there is still a need to improve the seed bed-planting systems to increase productivity.

Profitability:

The net income rice was higher with ZTDSR+R followed by CTDSR+R and TPR+R and the lowest being recorded with narrow raised beds (Table 2). The lower net income with the beds was due to the cost on preparing the beds in first season. Profitability of wheat was remarkably higher with double no-till practices (ZTDS-ZTW and permanent beds) due to higher productivity and less cost of production compared to conventional tillage practices. Further, the profitability of wheat was remarkably higher with residue retention compared to residue removal and the difference was more under ZTDSR-ZTW compared to other practices. The maximum net income of the system was recorded with ZTDSR-ZTW followed by WBedsTR-ZTW and CTDSR-ZTW and the lowest being with conventional puddled transplanted rice and conventional wheat system (TPR-CTW).

Water application and water productivity:

The input water application includes the irrigation water applied and the rainwater during the rice season (634mm) and wheat season (71 mm). The total water application in rice varied markedly due to tillage and crop establishment techniques (Table 3). The conventional puddled transplanted rice consumed more water 16 % (305050mm ha^{-1}) compared to conventional till direct seeded rice plots (2760 mm ha^{-1} with CTDSR and 2563 mm ha^{-1} with ZT DSR). The savings in water use with beds residue retaine plots and residue removal plots were 33.9% and 20.8%, respectively as compared to conventional puddled transplanted rice. Similarly, the water application in wheat was remarkably lower with permanent beds compared to other practices. Approximately eight times more water was applied to the rice crop than the wheat crop in this study.The higher irrigation water application in wheat under residue removal treatments as compared to residue retain plots. The total system water use was remarkably lower with permanent beds compared to other practices but the maximum water use was recorded with TPR-CTW. The system irrigation water productivity under permanent beds was higher compared to other tillage and crop establishment techniques and lowest system water productivity was recorded with conventional puddled transplanted rice and conventional wheat system (TPR-CTW).

TPR-puddle transplanted rice, ZTDSR-zero till direct seeded rice, CTDSR-conventional till direct seeded rice,WBed DSR-Direct seeded rice on wide raised beds,WBedTR-transplanted rice on wide raised beds, +S-with sesbania co-culture, ZTW-zero till wheat,WBed-wide raised bed planted wheat, CTW-conventional till wheat, +R-with rice residue

TPR-puddle transplanted rice, ZTDSR-zero till direct seeded rice, CTDSR-conventional till direct seeded rice, WBed DSR-direct seeded rice on wide raised beds, WBedTR-transplanted rice on wide raised beds, +S-with sesbania co-culture, ZTW-zero till wheat,WBed- wide raised bed planted wheat, CTW-conventional till wheat, +R-with rice residue

Table 2: Profitability of RW system under various tillage and crop establishment methods

Crop establishment		Net returns (Rs ha^{-1})			B:C ratio		
Rice	Wheat	Rice	Wheat	System	Rice	Wheat	System
TPR+S	ZTW+R	21700	29500	51200	1.81	2.88	2.30
TPR	ZTW	20250	28200	48450	1.64	2.65	2.11
ZTDSR+S	ZTW+R	23900	32700	56600	2.17	3.11	2.63
ZTDSR	ZTW	21200	29050	50250	1.86	2.69	2.26
CTDSR+S	RTW+R	20850	29750	50600	1.84	2.86	2.36
CTDSRR	RTW	20150	28750	48900	1.77	2.65	2.16
NBedDSR+S	ZTW+R	19650	29600	49250	2.10	2.86	2.47
NBedDSR	ZTW	19050	28200	47250	1.86	2.66	2.27
NBedTR+S	ZTW+R	20200	29900	50100	2.03	2.86	2.46
NBedTR	ZTW	19900	28200	48100	1.90	2.59	2.25
WBedDSR+S	ZTW+R	20600	31850	52450	2.26	3.03	2.68
WBedDSR	ZTW	20400	31000	51400	2.14	2.88	2.53
WBedTR+S	ZTW+R	20800	32400	53200	2.17	3.06	2.63
WBedTR	ZTW	20500	29000	49500	1.86	2.58	2.22
TPR	CTW	21050	22600	43650	1.71	1.97	1.83

