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RESOURCE CONSERVATION TECHNOLOGY IN RICE WHEAT CROPPING SYSTEM

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ABSTRACT

Predominant cropping system in India is the Rice-wheat cropping system as both rice and wheat are main staple food for the people of the country. Threat to sustainable food production has resulted due to the continued adoption of exhaustive rice-wheat cropping system. In order to address the problems like stagnant productivity, increasing production costs, declining resource quality, receding water table and increasing environmental problems alternative technologies are the major drivers. For improving and sustaining higher yields there are various efficient technologies that can be adopted in rice wheat system. Various Resource conservation technologies are Laser land-levelling, direct seeded rice (DSR), Zero tillage (ZT), furrow-irrigated raised-bed system (FIRBS) etc. Zero tillage (ZT) generally saves irrigation water in the range of 20–35% in the wheat crop compared to conventional tillage (Aslam *et al*., 1993). Adoption of furrow-irrigated raised-bed system (FIRBS) of wheat saves 25-30% seed, 30-40% w`ater and 25% nutrients without affecting the yield (Jat *et al*., 2012). Direct seeded rice (DSR) followed by zero tillage (ZT) wheat reduced the global warming potential of rice wheat system by 41% as compared to conventional system (Bhatia *et al*., 2012). Happy Seeder technology provides an alternative to burning for managing rice residues. Direct seeded rice under double no till with laser land levelling reduced cost of cultivation and improved the crop yields and system productivity while conserving natural resources and should be practiced in different ecologies including upland, lowland, deep water and irrigated areas by large as well as small farmers.

KEYWORDS: Rice Wheat Cropping System, Resource Conservation Technology, Direct Seeded Rice, Zero Tillage

INTRODUCTION

Rice-based cropping systems accounts for more than half of the total acreage where rice is grown in sequence with rice or upland crops like wheat, maize or legumes In South Asia. Rice based cropping systems provides food security and livelihoods for millions of people. Rice-wheat cropping systems alone occupy 13.5 million hectares in the Indo-Gangetic Plains (IGP) of South Asia (Gupta and Seth, 2007). The Indo-Gangetic Plain is one of the world's major food grain producing regions. The states of India falling under this region, viz. Punjab, Haryana, Uttar Pradesh, Himachal Pradesh, Bihar and West Bengal, are also the major rice-wheat growing states. Area under rice – wheat cropping system in different states in India is shown in Table:1. RWCCIMMYT, (2003) and Rice–Wheat Consortium (RWC), (2005) subdivided the rice–wheat areas of Indo Gangetic plains into five broad transects based on physiographic, bioclimatic, and social factors, as shown in Figure .1.

During the past 30 years, agricultural production growth in this region has been able to keep pace with population demand for food in the country mainly due to adoption of green revolution technologies inducing yield growth, followed by area expansion. But, this opportunity is ceasing very fast due to limited scope for increasing the availability of arable land and natural resources. The other issue is the conservation of the basic resources of land and water for sustainability of agriculture in the Indo- Gangetic Plain. It is generally believed that the rice wheat system has strained the natural resources in this region and more inputs are required to attain the same yield levels (Swarup and Singh, 1989; Kumar and Yadav, 1993; Lal *et al*., 2004).

THREATS FACING THE RICE-WHEAT CROPPING SYSTEM

Important issues emerging as a threat to the sustainability of rice-wheat system are:

- Over mining of nutrients from soil,
- Disturbed soil aggregates due to puddling in rice
- Decreasing response to nutrients
- Declining ground water table
- Build up of diseases/pests
- Build up of *Phalaris minor*
- Low input use efficiency in north western plains
- Low use of fertilizer in eastern and central India
- Lack of appropriate varietal combination.

The threats of rice – wheat cropping system in Indo-Gangetic plains are shown in Figure . 2. Water is one of the most precious natural resources for agricultural production and agriculture accounts for 70 percent of water use (FAO, 2002). It is predicted that by 2025 water consumption will exceed "blue water" availability if current trends continue (Ragab and Prudhomme, 2002). Traditionally rice is grown by hand transplanting of 25-30 day old seedling after puddling (PTR). Puddling require lot of tillage and water (>300 mm). Puddling destroys soil structure, which affects growth and development of succeeding upland crops in the rotation, thereby reducing system productivity (Hobbs *et al*. 2003a).

Table 1: Area under Rice-Wheat Cropping System in Different States in India

State	Area (m ha)
U.P & Uttarakhand	4.522
Bihar & Jharkhand	1.936
Punjab	1.614
MP + Chhattisgarh	1.064
Haryana	0.462
West Bengal	0.274
Jammu & Kashmir	0.228
Assam	0.183
Himachal Pradesh	0.093
Orissa and AP	0.042
Total	>10.5

