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Effective newer tillage options in rice-wheat system - an Indian perspective

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ABSTRACT

After Green revolution emphasis was for production of more food grains particularly rice and wheat. Recent estimates suggest that rice and wheat contribute 77.7% of total food grain production in the country. Among the various wheat based cropping systems, rice (Oryza sativa L.)- wheat (Triticum aestivum L.) crop sequence is the largest agriculture production system occupying 10.3 million hectare in India. Approximately 23 and 40 % of total rice and wheat area, respectively, is represented by rice-wheat system in India, which requires contrasting edaphic conditions Continuous adoption of this system and imbalance and injudicious use of fertilizers have been reported to decline soil and crop productivity resulting in lower profit margin of farmers. This necessitated thinking of reduction of cost of cultivation and also simultaneously enhancing grain yield. Since more than decades a go efforts were initiated to reduce the cost of cultivation by adoption of resource conservation technologies under rice-wheat system. Zero tillage, an eco-friendly technology, reduces the cost of cultivation to the tune of Rs 2500- 3000/ha besides many other additional benefits. Bed planting saves irrigation water (20 – 30 %), reduces lodging (50-60 %) and Phalaris minor population and provides additional window for maximizing wheat yield of varieties. This chapter describes pros and cons of various resource conservation technologies adopted and some in pipeline under rice-wheat system.

Key words: Rice-wheat system, tillage options, wheat

Rice and wheat are the world's two most important cereal crops, contributing 45% of the digestible energy and 30% of total protein in the human diet, as well as a substantial contribution to feeding livestock (Evans 1993). Rice and wheat are the major food crops of the Indo-Gangetic Plains (IGP) region. It has been reported that contribution of only these two cereals resulted a quantum gains in food grain production. During last four decades the growth rates of rice and wheat production in South Asia (2.5% and 5.2% per year, respectively) exceeded the population growth rate (2.22% per year), indicating an increase in the per capita availability of these two cereals that strengthen the food security, reduced rural poverty, and increased affordability of food at cheaper prices in the region (Pingali and Shah 1999). This happens due to advent of high yielding cultivars of rice and wheat and their intensive production technology. Demand for rice and wheat is expected to grow at 2.5 % per year over the next two decades but it will become increasingly more difficult as the per capita ricte–wheat growing area has already shrunk from 1200 m^2 in 1961 to less than 700 m2 in 2001 (Singh *et al.* 2002). Inevitably, this encouraged large-scale sequential cropping of rice and wheat in millions of ha even in non-traditional areas for both crops. The climate of the IGP has been also favorable for rice and wheat to be grown in a double cropping pattern within one calendar year, rice in the summer and wheat in the winter.

Table 1 Area of rice-wheat systems, their contribution to rice-wheat system area and to total cereal production in various Asian countries.

Country	Rice-wheat area		Area contribution (%) of the system-crop to the total area of individual crop				Contribution of rice and wheat to total cereal production‡	Contribution of rice-wheat systems to total rice and wheat production†
			Rice		Wheat			
	Estimate 1†	Estimate 2‡	Estimate 1	Estimate 2	Estimate 1	Estimate 2		
	---Mha-------		---%---					
China	-	13.5	-	31	-	35	72	-
India	9.1	10.3	22.3	23	38.7	40	85	25.7
Pakistan	1.6	2.2	80.3	72	22.4	19	92	35.8
Bangladesh	0.5	0.5	4.9	5	84.7	85	100	7.9
Nepal	0.6	0.6	34.3	35	81.7	84	71	77.6

†, Hobbs and Morris (1996). ‡, Timsina and Connor (2001).