Table 3 : Water application and water productivity in rice and wheat with various tillage and crop establishment techniques

Crop establishment		Irrigation water applied(mm ha^{-1})			Water productivity (kg grain m^{-3})		
Rice	Wheat	Rice	Wheat	System	Rice	Wheat	System
TPR+S	ZTW+R	2890	395	3295	0.20	1.35	0.34
TPR	ZTW	3050	420	3470	0.19	1.20	0.31
ZTDSR+S	ZTW+R	2563	325	2888	0.19	1.80	0.37
ZTDSR	ZTW	2693	385	3078	0.17	1.35	0.32
CTDSR+S	RTW+R	2710	385	3095	0.16	1.45	0.32
CTDSRR	RTW	2750	425	3175	0.17	1.24	0.31
NBedDSR+S	ZTW+R	2340	305	2645	0.18	1.74	0.36
NBedDSR	ZTW	2370	315	2685	0.18	1.60	0.34
NBedTR+S	ZTW+R	2390	310	2700	0.18	1.71	0.36
NBedTR	ZTW	2415	320	2735	0.19	1.57	0.35
WBedDSR+S	ZTW+R	2015	285	2300	0.23	2.00	0.45
WBedDSR	ZTW	2085	303	2380	0.20	1.83	0.41
WBedTR+S	ZTW+R	2145	297	2442	0.26	1.95	0.47
WBedTR	ZTW	2195	312	2507	0.25	1.71	0.43
TPR	CTW	3050	455	3505	0.18	0.89	0.28

TPR-puddle transplanted rice, ZTDSR-zero till direct seeded rice, CTDSR-conventional till direct seeded rice,WBed DSR-direct seeded rice on wide raised beds,WBedTR-transplanted rice on wide raised beds, +S-with sesbania co-culture, ZTW-zero till wheat,WBed-wide raised bed planted wheat, CTW-conventional till wheat, +R-with rice residue

Experiment-II:

Crop yields:

The data on yield of the three crop cycle (Table 4) revealed that the rice yield was significantly higher with TPR compared to other tillage and crop establishment techniques.Contrarily the wheat productivity was significantly lower with CTW following RTW compared to zero till and permanent beds. The system productivity under WBedDSR-ZTE and ZTDSR -ZTW was higher than TPR- CTW.The difference in system productivity was due to rice productivity.

Input use and saving:

The input use with different tillage and crop establishment techniques compared to traditional system of RW (puddle transplanted rice-conventional till wheat) showed (Fig. 3) perceptible advantages in savings on time, labour, diesel, cost, energy and water. In permanent beds, the savings in time, labour, diesel, cost, energy and water compared to TPR-CTW was 80, 77, 83, 81,79 and 34 %, respectively.

Soil physical properties:

The soil physical properties (bulk density,MWD,

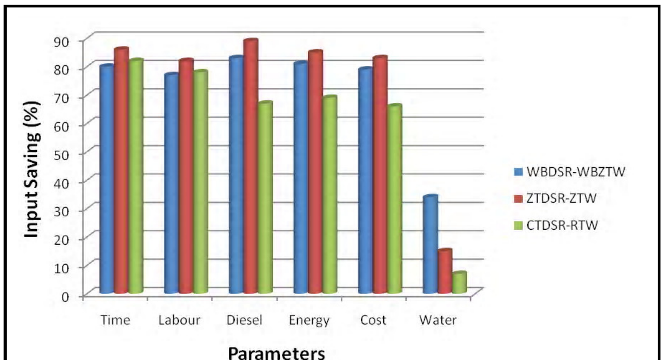

Fig. 3 : Per cent saving of input use over conventional practices

Table 4 : Productivity and profitability of RW under permanent bed planting in farmer managed plots (Average of 02 years)