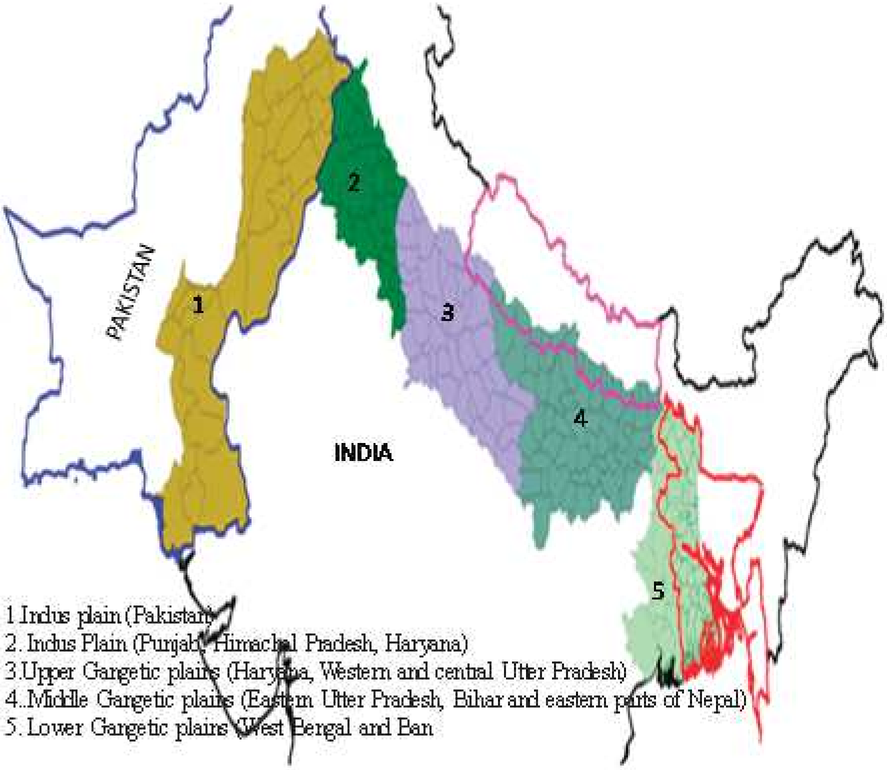


Figure 1: The rice-wheat areas of the Indo Gangetic Plains

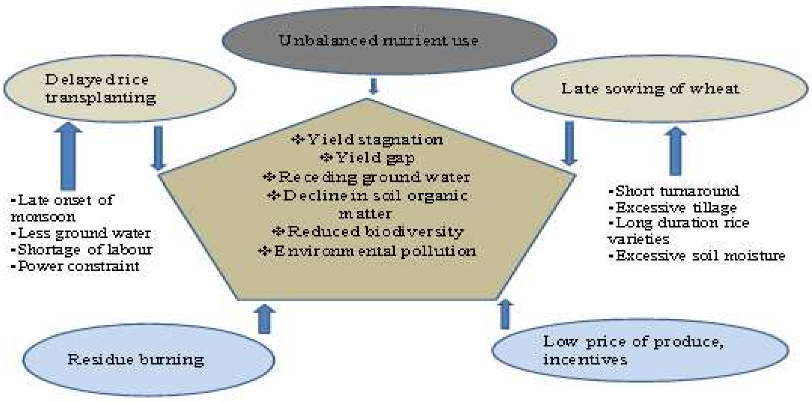


Figure 2: Threats Facing the Rice-Wheat Cropping System

Excessive pumping of water for puddling causing problems of declining water table and poor quality water for irrigation on one hand. Groundwater table is falling at a rate of 0.7 m per year in Punjab due to intensive irrigated agriculture (Aulakh, 2005). However, the decline of freshwater resources is due not only to increased consumption, but to careless management. Agriculture contributes to the problem by wasting water and by sealing and compacting the soils so that excess water cannot infiltrate and recharge the aquifer – one of the causes of the growing number of flood catastrophes (DBU, 2002). In regions where water is already the limiting factor for agricultural production, this wasteful practice threatens the sustainability of agriculture. Rising temperatures and evapotranspiration rates combined with more erratic rainfall further aggravate the water problems in rain fed agriculture (Met Office, 2005). Soil affects not only production, but also the management of other natural resources, such as water. Whereas, in eastern IGP rice transplanting depends mainly on monsoonal rains. Traditionally rice is grown by hand transplanting of 25-30 day old seedling after puddling (PTR). Puddling require lot of tillage and water (>300 mm). Puddling destroys soil structure, which affects growth and development of succeeding upland crops in the rotation, thereby reducing system productivity. Excessive pumping of water for puddling in peak summers in north west IGP causing problems of declining water table and poor quality water for irrigation on one hand of pounded water for customary practice of puddling delays rice transplanting by one to three weeks on the other. Delayed transplanting of rice affects growth and yields not only of rice but also succeeding crops, thereby reducing system productivity and profitability. The traditional system of hand-transplanting rice is based on the premise of cheap and readily available labour. However, in present scenario, rapid labour migration from agriculture to non agriculture sectors like construction, industries etc are seen in India. Country is currently experiencing an impressive phase of economic development causing drastically reduced availability of farm labour, especially for drudgery like transplanting and weeding in rice. More over ever increasing energy prices for pumping water and running tractors for puddling and other operations, limited water and labour availability for transplanting, stressed the farmers as well as researchers to develop alternative production systems for rice. Farmers need technologies that can conserve natural resources, reduce their costs of cultivation, improve their returns and are favourable to our environment.

Resource-conserving technologies (RCT) have been developed in order to reduce the use of and damage to natural resources through agricultural production; and increase the efficiency of resource utilization. Most of these technologies target the two most crucial natural resources: water and soil, but some also affect the efficiency of other production resources and inputs (e.g. labour, farm power and fertilizer).

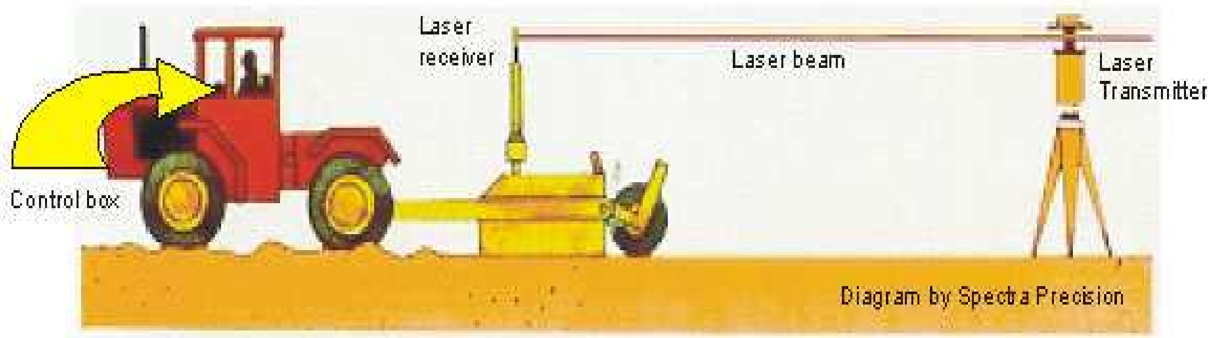
Some of the RCTs that are being promoted in the rice-wheat belt of the Indo-Gangetic Plains are: laser land levelling, zero/reduced tillage, bed planting, rotary tillage, use of leaf colour chart, mechanical rice transplanter, system of rice intensification, surface seeding, etc New varieties that use nitrogen more efficiently may be considered RCTs. The adoption of RCTs is expected to yield benefits to the farmers in terms of reduced losses due to soil erosion, saving of energy and irrigation costs, savings on labour input, increased productivity and water-use efficiency, reduced pumping of groundwater, increased nutrient-use efficiency and adoption of new crop rotations. Used in isolation, any of these technologies may face specific problems (e.g. surface crusting or weeds in direct seeding rice) or have limitations (e.g. zero tillage under irrigated conditions). The combination of resource-conserving technologies working in synergy is commonly referred to as “conservation agriculture” (CA). Conservation agriculture practices will only refer to the RCTs with the following characteristics:

- Soil cover, particularly through the retention of crop residues on the soil surface;
- Sensible, profitable rotations; and
- A minimum level of soil movement, e.g., reduced or zero tillage.

RESOURCE CONSERVATION TECHNOLOGIES

1) Laser levelling

For surface-irrigated areas, a properly levelled surface with the required inclination according to the irrigation method is absolutely essential. Traditional farmers’ methods for levelling by eyesight, particularly on larger plots, are not accurate enough and lead to extended irrigation times, unnecessary water consumption, and inefficient water use. The use of laser-guided equipment for the levelling of surface-irrigated fields has become economically feasible and, through hiring services, become accessible even to lower-income farmers. With laser levelling, the unevenness of the field is reduced to about ±2 cm, resulting in better water application and distribution efficiency, improved water productivity, better fertilizer efficiency, and reduced weed pressure. Water savings of up to 50% have been reported in wheat and 68% in rice (Jat *et al.*, 2006). Laser land leveller consists of a laser source (transmitter) which emits a parallel laser beam to a laser receiver attached to a scraper bucket behind a tractor and the vertical movement of scraper bucket is controlled by a hydraulic jack in a control box for levelling the field.



Leveling by animal & tractor drawn leveler results in Poor crop stand, Over irrigation and uneven distribution due to unevenness of the field. Laser land leveler have the following advantages;

- Increase water application efficiency up to 50 %
- Reduces labour requirement by 35%
- Increases crop yield by 15 to 66%
- Saving in time by 24%
- 3-4 % additional land recovery

A field experiment was conducted by Jat, *et al.*, 2011 at Modipuram (U.P) to quantify the benefits of precision land levelling and crop establishment technique and it was observed that Precision levelling with raised bed planting (PLRB) with recommended amount of balanced nutrients such as 120 $kg \cdot N \cdot ha^{-1}$; 26 $kg \cdot P \cdot ha^{-1}$ and 50 $kg \cdot K \cdot ha^{-1}$ (N120 + P26 + K50) gives higher yield than other treatments (Table 2).

1) Zero / Reduced Tillage

Reduced-till system combines the tillage done by a rotovator with seeding. Planting is done in a single pass. Reduced tilling and seeding can be accomplished both by the 2-wheel and 4-wheel tractors. In this system the entire swath of soil is rotovated while in others some of the rotovator blades are removed and only a strip is cultivated and planted. In the zero- or no- till system, an inverted- T coulter or a chisel opener is attached to a normal seed drill. This coulter makes a narrow groove/slit in the soil for the placement of the seed and fertilizer in one pass. Soil is disturbed in a very narrow groove 5 cm wide and 5 to 7 cm deep. For proper seed germination, wheat should be planted at slightly more than field capacity soil moisture content. Intensive soil tillage is the main cause for the reduction in soil organic matter and hence degradation of soils.