Rice-wheat cropping system (RWCS) has emerged as a major cropping system of the region in the last three decades. Presently this cropping system has been practiced on nearly 13.7 million ha (10.3 m ha in India, 2.2 m ha in Pakistan, 0.5 m ha in Bangladesh, and 0.7 m ha in Nepal) in the Indo-Gangetic plains (Gupta *et al.* 2003; Huke *et al.* 1993 a,b,c;

Ladha *et al.* 2000; Lianzheng and Yixian, 1994; Razzaque *et al.* 1995; Timsina and Connor 2001; Woodhead *et al.* 1993; 1994). The contribution to the total area, total production of the cereals and of the individual crops in IGP countries (excluding China) is mentioned in above Table 1.

PROBLEMS IN RICE – WHEAT CROPPING SYSTEM

Although production problems are unique to each transect/region of the IGP, the description of complex inter-related factors include delayed transplanting of rice, excessive tillage, weed infestations and soil wetness, delayed planting of winter season crops with resultant low crop productivity in the R-W systems. Herbicide resistance and problems with lowering water tables were major factors for unsustainability of R-W system in northwest IGP (Malik *et al.* 1998). Added concerns of residue management, organic matter decline, low input use efficiency, water-table declines, salt build-up and reduced environmental quality only suggest that rice-wheat systems are unsustainable (Ladha *et al.* 2003) in their present form in many areas. Rice-wheat monocropping in IGP has been showing signs of exhaustion and concerns are now being expressed about the sustainability of rice-wheat systems (Hobbs and Morris 1996). Continuous cultivation of rice and wheat is lowering soil fertility and organic matter (Yadav *et al.* 1998), depleting ground water resources in tube-well irrigated areas (Gulati 1999), exacerbating weed and herbicide resistance in weeds (Malik 1996), disease and pest problems (Pingali and Gerpacio 1997). Even micro-nutrient deficiencies started appearing in the IGP with the adoption and spread of intensive agriculture (Nayyar *et al.* 2001). In the northwest, essentially a wheat-based production system, introduction of intensive rice cultivation has raised concern about environmental sustainability due to antagonism between the current soil-water production requirements of the two crops. Sustainability of the production system is threatened by over-exploitation of ground water and inappropriate water-management practices, especially in the western transect. Canal water accounts for 35-40% of the total irrigation requirement and the remaining is met from groundwater. This has resulted in decline in the water tables and water quality in many regions (Sinha *et al.* 1998). In parts of the eastern IGP (largely West Bengal and Bangladesh) the groundwater, that is irrigation extensively for Boro rice cultivation and also for drinking, contains high concentration of toxic arsenic in about 45 out of the 64 districts, mostly in the Gangetic flood plains (Islam *et al.* 1999). There are many reasons for high water usage, such as zero or negligible tariffs on farm power in some states of India; no additional costs for extracting extra water; inadequate canal water; the cultivation of crops with a high water requirement (e.g. rice and sugarcane) in the low rainfall regions; and assured markets. It seems to be a rather difficult task to achieve this incremental food production from the intensively cultivated areas, which are already showing signs of fatigue. Indicative problems of system ecology such as soil organic carbon decline, secondary salinization, greater incidence of multiple micronutrient deficiencies and emergence of herbicide-resistant new weed biotypes are major challenges for sustainability of the rice-wheat systems. This necessitates that productivity gains in intensively cultivated areas are not only secured but further enhanced; and the gray areas made greener to reduce pressure on natural resources in the IGP (Gupta *et al.* 2005).