Crop establishment		Yield (tonnes ha^{-1})			Net profit (Rs ha^{-1})		
Rice	Wheat	Rice	Wheat	System	Rice	Wheat	System
TPR	ZTW	5.76	5.35	11.11	21700	29900	51600
ZTDSR	ZTW	4.85	5.65	10.50	24250	31150	55400
CTDSR	RTW	4.45	5.60	10.05	23950	30450	54400
WBed DSR	WBedZTW	4.70	5.90	10.60	21100	34400	55500
TPR	CTW	5.76	4.35	10.11	21700	24300	46000
C.D. (P=0.05)		0.47	0.96	0.49			

Table 5: Physical properties in different permanent tillage techniques after 2 years

Treatments	Bulk density (Mg m^{-3})	MWD (mm)	Infiltration rate (mm hr^{-1})	Cone index
TPR – ZTW	1.62	0.39	36.4	2.78
ZTDSR – ZTW	1.53	0.48	54.2	2.49
CTDSR – RTW	1.59	0.41	57.3	2.53
WBedDSR – WBedZTW	1.55	0.54	84.7	2.57
TPR – CTW	1.64	0.29	32.4	2.82
Initial	1.52	0.37	-	2.29
C.D. (P=0.05)	0.08	0.87	9.62	0.17

infiltration rate, cone index) in surface (0-15 cm) layer analyzed after 2 crop cycles showed remarkable changes due to tillage and crop establishment techniques(Table 5). The mean weight diameter of aggregates (MWD) improved significantly with double no-till systems from initial value of 0.37 to 0.48 in double zero till (flat bed),0.41 in conventional till direct seeded rice- reduced till wheat and 0.59 in permanent beds, where as it declined to 0.29 in conventional practice (TPR-CTW). Similarly, maximum infiltration rate was recorded with permanent beds followed by CTDSR-RTW, ZTDSR-ZTW and the lowest being with TPR-CTW (Table 5). The bulk density of surface layer under double no-till system did not change over initial values but under conventional till practices, it increased significantly. The cone index was increased significantly under all the tillage and crop establishment techniques but the extent of increase was more under conventional tillage systems. With the passage of time the differences between soil physical parameters get narrowed because height of bed gets reduced and become compacted. As a result of better physical environment (loose soil) under bed planting, higher root length density in upper 0-50 cm soil layer was observed than that of CT system, which was reflected in yield improvement. The adoption of permanent beds will lead to controlled traffic thereby providing a healthy root environment. Fine tilth and better aeration causing less penetration resistance are responsible for better root development thereby producing higher yield attributes. Higher yield recorded in ridge planting can be attributed to better soil environment in ridges since prolonged ponding reduces yield (Tisdall and Hodgson,1990).

TPR-puddle transplanted rice, ZTDSR-zero till direct seeded rice,CTDSR-conventional till direct seeded rice, WBed DSR-direct seeded rice on wide raised beds, ZTW-zero till wheat, RTW-reduced till wheat, WBedZTW-wide beds zero till wheat.

TPR-puddle transplanted rice, ZTDSR-zero till direct seeded rice,CTDSR-conventional till direct seeded rice,WBed DSR-direct seeded rice on wide raised beds, ZTW-zero till wheat, RTW-reduced till wheat, WBedZTW-wide beds zero till wheat,CTW-conventional till wheat.

Conclusion:

The mission of Sardar Vallabhbhai Patel University Meerut, U. P.India is to create technologies that will increase food security improve the productivity and profitability of farming systems and sustain natural resources.Reduced tillage systems offer advantages over conventional tillage through reduction in costs and by conserving soil and water.Conventional practices of puddled transplanting in rice and extensive tillage in wheat require a large amount of water and labour. The emerging shortages and increasing costs of water and labour will, therefore, force a change in the way farmers grow these crops.An extented turnaround time between rice and wheat delays wheat planting that can result in yield losses. In addition, many farmers tend to transplant rice during the hot, high water evaporative demand months of May and June. Reduced -tillage can allow timely seeding of wheat immediately after rice harvest. This would also enable farmers to delay rice seeding until end of June when the monsoon season starts, thereby reducing the irrigation application in rice planting. But there is grower apprehension that planting of rice in May will result in more yield compared to planting in July. Therefore, delaying rice planting up to 20 July may not affect yield potential.