Table 2: Effect of Laser Land Levelling and Planting Techniques on Growth and Yield of Wheat

Treatment	Plant height at harvest (cm)		Productive tillers m^{-2} (No.s)		Length of spike (cm)		Grains/spike (No.s)		Grain yield ($t \cdot ha^{-1}$)		Straw yield ($t \cdot ha^{-1}$)	
	2002-2003	2003-2004	2002-2003	2003-2004	2002-2003	2003-2004	2002-2003	2003-2004	2002-2003	2003-2004	2002-2003	2003-2004
T_1	99.9a	101.7a	311a	316a	9.9	10.15a	44.2a	46.43a	**5.00a**	**5.19a**	**6.00a**	**6.23a**
T_2	87.9c	90.1b	282c	285b	9.7	9.90ab	41.4c	43.45b	4.60b	4.74b	5.30b	5.44b
T_3	95.5b	97.5c	300b	305c	9.8	9.93ab	43.0b	45.07c	4.60b	4.78b	5.20b	5.41b
T_4	87.4c	88.4d	264d	268d	9.6	9.73b	41.1c	43.35b	4.30b	4.42c	4.50c	4.60c
T_5	76.1d	75.7e	231e	229e	9.1	8.93c	39.2d	38.82c	2.70c	2.64d	2.90d	2.88d
SE **±**	0.76	0.56	3.06	2.42	0.21	0.138	0.383	0.328	0.165	0.111	0.184	0.102

Means with the same letters are not significantly different at P = 0.05.

(T_1) Precision levelling with raised bed planting (PLRB) with recommended amount of balanced nutrients such as 120 kg·N·ha–1; 26 kg·P·ha–1 and 50 kg·K·ha–1 (N120+ P26 + K50).

(T_2) Traditional levelling with raised beds (TLRB) with N120 + P26 + K50.

(T_3) Precision levelling with flat beds (PLFB) with N120 + P26 + K50.

(T_4) Traditional levelling with flat beds (TLFB) with N120 + P26 + K50.

(T_5) Traditional levelling with flat beds (TLFB) with o fertilizer application (N0 + P0 + K0)

Tillage accelerates the mineralization of organic matter and destroys the habitat of soil life. To the extent that soil tillage is reduced or eliminated, soil life returns and the mineralization of soil organic matter decreases. This results in better structuring of the soil. Under zero-tillage, the mineralization of soil organic matter can be reduced to levels inferior to the input converting the soil into a carbon sink. In addition to this, zero-tillage results in water savings and improved water-use efficiency. Since the soil is not exposed through tillage, the unproductive evaporation of water decreases. At the same time, water infiltration is facilitated (DBU 2002). The possible water savings through zero-tillage vary depending on the cropping system and climatic conditions. On average, water savings of about 15–20% can be expected (PDCSR 2005). However, used in isolation, zero-tillage might face problems with weed control, compaction, or surface crusting depending on the soil type.

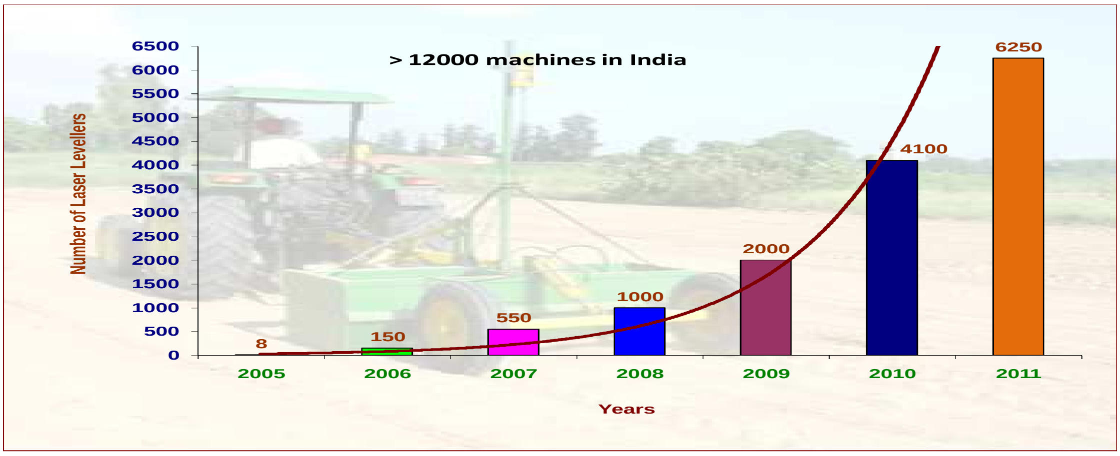


Fig 2 GROWTH OF LASER LEVELING IN PUNJAB

RWC, 2004

Figure 3: Increasing Trend of Number of Laser Levellers with Respect to Time in Punjab

In the 2004-2005 wheat season, zero tillage is estimated to have been used on nearly 2 mha of sown area (RWC, 2005). Zero-tillage wheat allows for a drastic reduction in tillage intensity, with significant costs savings as well as potential wheat yield gains through planting of the wheat crop at a better time. The cost-saving effect alone makes zero tillage profitable and is the main driver behind its spread. Zero-tillage planting of wheat after rice has been the most successful resource-conserving technology to date in the Indo-Gangetic Plains, particularly in northwest India and to a lesser extent the Indus plains in Pakistan (Erenstein and Laxmi 2008). The interest in zero tillage in the Indo-Gangetic Plains originated from diagnostic studies that highlighted the importance of time conflicts between rice harvesting and wheat planting in both northwest India (Fujisaka, Harrington, and Hobbs 1994; Harrington *et al*. 1993) and Pakistan (Byerlee *et al*. 2003). Zero-tillage wheat has a number of advantages, alleviating a number of constraints in the rice-wheat system: it permits earlier wheat planting, helps control obnoxious weeds like *Phalaris minor*, reduces costs, and saves water (Erenstein and Laxmi 2008).

The prevailing zero-tillage technology in rice-wheat systems in the area is use of a tractor-drawn seed drill with 6 to 11 inverted-T tines to seed wheat directly into unplowed fields with a single pass of the tractor. In contrast to zero tillage, conventional tillage practices for wheat in these systems involve multiple passes of the tractor to accomplish ploughing, harrowing, planking and seeding operations. Conventional tillage and crop establishment methods such as puddled transplanting in the rice–wheat (*Oryza sativa* L.–*Triticum aestivum* L.) system in the Indo-Gangetic Plains (IGP) require a large amount of water and labor, both of which are increasingly becoming scarce and expensive. In India, the same inverted-T openers were introduced in 1989 by CIMMYT, and in 1991 a first prototype of the Indian zero-tillage seed drill was developed at G. B. Pant University of Agriculture and Technology, Pantnagar. Surface seeding is one option for employing zero tillage without the use of a tractor or seed drill but its use is largely confined to low-lying fields with drainage problems in the Eastern Gangetic Plains. Among the different stand establishment techniques double zero tillage technique attained the highest plant height (136 cm) over Direct seeding of rice, Brown manuring of rice, Transplanting on beds and Conventional transplanting. The productive tillers per unit area (m^2) were recorded highest in direct seeding followed by double zero tillage and bed planting (Aslam *et al*. 2008). The effect of different stand establishment techniques on rice yields, its attributes and on benefit cost ratio is shown in Table 3 and 4.