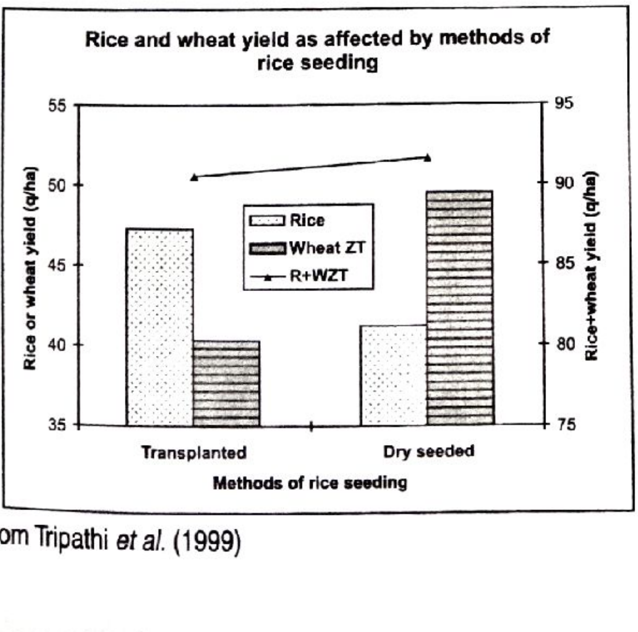
It is apparent that unsustainability of R-W system has been associated with late planting of wheat after rice, depletion of ground water and contamination of surface and ground water, over mining of plant nutrients from soil pool, reduction in soil organic carbon, emergence of weed and pest problems etc. A diagnostic study of constraints in rice–wheat cropping systems (RWCs) showed that a high population of *Phalaris minor*, a serious weed of wheat in the RWCs, and a decline in soil productivity were two major constraints of the system (Harrington *et al.* 1992). Other causes of decline in the total factor productivity of the RWCs throughout the region included decline and changes in soil organic matter, a gradual decline in the supply of soil nutrients causing macro and micro nutrient imbalances due to inappropriate fertilizer applications, a scarcity of surface and groundwater, and in some places poor water quality (Paroda *et al.* 1994). Considering these facts related to low productivity of rice-wheat cropping in Indo-Gangetic Plains a number of alternative tillage technologies have been tried. The main alternatives tillage technologies used so for has been described as under.

ZERO TILLAGE

Efforts to adapt and promote resource conservation technologies in IGP have been underway in early 1990s. Efforts have been made to develop and extend zero tillage in IGP (Indian region) through the combined initiatives of several SAUs, ICAR institutes and international institute like CG system, specifically, Rice-Wheat Consortium for the Indo-Gangetic plains. Unlike, in the rest of the world, spread of technologies is taking place in the irrigated regions in the IGP where rice-wheat cropping system dominates. Zero-tillage and bed planting have the potential of water savings but the extent of savings at different levels and its likely impact of the restoration of regional hydrological sustainability are little known. Positive effect was noticed for laser leveler in improving crop establishment, uniformity of crop maturity, 3% (canal irrigated) to 6% (tubewell irrigated) increase in cultivable area, increase in water application efficiency upto 50%, increase in water productivity, yields of crops (15 to 25%), 35-45 % savings in irrigation water, increase in nutrient use efficiency (15-25%), weeds control etc., (CASA 2004). Due to the above mentioned benefits level of adoption at farm level is increasing. Field experiments at Modipuram using resource conservation technologies such as aerobic cultivation of rice on raised beds enable to grow rice on non-puddled, enhancement of resource use efficiency (land, labour and water) to improve the sustainability of intensive rice-wheat systems. Long term experiments since 1998, at Modipuram conducted to evaluate five conservation tillage practices namely, zero till drilling, strip till drilling, rotary till drilling, bed planting and conventional sowing and three crop residue management practices namely, residue retrieval, residue burning and residue recycling revealed several benefit over the conventional agriculture like savings in time, labour, fuel, cost, energy, yields etc., (CASA 2004). The main focus of the developing and promoting Resource Conservation Technologies has been wheat crop in the rice-wheat cropping system.