This 2-yr study showed that with reduced-tillage and direct seeding,net income, were greater than in the conventional farmers' practices. The water-saving feature of direct seeding is largely attributed to the avoidance of puddling used in transplanted rice. However, savings in irrigation largely depended on the occurrence and distribution of rainfall during the crop growing period. Therefore, more efforts will be needed to evaluate and improve the technologies on a site- and season-specific basis. Shifting from conventional tillage practice to no-till system may cause changes in soil properties, microflora, microfauna, and weed flora affecting long-term crop productivity and input use efficiency. Therefore, long-term changes in the crop performance, input efficiencies, and weed flora should be monitored to achieve a paradigm shift in farmers' practices.Appropriate integration of crop residue in no tillage rice–wheat systems is another crucial issue which needs to be addressed. Therefore, it is needed to develop cost effective and profitable residue management practices which will attract the farmers for adoption. It is also important that small-scale farmers be trained and have access to these technologies.

REFERENCES

Bhuiyan, S.I., Sattar, M.A. and Khan, M.A.K. (1995). Improving water use efficiency in rice irrigation through wet seeding. *Irrig. Sci.,* **16**:1–8.

Borrel, A.K., Garside, A.L. and Fukai, S. (1997). Improving efficiency of water for irrigated rice in semi-arid tropical environment. *Field Crops Res.,* **52**:231–248.

Bouman, B.A.M. (2001). Coping with the water crisis: Water management strategies in rice production. Paper presented at the International Symposium on Sustainable Soil and Water Resources Management. 30–31 May 2001. Diliman, Quezon City, the Philippines.

Dawe, D., Dobermann, A., Moya, P., Abdulrachman, S., Singh, Bijay, Lal, P., Li, S.Y., Lin, B., Panaullah, G., Sariam, O., Singh, Y., Swarup, A., Tan, P.S. and Zhen, Q.X. (2000). How widespread are yield declines in long-term rice experiments in Asia? *Field Crops Res.,* **66**:175-193.

Duxbury, J.M., Abrol, I.P., Gupta, R.K. and Bronson, K.F. (2000). Analysis of long-term soil fertility experiments with rice-wheat rotations in South Asia. p. 7-22. *In* I.P. Abrol *et al.* (ed.) Long-term soil fertility experiments with rice-wheat rotations in South Asia. Rice-Wheat Consortium Paper Series No. 6. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

Gill, K.S. (1994). Sustainability issues related to rice–wheat production system. p. 30–61. In R.S. Paroda *et al.* (ed.) *Sustainability of rice– wheat production systems in Asia*. FAO, Bangkok, Thailand.

Gleik, P.H. (ed.). (1993). Water crisis: *A guide to the world's fresh water resources*. Pacific Institute for Studies in Development, Environment and Security. Stockholm Environment Institute. Oxford Univ. Press, New York.

Gupta, R.K., Hobbs, P.R. Jiaguo, J.and Ladha, J.K. (2003). Sustainability of post-green revolution agriculture. 1–25. In J.K. Ladha *et al.* (ed.) *Improving the productivity and sustainability of rice–wheat systems: Issues and impacts*. ASA Spec. Publ. 65. ASA, CSSA, and SSSA, Madison, WI.

Harrington, L.W., Fujisaka, S., Morris, M.L., Hobbs, P.R., Sharma, H.C., Singh, R.P., Choudhary, M.K. and Dhiman, S.D. (1993). Wheat and rice in Karnal and Kurukshetra districts, Haryana, India: Farmers' practices, problems and an agenda for action. ICAR,HAU, CIMMYT,Mexico, and IRRI, Los Ban˜ os, the Philippines.