Table 3: Effect of Different Stand Establishment Techniques on Rice Yields and Its Attributes

Treatments	Plant height (cm)	Productive tillers/m^2	Panicle length (cm)	Number of grains/panicle	1000 grain wt.(g)	Paddy yield (t/ha)
Double Zero tillage	136.1^{a}	219.0^{ab}	27.93^{a}	96.50^{a}	23.17^{a}	4.80^{a}
Direct seeding	126.6^{c}	231.7^{a}	25.23^{b}	72.67^{b}	22.17^{b}	3.36^{c}
Brown manuring	128.2^{bc}	186.3^{c}	27.67^{a}	93.83^{a}	22.83^{ab}	4.23^{b}
Bed planting	129.2^{bc}	206.7^{abc}	27.93^{a}	95.73^{a}	23.17^{a}	4.43^{b}
Conventional planting	130.2^{b}	200.2^{bc}	27.93^{a}	98.57^{a}	23.50^{a}	4.72^{a}
LSD at α: 0.05	2.782	26.65	0.9019	8.851	0.9676	0.2844

The means in rows bearing same letters do not differ significantly ($P<0.05$)

Table 4: Effect of Different Stand Establishment Techniques on Cost Benefit Ratio

Treatment	Paddy yield (t/ha)	Cost (Rs./ha)	Income (Rs./ha)	Profit	Cost benefit ratio
Double Zero tillage	4.80	59660	114000	35643	1: 1.91
Direct Seeding	3.36	55057	79800	5793	1: 1.14
Brown manuring	4.23	60402	100462	21310	1: 1.66
Bed Planting	4.43	60452	105212	26010	1: 1.74
Conventional Planting	4.72	61045	104975	25180	1: 1.72

The review of zero tillage in India found a yield effect amounting to a 5–7 percent yield increase for wheat being reported across studies (including on-station trials, on-farm trials, and surveys (Erenstein and Laxmi 2008). This provides a further boost to the returns to zero tillage. The yield effect, if any, is closely associated with enhanced timeliness of wheat establishment after rice. Heat stress at the end of the wheat season implies that the potential wheat yield is reduced by 1-1.5 percent per day if planting occurs after mid November (Hobbs and Gupta 2003a). It is estimated that about a third of the wheat area in the Indian Indo-Gangetic Plains is sown late—often linked to late maturing Basmati rice in the northwestern Indo-Gangetic Plains (including Pakistan Punjab) and generally late rice harvesting in the eastern plains—and zero tillage potentially would alleviate this by allowing for timelier establishment.

Impact on the Environment

Straw retained on the soil surface reduces weed seed germination and growth, moderates soil temperature and reduces loss of water through evaporation. In addition, crop residue is also an important source of fodder for animals in the IGP countries. Despite these potential benefits, however, large quantities of straw (left over after rice and wheat harvesting) are burnt each year by farmers to facilitate land preparation for crop planting. It is estimated that the burning of one ton of straw releases 3 kg particulate matter, 60 kg CO, 1460 kg CO2, 199 kg ash and 2kg SO_2. With the development of new drills, which are able to cut through crop residue, for zero-tillage crop planting, burning of straw can be avoided, which amounts to as much as 10 tons per hectare, potentially reducing release of some 13–14 tons of carbon dioxide (Gupta *et al*., 2004). Elimination of burning on just 5 million hectares would reduce the huge flux of yearly CO_2 emissions by 43.3 million tons (including 0.8 million ton CO_2 produced upon burning of fossil fuel in tillage). Zero-tillage on an average saves about 60 l of fuel per hectare thus reducing emission of CO_2 by 156 kg per hectare per year (Grace *et al*., 2003; Gupta *et al*., 2004) the submergence of soils promotes the production of methane by anaerobic decomposition of organic matter. However, worries that such rice systems are a major contributor to global warming were allayed through a wide-scale study in the region (Wassman *et al*., 2001). It has been noticed that methane emissions from rice fields range from 16.2 to 45.4 kg/ha during the entire season, whereas nitrous oxide emission under rice and wheat crops amounts to

0.8 and 0.7 kg/ha, respectively (Pathak *et al*., 2002). Incorporation of straw increases methane emissions under flooded conditions, but surface management of the straw under aerated conditions and temporary aeration of the soils can mitigate these effects. Thus, adoption of aerobic mulch management with reduced tillage is likely to reduce methane emissions from the system. The water regime can strongly affect the emission of nitrous oxide, another GHG, which increases under submergence, and is negligible under aeration. Any agronomic activity that increased nitrous oxide emission by 1 kg/ha needs to be offset by sequestering 275 kg/ha of carbon, or reducing methane production by 62 kg/ha. Adoption of RCTs would favour the decrease of this GHG.

Researchers of both India and Pakistan reported higher grain yield in Zero tillage as compared to Farmers practice, it may be due to the fact that the Zero tillage eliminates the preparatory tillage that facilitates the timely sowing of wheat and hence gives the higher yield Table 5.

Table 5: Grain Yield of Wheat in Zero-Tillage and Farmers' Practice after Puddled Transplanted Rice in Pakistan and India

Year	Country	No. of farmers Involved	Grain yield (kg/ha) Zero tillage	Farmers' practice
1985–1988	Punjab, Pakistan	34	3890[a]	3528[b]
2001–2004	Western Uttar Pradesh, India	27	5120	4980
1999–2000	Haryana, India	124	5380	5110
2000–2003	Eastern UP and Bihar	357	3350	2980

Table 6: Benefits of zero-Tillage over Conventional Tillage for Planting of Wheat after Rice in Haryana, India

Item	Farmers' perceptions	Researchers' findings
Sowing	Wheat sowing earlier by 5-8 days (small-to-medium farms) to 2 weeks (large farms)	On average, wheat sowing can be advanced by 5-15 days
Fuel savings	Not available	On average 60 l diesel per ha
Cost of cultivation	US$ 42-92 ha^{-1}	US$ 37-62 ha^{-1}
Plant population	20-30% more plants in zero-tillage fields	13.5% more plants in zero-tillage fields
Weed infestation	20% less and weaker weeds in zero-tillage fields	43% less weeds in zero-tillage fields
Irrigation	Saves30-50% water in the first irrigation and 15-20% in subsequent irrigations	36% less water used, on average
Rice stubble	Decayed faster	Decayed faster
Fertilizer-use efficiency	High	Higher because of placement
Wheat yields	Higher than under conventional system depending on days planted earlier	420-530 kg more per ha

Source: Hobbs and Gupta (2003a).

2) Direct Seeded Rice (DSR)

Paddy is generally transplanted in the first fortnight of July in puddled (wet tillage) soil, which leads destruction of macropores and reduction in permeability. With direct seeding, rice seed is sown and sprouted directly into the field, eliminating the laborious process of planting seedlings by hand and greatly reducing the crop's water requirements (Polycarpou 2010). Traditional paddy cultivation requires 200-250 man-hours per hectare, which are about 25 percent of the total labour requirement for the crop production. Resource conservation by adopting direct seeded rice (DSR) with the help of seed-cum-fertilizer drill have the potential to reduce the production costs by consuming less time, labour, fuel, energy and machinery inputs. Puddling breaks capillary pores, reduces void ratio, destroys soil aggregates, disperses fine clay particles, and lowers soil strength in the puddle layer. The destruction of soil aggregates by puddling leads to the formation of surface crusts and cracks on drying thereby delaying preparation of a seedbed for ensuring crops. Direct seeding of rice mainly done by two methods, dry direct seeding (DSR) and wet direct seeding (WSR). DSR practiced by seeding dry seeds in unsaturated soil by line sowing or broadcasting.