Evaluation of zero-till transplanted rice (unpuddled) at farmer's fields in Upper IGP revealed a higher yield but more infestation with grey weeds. This raises the question here, whether rice is amenable to zero tillage. Zero tillage is currently being adopted mainly in wheat crop in Rice –wheat cropping system. (CASA 2004). Edaphic requirements of rice do not permit either zero-tillage or surface retention of crop residues. The cropping systems strongly influences resource quality through processes such as nutrient depletions and /or enrichment through underground biomass/ crop residues, need for external inputs, impact on environment etc. When rice is grown after 'zero' till wheat, these benefits are not likely to occur. Various researches showed that by using zero and reduced tillage options, wheat can be planted on time at reduced cost without sacrificing yield (Hobbs *et al.* 1998; Hobbs and Gupta 2003; Gupta *et al.* 2005; Tripathi *et al.* 1999)

In the rice-wheat cropping system, the two crops have contrasting edaphic requirements. Whereas, rice is commonly transplanted into puddled soils and gets continued submergence, wheat is grown in upland well drained soils, having good tilth. Puddling reduces infiltration of water but destroys soil structure. Expecting a better wheat crop, farmers generally do 6-8 preparatory ploughings in rice drying soils to achieve good seed bed. However, excessive tillage results in late planting and reduced wheat yields. The turn around time between rice and wheat crops is 3- 6 weeks. In order to timely plant wheat, many farmers harvest the rice crop with a combine and burn loose residues. Burning releases greenhouse gases and particulate matter in large quantities in sudden spurts. This deteriorates the air quality and results in significant losses of nutrients (Sharma and Misra 2001). Direct seeding of rice saves energy and water for rice establishment and eliminates labour in transplanting. It can result in earlier maturity of rice, which helps improve wheat productivity through timelier establishment. Zero-till wheat is now an established crop management activity for farmers in rice-wheat areas of NW-IGP. This is another RCT, in which the seed is placed into the soil by a seed drill without prior land preparation. This technology, which has been tested various regions of IGP (Sheikh *et al.* 1993; Aslam *et al.* 1993), is more relevant in the higher-yielding, more mechanized areas of northwest India and Pakistan, where most land preparation is now done with four-wheel tractors. No-till helps solve the problem of late planting and excessive costs of production in wheat, but if rice can be grown without puddling, the total system productivity would be even greater. Changing from transplanted, puddled rice to direct seeded aerobic rice would also reduce methane emissions significantly, a green house gas that is 21 times more effective than carbon dioxide (Grace *et al.* 2003).



From Tripathi *et al.* (1999)

The experiments conducted at DWR, Karnal showed that zero till wheat under dry seeded condition recorded 14.3% higher grain yield compared to transplanted rice conditions. On the other hand, rice yields were higher under transplanted condition than dry seeded which ultimately resulted in similar rice-wheat productivity (Tripathi *et al.* 1999). Maximum wheat production under zero tillage situations could be obtained by use of 25% higher seed rate over the recommended practice (Tripathi and Chauhan 2000). In this altered tillage situation, first irrigation should be given 15 to 18 days after sowing for proper crop establishment. However, this requirement will depend upon the soil type and prevailing agro-climatic conditions.

BENEFITS OF ZT

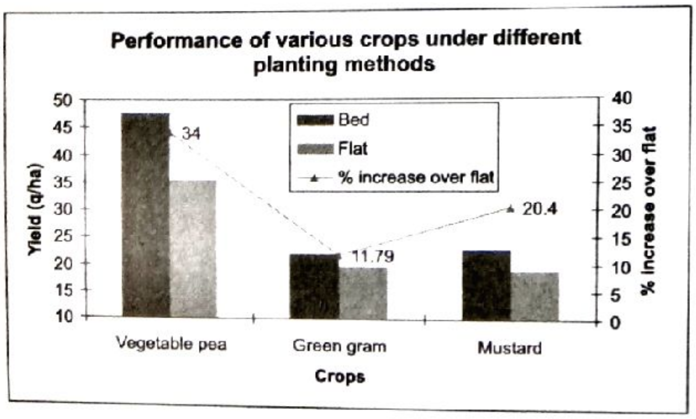
Zero tillage technology has several advantages over conventional tillage and some important ones includes saving of 92% diesel, which comes to 61 litres/ha for field preparation and sowing compared to conventional system. Thus, it reduces the cost of cultivation (Rs 2500-3000/ha), saves forex, advances time of wheat sowing (4-5 days), requires less water for first irrigation and less infestation of *Phalaris minor*, which is a burning problem in North-West India. If savings on account of diesel requirement for tillage per hectare are extrapolated for 10.5 million hectare area under rice-wheat system then about 640 million litres diesel per year will be saved, which comes to 200 million US $ per year (excluding subsidy from Indian Government). Besides this, it provides eco-friendly wheat cultivation by reducing 135 kg Co_2/ha (assuming 2.6 kg Co_2 production/ litre of diesel burnt), which is one of the major fossils for global warming. In Haryana, scientists and extension agencies at the university and state level took the popularization of zero tillage on war footing and as a result it became popular among farmers (Chauhan *et al.* 2000, 2001).