Hobbs, P.R. and Morris, M.L. (1996). Meeting South Asia's future food requirements from rice-wheat cropping systems: Priority issues facing researchers in the post Green Revolution era. NRG Paper 96-01. CIMMYT, Mexico.

Hobbs, P.R. and Gupta, R.K. (2002). Rice–wheat cropping systems in the Indo-Gangetic plains: Issues of water productivity in resourceconserving technologies.Water ProductivityWorkshop, 12–14 Nov. 2001. Int. Water Management Inst., Colombo, Sri Lanka. IRRI. 2005. IRRISTAT for Windows: A statistical package for analysis of data [CD-ROM]. IRRI, Manila, the Philippines.

Ladha, J.K., Pathak, H., Padre, A.T., Dawe, D. and Gupta, R.K. (2003). Productivity trends in intensive rice–wheat cropping systems in Asia. 45–76. In J.K. Ladha *et al.* (ed.) *Improving the productivity and sustainability of rice–wheat systems: Issues and impacts*. ASA Spec. Publ. 65. ASA, CSSA, and SSSA, Madison, WI.

Murgai, R., Ali, Mubarik and Byerlee, D. (2001). Productivity growth and sustainability in post-Green Revolution agriculture: The case of the Indian and Pakistan Punjabs. *World Bank Observer,* **16**(2):199-218.

Seckler, D., Amarasinghe, U., Molden, D., De Silva, R. and Barker, R. (1998). World water demand and supply, 1990 to 2025: Scenarios and issues. Res. Rep. 19. Int.WaterManagement Inst., Colombo, Sri Lanka.

Sharma, P.K., Bhushan, L., Ladha, J.K., Naresh, R.K., Gupta, R.K., Balasubramanian, V. and Bouman, B.A.M. (2002). Crop–water relations in rice–wheat cropping systems and water management practices in a marginally sodic, medium-textured soil. p. 223–235. In B.A.M. Bouman *et al.* (ed.) *Water-wise rice production*. IRRI, Los Ban˜ os, the Philippines.

Sharma, H.C., Dhiman, S.D. and Singh, V.P. (1994). Rice–wheat cropping system in Haryana: Potential, possibilities and limitations. p. 27–39. In S.D. Dhiman *et al.* (ed.) Proc. of the Symp. on Sustainability of Rice–Wheat System in India. CCS Haryana Agricultural University, Regional Research Station, Karnal, Haryana (India).

Sharma, P.K., Ladha, J.K. and Bhushan, L. (2003). Soil physical effects of puddling in rice–wheat cropping system. p. 97–114. In J.K. Ladha *et al.* (ed.) *Improving the productivity and sustainability of rice–wheat systems: Issues and impacts*. ASA Spec. Publ. 65. ASA, CSSA, and SSSA, Madison, WI.

Singh, Y., and Ladha, J.K. (2004). Principles and practices of no-tillage systems in rice–wheat systems of Indo-Gangetic plains. p. 167–207. In R. Lal et al. (ed.) *Sustainable agriculture and the rice–wheat systems*. Marcel Dekker, New York.

Sondhi, S.K., Kaushal, M.P. and Singh, P. (1994). Irrigation management strategies for rice–wheat cropping system. p. 95–104. In S.D. Dhiman *et al.* (ed.) Proc. of the Symp. on Sustainability of Rice–Wheat Systems in India. CCS Haryana Agricultural Univ., Regional Research Station, Karnal (India).

Tisdall , J.M. and Hodgson, A.S. (1990). Ridge tillage in Australia: a review. *Soil & Tillage Res.,* **18**: 127-44.

Toung, T.P. and Bhuiyan, S.I. (1994). Innovations towards improving water-use efficiency in rice. Paper presented at theWorld Bank's 1994 Water Resource Seminar, 13–15 Dec. 1994. Landsdowne, VA, USA.

Vories, E.D., Counce, P.A. and Keisling, T.C. (2002). Comparison of flooded and furrow irrigated rice on clay. *Irrig. Sci.,* **21**:139–144.

Received : September, 2010; Accepted : December, 2010