In wet seeding, sprouted seeds of rice broadcasted in puddled soil. DSR seeded with a planter or a seed cum fertilizer drill have many advantages over conventional puddled transplanting i.e. *viz.* easier and timely planting, reduced labour burden at least 50% (Isvilanonda 1990, Fujisaka *et al.* 1993, Singh *et al.* 1994, Pandey *et al*. 1995, 1998, Pandey and Velasco 1998), 8-10 days earlier crop maturity (helpful in timely planting of succeeding crop), higher water and nutrient use efficiency, efficient root system development that enhance drought tolerance reduced lodging problem and higher yield of succeeding upland crops. In general, a total of 1382 mm to 1838 mm water is required for the rice-wheat system accounting more than 80% for the rice growing season (Gupta *et. al*., 2002). Direct seeded rice avoids repeated puddling, preventing soil degradation and plough-pan formation. It facilitates timely establishment of rice and succeeding crops as crop matures 10-15 days earlier. The total growing period from seed to seed is reduced by about 10 days. It saves water by 35-40% and reduces production cost by Rs 3000/ha with an increase in yields by 10%. It saves energy, labor, fuel and seed besides solving labor scarcity problem and reduces drudgery of labours (PDCSR, 2005). In a long-term trial on crop establishment methods in rice-wheat system started in 2006 at Rajendra Agricultue University, Pusa, Samastipur, to find out the effect of rice wheat establishment methods on productivity of either crops. Treatments including puddle transplanted or puddle direct seeded rice, tilled dry direct seeded rice and zero til direct seeded rice in presence or in absence of residue in combination with conventional and zero till wheat were evaluated on faouable low land silty clay soil at Pusa. Results revealed that growing rice and wheat without tillage and direct seeding in presence of residues led {ZTR-ZTW (+R)} to stable and higher crop yields of rice and wheat plots over the years. However in initial years the grain yield of rice was slightly higher in puddle transplanted rice but since 2008 not much difference in rice yield was observed due to puddling and transplanting (Figure 4), while the cost of production was significantly low in zero tillage rice (ZTR). Grain yield of wheat was always higher when wheat is planted after Unpuddled rice than puddle transplanted or direct seeded rice. Wheat growth was always better in Unpuddled soils, resulting highest system productivity. It is interesting to see that zero tillage rice followed by zero tillage wheat with residue retention {ZTR-ZTW (+R)} continuously improved the rice and wheat yield over the years.

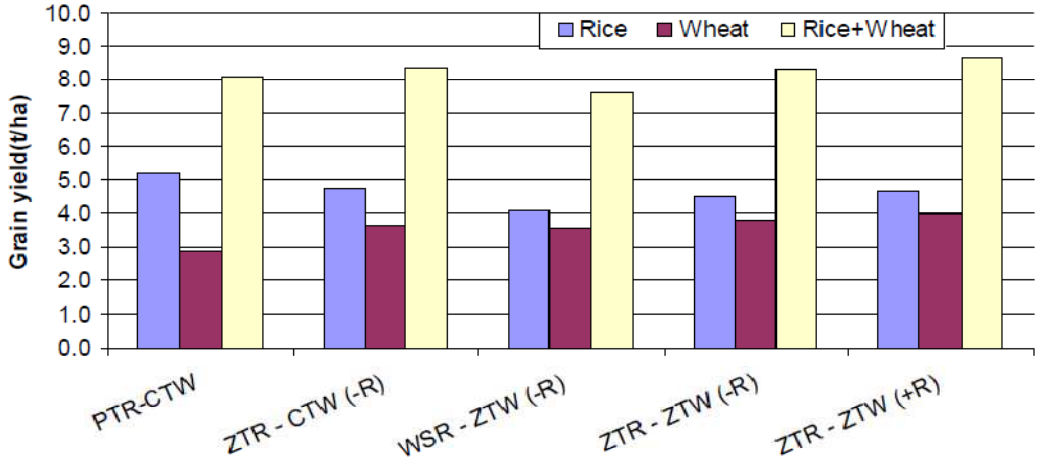


Figure 4: Effect of Crop Establishment Methods on Productivity of Rice in Rice-wheat System (3 years Mean) (Ravi Gopal, Unpublished 2010)

The research carried out by Singh, *et al*., 2012 at Kushinagar district in Eastern Uttar Pradesh, showed the average yield of paddy was more in DSR due to more number of panicles per unit area. Besides this rice-wheat system productivity was more than 90 quintal per ha (Table-7) when rice was sown upto 28th June. This was reduced by more than 30% when fields were transplanted after 25th July (75 quintal/ha). The key issue is if higher system productivity is desired, the rice crop must be sown/planted early with the onset of monsoons by raising rice nurseries with ground water and vacating the main fields early in the season for the succeeding wheat or other crop (Gupta et.al. 2002). It has also been observed that in case of timely sown rice by DSR average number of tillers was 16-17 per plant with plant height of 108-116 cm.

4. Bed Planting

Bed planting in rice-wheat cropping systems may be a technique for improving resource use efficiency and increasing the yield. In this system, the land is prepared conventionally and raised bed and furrows are prepared manually or using a raised bed planting machine. Crops are planted in rows on top of the raised beds and irrigation water is applied in the furrows between the beds. Recent research activities in India and Pakistan showed many advantages of bed planting of wheat in rice-wheat systems (Gupta *et al*., 2000; Hobbs and Gupta, 2003a; Connor *et al*., 2003a). Bed planting refers to a cropping system where the crop is grown on beds and irrigation water is applied in furrows between the beds. This is a common practice for row crops, but not for small grain crops such as wheat and rice. The advantages are improved fertilizer efficiency, better weed control, and a reduced seed rate. The most important one as an RCT is the saving of irrigation water because of reduced evaporation surface and efficiency in distribution. In addition, the rooting environment is changed and aeration of the bed zone is better than with flat planting. Water savings compared to flat surfaces of 26% for wheat and 42% for transplanted rice have been reported, with yield increases at the same time of 6.4% for wheat and 6.2% for rice (RWC-CIMMYT 2003).

Table 7: Performance of Demonstrated Paddy Technologies under DSR in Kushinagar District

Variety	Average grain yield (q/ha)		Increase in yield (%)	Average cost of cultivation (Rs/ha)		Net profit (Rs.)		Profit ratio
	Demo.	Local Check		Demo.	Local Check	Demo.	Local Check	
Krishna Hans	56.57	38.71	46.14	13570.78	13673.22	35941.72	22642.1	1.59

Sarju-52	52.53	41.97	25.20	12958.81	13842.67	33743.19	21874.3	1.54
PRH-10	62.35	41.97	48.56	16842.6	13842.67	38444.90	21874.3	1.76
PB-1	30.41	30.51	-0.33	21,867.1	21,779.5	34,288.9	20,415.5	1.68
Rajendra Mansoori	41.52	38.83	6.93	17663.4	23722.9	27770.3	18805.7	1.48
Pusa-44	42.53	36.21	17.45	18665.5	21692.5	27392.0	17817.5	1.54
Rajshree	46.71	30.87	51.31	18791.6	15625.5	32397.3	17746.1	1.83

Table 8 Yield attributes of rice crops under two methods of crop establishment at Kushinagar

Treatment	Panicles/m^2 (No.)	Grain weight/ panicle (g)	1,000-grain weight (g)
Transplanted	243	2.7	30.3
Direct-seeded	361	2.1	30.1
CD (5%)	21	0.2	NS