BED PLANTING

The Resource Conservation Technologies (RCT's), which were evolved with the efforts of scientists, farmers, extension workers and private industry groups gained importance due to increased profit to farmers. The 'Bed Planting', an important input saving planting technique, especially water (20-30%), was introduced in India on the pattern of CIMMYT, Mexico. In this planting method, crop is grown on top of bed (40 cm) and irrigation is applied in furrows (30 cm). There are many additional benefits including lesser seed and nutrient requirement, opportunity for enhancing diversification and intercropping, moving towards conservation agriculture by using same beds for succeeding crops, reducing cost of cultivation, lesser lodging (Tripathi *et al.* 2002) furrows providing efficient passage for irrigation as well as for drainage (Sayre and Moreno Ramos 1997), increased surface area for capturing more rainfall, possibility of mechanized interculture operations as well as placement of fertilizer, manual and easy rouging, higher productivity of oilseed and pulses as compared to flat planting, additional window for maximizing yield with the help of interaction study of RCT's and wheat varieties (Tripathi *et al.* 2002, 2005). Bed planting, sometimes termed as Furrow Irrigated Raised Bed (FIRB) technology, works as catalyst for diversification of rice-wheat system.

Studies on eight crop sequences showed that diversification/intensification of rice -wheat system, once in three years, always enhanced the net return, when all crops (except rice) were grown on raised bed in a system approach. Inclusion of oilseed or pulses once in three years or intensification by growing vegetable pea in between rice and wheat or green gram after wheat showed higher return compared to conventional rice-wheat system (Tripathi *et al.* 2004). Study conducted by Connor *et al.* (2003) in a farmers participatory trial in India showed that following crops planted on bed gave higher grain yield: maize (37.4%), urdbean (33.6%), mungbean (21.8%), greenpeas (14.5%), wheat (6.4%), rice (6.2%), pigeon pea (46.7%) and gram (37.0%) as compared to flat planting. Moreover, there was a saving of 26 to 42% irrigation water under bed compared to flat planting by various crops.

Bed planting will also grow in popularity as more machinery and more farmers experiment with it. Permanent bed planting will cut costs, improve yields and drastically reduce natural resource use, especially water. The technology needs to be adapted to smaller two-wheel and animal drawn systems that would be more reasonable for the resource poor farmers of the eastern IGP where plot size is also much smaller. In low lying areas of eastern UP, Bihar (India) and parts of Bangladesh where water recedes late or soils remain wet for long, farmers seed lentil, peas and wheat on drying paddies a couple of days before harvest of rice (Razzaque *et al.* 1995 and Gupta *et al.* 2002). In comparison to north-western IGP, eastern farmers diversify the R-W systems more to covers risks of drought-flood prone agriculture. Many farmers replace wheat by oilseeds (*Brassica juncea* or napus), pulses (pea, *Pisum sativum*), grass pea (*Lathyrus* spp.), chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), potato or sugarcane and occasionally rice by pigeon pea (*Cajanus cajan*), maize, sunflower and sorghum. Winter maize is also popular in eastern parts of the Gangetic Plains in Bihar and UP, and Bangladesh.