Singh, *et al.*, 2012

Mollah, *et al.*, (2009) reported the highest grain yield in 70 cm wide beds with two plant-rows bed^{-1} (2.85 t ha^{-1} in 2002 and 3.34 t ha^{-1} in 2003), which was statistically identical with the grain yield of 70cm wide beds with three plant-rows bed^{-1} (2.82 t ha^{-1} in 2002 and 3.28 t ha^{-1} in 2003) and significantly higher than conventional method and 80 and 90 cm wide beds with both two and three plant rows. The yield increase by bed planting using 70 cm wide beds with two and three plant rows bed^{-1} over conventional method were 21 and 20%, respectively, in 2002 and 19 and 17%, respectively, in 2003. Similar yield increase by bed planting in wheat was also reported by Dhillon *et al.* (2000), Gupta *et al.* (2000), Reeves *et al.* (2000), Connor *et al.* (2003b), Hobbs and Gupta (2003b), and Meisner *et al.* (2005). With the increase in bed width, yield was decreased in both the years. There was no significant yield difference between three and two plant-rows bed^{-1} in same bed width. The highest yield in the bed planting with 70cm beds were attributed to higher number of panicles m^{-2}, grains panicle^{-1} and 1000-grain weight **(Table 9)** . Mollah, *et al.*, (2009) reported that Weed population and dry biomass were greatly influenced by different planting methods of wheat. Bed planting significantly reduced weed population resulting in lower dry biomass than conventional method in both the new and old beds. The lowest number of weeds m^{-2} and dry biomass yield were recorded in the 70 cm wide beds with three plant rows bed^{-1} which was followed by same width bed with two plant rows bed^{-1} (Table 10). Ram *et al.* (2005) also found lower weed biomass in raised beds than the conventional method. Both weed population and dry biomass yield were increased with the increase in width of beds and these were also higher in bed with two plant rows than three plant rows. The low number of weeds in beds might be due to dry top surface of beds that inhibited the weed growth. Moreover, at the time of bed preparation, the top soils of the furrows were mulched to the raised beds, which drastically reduced the weeds in furrows.

Amount of water required for different irrigations differed remarkably between the conventional and bed planting methods. The conventional method received the highest amount of water at every irrigation and total amount was 315 mm and 318 mm in 2001-02 and 2002-03, respectively (Table 11). Total water savings by 70, 80 and 90 cm wide beds over conventional method were 41-46 %, 42-48 % and 44-48 %, respectively. Among the beds, the narrow bed (70 cm) required slightly higher amount of irrigation water than wider bed. In the bed planting, irrigation water was applied only in furrows. The area of furrows unit^{-1} area in the wider beds is lower than the narrow beds. So, it received lower amount of irrigation water. Savings of irrigation water by bed planting of wheat ranged from 18% to 50% were reported many scientists (Mollah, *et al*., 2009, Gupta *et al.*, 2000; Yadav *et al.*, 2002; Gupta, 2003; Hobbs and Gupta, 2003b and Sayre, 2003)

Table 9: Effect of Planting Method on the Yield and Yield Components of wheat

Method of planting		**Grain yield (t ha^{-1})**		**Panicles m^{-2} (no.)**		**Grains panicle^{-1} (no.)**		**1000-grain wt. (g)**	
Bed width (cm)	Rows bed^{-1} (no.)	2002	2003	2002	2003	2002	2003	2002	2003
70	2	2.85 a (21)*	3.34 a (19)	306 a	310 a	34.3 a	36.3 a	42..3 a	42.3 a
70	3	2.82 a (20)	3.28 a (17)	312 a	325 a	32.0 b	33.8 b	41.7 a	41.9 a
80	2	2.54 bc (8)	2.78 bc (-1)	231 c	260 c	34.2 a	35.9 a	41.3 a	41.5 a
80	3	2.65 b (13)	2.87 b (2)	244 b	282 b	31.1 c	32.9 c	41.4 a	41.5 a
90	2	2.26 d (-4)	2.64 c (-6)	219 c	241 d	34.2 a	36.0 a	41.9 a	42.1 a
90	3	2.43 c (3)	2.67 bc (-5)	231 c	242 d	31.3 bc	33.0 c	41.5 a	41.7 a
Conventional		2.35 dc	2.81 bc	305 a	274 bc	27.3 d	28.3 d	39.2 b	39.6 b

Figures in a column followed by different letters differ significantly at 5% level of probability as per DMRT.

Table 10: Weed Vegetation in wheat as Influenced by Method of Planting

Method of planting	Weed vegetation				
	2002			2003	
Bed width (cm)	Rows bed^{-1} (no.)	Population (no. m^{-2})	Dry biomass (kgha^{-1})	Population (no. m^{-2})	Dry biomass (kg ha^{-1})
70	2	64 f	55.7 e	77 f	69.6 f
70	3	51 g	47.2 f	59 g	53.5 g
80	2	105 d	96.7 c	120 d	104.5 d
80	3	83 e	71.2 d	96 e	85.5 e
90	2	136 b	115.0 b	162 b	147.4 b
90	3	116 c	97.4 c	136 c	123.5 c
Conventional		205 a	173.2 a	240 a	207.8 a

Mollah, *et al*., (2009)

Table 11: Water Required in Wheat as Influenced by Method of Planting

Tillage option	**Water required at different times of irrigation (mm)**					
	Sowing	**Crown root initiation**	**Maximum tillering**	**Grain filling**	**Total**	**Water saved over conventional (%)**
2001-02						
70 cm bed	57	49	41	23	170	46
80 cm bed	55	49	40	21	165	48
90 cm bed	55	48	39	21	163	48
Conventional	95	89	76	55	315	-

2002-03						
70 cm bed	58	48	45	35	186	41
80 cm bed	56	46	44	34	180	42
90 cm bed	55	45	42	32	174	44
Conventional	94	85	79	60	318	-

Bed planting also has the advantage of lower seed rates, bolder seed and greater panicle length, an important issue for hybrid seed multiplication programmes. The main benefit of bed planting is savings in water. Almost all farmers report 30-35 per cent less irrigation time in tube well irrigated areas and also less crop lodging and possibility of last irrigation to be given. Therefore under high production situations, bed planting exceeds the yields possible on the flat bed. In rice-wheat areas raised beds work best in partially reclaimed alkali soils, low-lying areas where water-logging and weeds are problems, and in cracking soils. Where there is an urgent need for rainwater conservation to prevent receding water-tables and need to increase water-use efficiency dramatically, bed planting is a blessing in disguise. Raised bed prepared from the amended soils increases the depth of rooting zone and improves crop productivity (APAARI vision).

Mann *et al*., 2008 conducted a three year experiment in Pakistan (Punjab) at three different locations with four crop establishment techniques and it was observed that mean yield of wheat was more in beds with two rows as compared to other treatments (Table 12).

Bhuyan *et al*., 2012 reported that that bed planting method is a new approach for optimum fertilizer and water use efficiency as well as higher yield compared to conventional flat method as the bed planting method increased the Water use efficiency, number of panicle m^{-2}, number of grains $panicle^{-1}$, 1000-grain weight and increased grain yield of rice up to 16% than the conventional method and Sterility percentage and weed infestation were lower in bed planting than conventional method. He also concluded that about 42% of the irrigation water and time for application could be saved through bed planting in transplanted aman rice cropping system.

Table 12: Grain Yield (t ha^{-1}) in Wheat Planted with Different Techniques

Techniques	M.K. Farm	Zaidi Farm	Dogar Farm	Mean
Beds (two rows)	3.92 a	5.27 a	4.60	4.60
Zero Tillage (flat)	4.02 a	4.95 ab	4.15	4.43
Beds (three rows)	4.25 a	4.70 b	4.37	4.42
Conventional	3.45 a	4.25	4.05	3.95
Mean	3.92	4.80	4.30	4.35

5) **Leaf colour chart**

The leaf colour chart (LCC) is a good eco-friendly cheap tool in the hands of small farmers to approximately optimize N use, irrespective of the source of N applied -organic, bio-, or chemical fertilizers. It costs about US$l per piece. It is being introduced to farmers through field researchers, extension staff and private sector agencies (Balasubramanian *et at*., 2000) .It was observed that 74 per cent of the farmers obtained equal or higher yields.