Crops like green gram, vegetable pea, mustard, pigeon pea, maize and wheat were grown on flat and raised bed and it was observed that bed planting exhibited higher yield compared to flat planting. Vegetable pea (as a green pod), mustard and green gram recorded up to 34.0, 20.4 and 11.8 % higher yield as compared to flat planting, respectively. This showed that bed planting could be used for diversification/ intensification of rice-wheat system with better returns.

TILLAGE AND GENOTYPE INTERACTIONS

In most of the agronomic research there is lack of interaction study with respect to genotype to exploit the full potential of any cultivar. It is generally believed that a cultivar performing better at high fertility condition or in fine tilth soil will also do better in the just opposite situations i e low fertility / no till situations. In the altered tillage scenario like bed planting it was observed that there is interaction between the genotype and planting method for the yield as well as other yield attributing parameters (Sayre and Moreno Ramos 1997, Tripathi *et al.* 2002, 2005). The wheat crop planted on beds produces bolder grain resulting higher thousand grain weight with lesser lodging. Therefore, there is need to develop new plant type for the new tillage system in wheat or aerobic rice cultivar to harness the potential yield in a system perspective. Bed planting reduces lodging owing to lesser water contact on wheat culm and increase in thickness of basal internode. At the same time furrow provides easy movement of air. This planting method also reduces the population of *Phalaris minor* on the top of bed due to faster drying and lesser soil moisture compared to furrows. It also provides an opportunity of mechanical weeding in furrows and on the top of beds, if two rows are grown, at an early stage of the crop. At later stages, if weeds are still left then manual weeding is also easy.

Table 2 Interaction between planting method and varieties on grain yield

	Grain yield (kg/ha)		
Planting methods (M)	Flat	Beds	Permanent -Beds (without residue)
Varieties (V)			
PBW 343	8460	8411	5722
Baviacora 92	8776	9475	7103
WH 542	8817	8933	6137
Rayon 89	8079	8187	6095
LSD (MxV) at 5%			245

Source: Tripathi *et al.* (2002)

SURFACE SEEDING

Surface seeding is the simplest zero-tillage system being promoted. In this tillage option, wheat seed is placed onto a saturated soil surface without any land preparation. This is a traditional farmer practice for wheat, legume, and other crop establishment in parts of eastern India and Bangladesh (Catling *et al.* 1983). Wheat seed is either broadcast before the rice crop is harvested (relay-planted) or after harvest. Broadcasting of dry or soaked wheat seeds a few days before or after harvest of rice under wet soil / saturated condition. This technology performs well in situations where wheat sowing is not possible due to wet soil condition inhibiting immediate tillage operations after harvest of paddy. Surface seeding provides an elbow space for growing wheat, eliminating tillage cost and doubling cropping intensity. It helps in bringing more area under wheat cultivation. Depending on soil wetness, dry or soaked seed (in fresh water for 6-10 hours) can be used for seeding. Soaked seed should be preferred as it germinates quickly and uniformly. If dry seeds are to be used, seeding should be done in the afternoon to facilitate imbibition of water and swelling of seeds in cooler environment. It is essential to maintain saturated conditions till root anchorage. Water stagnation should not be allowed to ensure proper germination and good crop stand.

Surface seeding could be employed under low land rice-wheat cropping system where excessive soil wetness is the main constraint for taking another crop after harvest of rice. This type of soil dominates in clay or silt or both with high water storage capacity and remains sticky for longer period, which does not permit the tillage operation. Such conditions are found in parts of eastern UP, Bihar and West Bengal. In North-West India also, the poor farmers, who can not afford to hire tractor for land preparation, surface seeding of wheat in standing crop of rice will be the right option to be adopted for reasonably good production of wheat at minimum cost (Tripathi et al. 2000). Important benefits of this technology is as under.