6) Surface seeding

Surface seeding is the simplest of all the crop establishment options. Seeds of wheat and other upland crops are broadcast or seeded in rows using drum seeders on the surface without any disturbance of the soil. The treated seed (with

Vitavax, 2.5 9 kg^{-1} seed) can be sown before or after the rice harvest depending on the soil moisture. The key to success is having the soil moist/ saturated during the initial stage as this facilitates seed germination and corking-in of roots into soil during root elongation stage. Mulching of surface seeded crops deters weed growth; keep the soil surface moist for long and delaying nitrogen application. In the Yangtze River Valley of China, seeds are sown after a pre-plant herbicide application and then covered with rice straw mulch.

7) **Mulching and green manure**

The supply of organic matter to the soil through mulching and green manure is an important factor for maintaining and enhancing soil fertility. The mulching material can result from crop residues or green manure crops. This provides feed for the soil life and mineral nutrients for plants. If legume crops are used as green manure, they can supply up to 200 kg ha^{-1} nitrogen to the soil. This can result for rice in savings of mineral fertilizer of 50–75% (RWC-CIMMYT 2003). Left on the soil surface, the mulch reduces evaporation, saves water, protects from wind and water erosion, and suppresses weed growth.

Green manure has significantly increased soil organic matter, soil health and crop growth. The *S. aculeata* produced more biomass and was superior to other two green manure crops. Soil densities, porosity, texture, field capacity and soil moisture were influenced due to the green manure crops and tillage practices. The lowest bulk density (1.45 g cm^{-3}) and particle density (2.48 g cm^{-3}) were found in *S. aculeata* and deep tillage practice. The highest porosity (41.73%) and field capacity (24.24%) were also observed in *S. aculeata* and deep tillage practice. The incorporation of *S. aculeata* and deep tillage practice also showed the highest yield of T. aman and maize. Therefore, application of *S. aculeata* and deep tillage practice may be recommended as green-manure cultivation strategy in T. aman (*O. sativa*) and maize (*Z. mays*) cropping to maintain soil health and sustainable crop production (Salahin, *et al*., 2013) (Table 13).

Ali *et al.*, 2012 reported that green manuring of sesbania rostrata and legume crops (mungbean, cowpeas and lentil) produced significantly better grain yield of rice and wheat than the other crops (Table 14). Maximum paddy yield of 3.73 t/ha was produced by rice – wheat – sesbania cropping system followed by 3.57, 3.52, 3.40 and 3.39 t/ha produced by rice – wheat – mungbean, rice – berseem, rice – wheat – cowpeas and rice – lentil cropping systems respectively and these were statistically at par with each other. The other cropping patterns gave significantly lower yields. Rice - wheat system produce paddy yield of 3.34 t/ha. Sowing of sesbania rostrata increased rice yield by 12%, mungbean (7.2 %), Berseem (5.3 %), cowpeas (1.8 %) over the traditional rice – wheat cropping system.

(8) Controlled traffic farming

Controlled traffic farming restricts any traffic in the field to always the same tracks. Although these tracks are heavily compacted, the rooting zone never receives any compaction, resulting in better soil structure and higher yields. Through border effects, the area lost in the traffic zones is easily compensated for by better growth of plants adjacent to the tracks so that overall yields are usually higher than in conventional systems with random traffic (Kerr 2001). Obviously, controlled traffic farming is the ideal complement to zero-tillage or bed-planting systems. Also in conventional agriculture, controlled traffic provides advantages through time and fuel savings since the resistance to soil tillage in the compaction-free rooting zones is significantly lower and traction is more efficient when tires work on compacted tracks (RWC-CIMMYT 2003). However, in this case, provision must be made either by GPS guidance or visible bed and furrow systems to limit tillage operations to the rooting zones and not to disturb the tracks.

Table 13: Yield of T. aman as Influenced by Various Green Manure Crops

Treat.	T. aman 2010				T. aman 2011			
	Grain (t ha^{-1})	Straw (t ha^{-1})	Grain increase (%)	Straw increase (%)	Grain (t ha-1)	Straw (t ha-1)	Grain increase (%)	Straw increase (%)
G1	5.19a	5.43 a	35.5	33.7	5.09a	5.29a	46.26	33.3
G2	4.84b	5.07 b	26.4	24.9	4.54b	5.23b	30.46	31.7
G3	4.35b	4.58 c	13.6	12.8	4.32c	4.62bc	24.14	16.4
G4	3.83d	4.06 d	-	-	3.48c	3.97c	-	-
F value	20.93**	49.42**	-	-	26.9**	27.0**	-	-
CV (%)	12.34	3.70	-	-	3.81	8.01	-	-

G1= Sesbania aculeata; G2=Mimosa invisa; G3=Vigna radiata; G4= control.

* Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; ns, not significant. Means followed by common letter do not differ significantly at 5%

Table 14: Effect of Green Manuring and Legume Crops on Rice & Wheat Grain Yield

Yield (t/ha)			
Cropping System	**Rice**	**Rabi Crops**	**Summer Crops**
Rice – Wheat	3.34b	2.59b	-
Rice – Berseem	3.52a	28.50a	-
Rice – Lentil	3.39ab	0.71c	-
Rice – Canola	0.53c	3.21b	-
Rice – Wheat -Mungbean	3.57a	2.63b	0.78
Rice – Wheat - Cowpeas	3.40ab	2.69b	0.98
Rice – Sunflower	3.32b	-	1.08
Rice – Wheat - Sesbania	3.73a	2.81b	-
LSD	0.3163	1.073	NS

Means followed by common letter do not differ significantly at 5% Ali *et al.*, 2012

9) The system of rice intensification (SRI)

The system of rice intensification (SRI) developed in Madagascar is gaining acceptance in many parts of India and in three dozen other countries.SRI helps farmers achieve higher yields with reduced inputs: fewer seeds, less water, lower costs of production, and often less labor. This makes it more accessible to resource-limited farmers than Green Revolution technologies and thus it can assist in poverty reduction as well as enhanced food security. Young seedlings are transplanted at 8-12 days old. Seedlings are carefully lifted from the nursery and transported to fields in baskets or on trays for immediate transplanting. Seeding rate: 5-7 kg/hectare. 1-2 seedlings per hill are transplanted with shallow depth (1-2 cm) into soils that are not flooded. Roots are carefully positioned just under the soil surface to avoid trauma to the roots, thereby avoiding “transplant shock.” Wider spacing, with hills 20-30 cm apart, set out in a square or matrix pattern to facilitate moving through the field with a weeder, and to expose plants fully to the sunlight. Non-flooded aerobic soil conditions with intermittent irrigation. Where possible, small applications of water, or alternate wetting and drying during the growth period; just 1-2 cm of water on fields after the plants flower. Organic matter is preferred to the extent feasible but may be complemented with synthetic fertilizers. Combinations can be used to ensure appropriate soil:plant nutrient balance. Manual weeders can remove weeds and aerate the topsoil at the same time. Integrated Pest Management (IPM) practices are encouraged. SRI plants are generally more resistant to pests and diseases so require less chemical protection. Benefits of SRI 47% Yield increase

- 40% Water saving
- 23% Reduction in costs per hectare
- 68% Increased income per hectare

SRI practices enhance the rice plants' growing conditions by:

1. Reducing the recovery time seedlings need after transplanting;

2. Reducing crowding and competition;

3. Optimizing soil and water conditions.

These conditions contribute to:

- Larger, deeper root systems;
- Enhanced photosynthetic capacity;
- More productive plants that are more resistant to climate extremes, pests and diseases;
- More grain yield.

SRI methods require:

- Less time before transplanting, as seedlings can be ready in 8-12 days instead of one month;
- 80-90% fewer seeds, due to much lower plant populations;
- Less time required for transplanting due to fewer seedlings;
- 25-50% less water, as the field is not continuously flooded;
- Less cost per hectare, as there is less need for purchased seeds, synthetic fertilizers, herbicides or pesticides, and in some countries less labor is required.

A research trial was conducted at SKUAST-K Shalimar, Srinager in Research council meet (RCM) during 2008 to study effect of system of rice intensification on grain yield (q/ha), straw yield (q/ha) and test weight (g) of rice and it was observed that the treatment T8 = SRI + 100 % of RDF of NPK through chemical fertilizer gave significantly higher grain yield (q/ha) over all the other treatments and remained at par with T7 = SRI + 50 % of RDF of N through FYM+ 50 % of RDF of N through chemical fertilizer in case straw yield (Table 15). A research trial was conducted at rice research and regional station at Kudhwani by Nazir, N (2010) to study the effect of agronomic manipulation of system of rice intensification SRI practices yield of rice (*Oryza sativa* L.) under temperate valley conditions. 16 days seedlings; 01 seedling hill^{-1}; 25 x 25 cm; RFD + FYM 10 t ha^{-1}; chemical + Rotary weeder; Alternate wetting and drying (AWD) (T_1) gave the higher grain and straw yield as compared to other treatments (Table 16).

Table 15: Effect of System of Rice Intensification on Grain Yield (q/ha), Straw Yield (q/ha) and Test Weight (g) of Rice

Treatments	Grain yield (q/ha)		Straw yield (q/ha)		Test weight (g)	
	2006	2007	2006	2007	2006	2007
T1: Farmers practice	51.38	53.11	65.25	68.28	25.74	26.12
T2: Recommended package of practices	52.80	54.30	66.53	72.11	26.65	27.23
T3: SRI practices	57.52	62.20	72.42	78.24	27.34	28.10
T4: : SRI practices with no fertility	55.24	59.05	68.26	74.05	26.88	27.67
T5: : SRI practices + 50 % N through FYM	58.90	62.22	73.44	78.42	27.19	28.36
T6: : SRI practices + 50 % N through chemical fertilizer	60.65	64.26	73.99	80.08	27.70	28.31
T7: : SRI practices + 50 % N through FYM + 50 % N through chemical fertilizer	61.42	66.36	74.32	82.66	27.62	28.45
T8: : SRI practices + 100 % N through chemical fertilizer	64.77	68.22	77.72	84.20	27.92	28.80
CD at 5 %	2.28	3.06	4.08	4.31	0.46	0.58

Source: RCM *Kharif*, 2008

9) Crop residue management

Combine harvested rice field are being burnt which results in environmental pollution and loss of nutrients.. It is estimated that the burning of one ton of straw releases 3 kg particulate matter, 60 kg CO, 1460 kg CO2, 199 kg ash and 2kg SO_2. ***Z***ero-tillage crop planting, avoids burning of straw of about 10 t/ha which reduces release of 13–14 tons of carbon dioxide (Gupta *et al*., 2004). Happy Seeder technology provides an alternative to burning which cuts, lifts and throws the standing stubbles and sows the seeds in one operation Pass.

Table 16: Grain Yield, Straw Yield (q ha-1) and Harvest Index (%) of Rice as Affected by Different Treatments

Treatment	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Harvest index (%)
T_1	63.23	88.52	44.86
T_2	66.36	93.51	44.23
T_3	67.53	94.54	43.67
T_4	68.56	95.90	42.79
T_5	50.33	70.62	41.62
T_6	51.36	72.01	41.89
T_7	70.86	96.20	43.11
T_8	72.63	101.66	42.72
T_9	74.76	104.64	42.57
T_{10}	77.61	108.68	42.36
SE ± (m)	**1.18**	**1.42**	**0.95**
C.D.(p=0.05)	**3.15**	**4.22**	**NS**

T_1 = 30 days seedlings; 03 seedling $hill^{-1}$; 15 x 15 cm; RFD + FYM 5 t ha^{-1}; Butachlor + 1 hand weeding; Submergence with 3-5 cm water

T_2 = 16 days seedlings; 03 seedling $hill^{-1}$; 15 x 15 cm; RFD + FYM 5 t ha^{-1}; Butachlor + 1 hand weeding; Submergence with 3-5 cm water

T_3 = 16 days seedlings; 01 seedling $hill^{-1}$; 15 x 15 cm; RFD + FYM 5 t ha^{-1}; Butachlor + 1 hand weeding; Submergence with 3-5 cm water

T_4 = 16 days seedlings; 01 seedling $hill^{-1}$; 25 x 25 cm; RFD + FYM 5 t ha^{-1}; Butachlor + 1 hand weeding; Submergence with 3-5 cm water

T_5 = 16 days seedlings; 01 seedling $hill^{-1}$; 25 x 25 cm; FYM 10 t ha^{-1}; Butachlor + 1 hand weeding; Submergence with 3-5 cm water

T_6 = 16 days seedlings; 01 seedling $hill^{-1}$; 25 x 25 cm; FYM 20 t ha^{-1}; Butachlor + 1 hand weeding; Submergence with 3-5 cm water

T_7	=	16 days seedlings; 01 seedling hill^{-1}; 25 x 25 cm; RFD + FYM 10 t ha^{-1}; Butachlor + 1 hand weeding; Submergence with 3-5 cm water
T_8	=	16 days seedlings; 01 seedling hill^{-1}; 25 x 25 cm; RFD + FYM 10 t ha^{-1}; Rotary weeder; Submergence with 3-5 cm water
T_9	=	16 days seedlings; 01 seedling hill^{-1}; 25 x 25 cm; RFD + FYM 10 t ha^{-1}; chemical + Rotary weeder; Submergence with 3-5 cm water
T_{10}	=	16 days seedlings; 01 seedling hill^{-1}; 25 x 25 cm; RFD + FYM 10 t ha^{-1}; chemical + Rotary weeder; Alternate wetting and drying (AWD)

The on-station experiment was conducted by Gathala *et al*., 2011 on sandy loam from 2007 to 2010 at the research farm of Sardar Vallabh Bhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh, India and it was observed that on-station wheat grain yield of ZTW-HST was 10% and 9% higher than CTW and ZTW, respectively. A similar trend was observed in on-farm trials with 3% higher yield in ZTW-HST than CTW (Table 17).

Table 17. Wheat grain yield (t ha^{-1}) under different tillage and residue management methods.

Treatment	On-station	On-farm
CTW	4.13 b	4.67 b
ZTW	4.18 b	4.77 ab
ZTW-HST	4.55 a	4.83 a

Means with the same letters are not significantly different at P = 0.05.

No. of farmers: CTW=61; ZTW= 29; and ZTW-HST= 36

(CTW) Conventional tilled wheat after conventional puddled transplanted rice;

(ZTW) Zero-till wheat without rice residue after zero-till dry direct seeded rice and;

(ZTW-HST) Zero-till wheat drilled directly in the rice residues retained as soil surface mulch using Happy Seeder technology after zero-till dry direct seeded rice.

CONCLUSIONS

Based on findings of long-term experiments as well as experience of farmers participatory trials of RCTs in rice based systems, it can be concluded that direct seeded rice under double no till with laser land levelling reduced cost of cultivation and improved the crop yields and system productivity while conserving natural resources. The technology does not affect rice quality and can be practiced in different ecologies including upland, medium and lowland, deep water and irrigated areas by large as well as small farmers**.**

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