- Provides additional window for increasing the wheat area by doubling the cropping intensity.
- Reduces 25-30 per cent cost of cultivation and eliminate the need for tillage operations.
- Money saved by elimination of tillage practices could be utilized for other purposes.
- Poor farmers need not to maintain their bullocks or hire tractors for tillage operations.
- Utilizes residual soil moisture and saves the water required for seedbed preparation.
- Reduces the turn around time by early sowing of wheat.

NEW MACHINERIES/SEED DRILLS

Combine harvesting of rice leaves anchored stubbles of 30-45 cm height along with loose straw in strips. It is not feasible to decompose this loose residue in 2-4 weeks time before wheat sowing. Seeding of wheat or any other crops in loose residue of rice was major impediment for the good crop establishment. The initial good crop stand ensures the success of any crop to great extent. The recent development in machinery sector is a boon to address the long standing problem of the farmers. The important features of some of the machines are as under.

ROTARY DISK DRILL

This machine works on the principle of rotary mechanism followed by attached disc to facilitate a cutting edge resulting into a conservation agriculture practice by keeping the crop residue intact with the soil. The beauty of this machine is to sow the wheat seed in loose paddy residue and vice versa, which was a long standing problem of farmers of India particularly north west India. This will reduce the burning of crop residues of both crops i.e. rice and wheat, leading to eco friendly cultivation (Sharma *et al.* 2005). The other features of the machine like seed and fertilizer metering and delivering system are similar with zero till fertilizer cum seed drill, which is also capable of seeding in partial burned or 30-35% standing rice residue. The rice straw is very rich in silica, therefore, high quality rotary plates are required to enhance the longevity of the machines. This will enable the farmers to cover more area without much maintenance cost. The performance of this machine is slightly better in dry soil rather than wet soil.

HAPPY SEEDER

This machine was developed at PAU, Ludhiana in collaboration with international institutes and works on the principle of chopping the paddy straw and putting as mulch after seeding. Happy seeder combines two units, one straw management unit and another sowing unit. Straw management unit cuts and lift the standing stubbles and loose straw and throws this material behind the sowing unit on the sown field. This machine completes the sowing operation in combine harvested field in a single pass at the same time retain the rice residue as surface mulch. The latest model includes development of straw managing rotor to cut the standing stubbles for a width of 75 mm straw width thus leaving 125 mm strip of standing stubble between two furrows. The above modification reduced the total straw load by nearly 30%. This PTO driven machine can be operated with 45 hp tractor and can cover 2.5-3.0 ha/ day. Machine cost is about Rs. 60, 000/-.The advantage of this machine over previous one is that it spreads the paddy straw uniformly whereas previous one cuts in situ due to heap of rice straw in strip after combine harvesting (Sidhu and Thakur 2007).

PUNCH PLANTER

This machine works on the principle of piercing the one seed at a time in to the moist zone. This can work under tilled or untilled with and without residue conditions. The minor problem is only when the loose residue were lying on standing stubbles. This machine some times piles part of residue, which hinders the seeding of the machine. It is better to improve the shortcomings of this machine as a future strategy so that this will be able to sow any crop in any condition. Generally high seed rate of cereals are recommended due lack good machines. The main feature of this machine is that it can reduce the seed quantity to 50 %. Probably, this will be the cheapest and versatile seeding machine among all the second generation development machineries. The fuel consumption should also be very less compared to rotary disk drill or happy seeder where one additional operation is involved.

ECONOMIC BENEFITS

Application of herbicides will reduce employment in agriculture for some of the poorest people, including women, who are replacing men in India's rice fields. Under the farmers' field conditions Malik *et al.* (2002) observed that four year continuous zero-till practice can significantly reduce the investment on weed control On average, based on many monitored zero-till farmer fields in India, yields of zero-till wheat are from 2-400 kg/ha more. This works out to \$20-40 per hectare extra income. Gill and Ahmed (2003) in Pakistan showed a 500 kg increase in yield from fields they monitored. Since plowing is dramatically reduced, farmers use 40-60 liters less fuel for land preparation and planting than conventional systems. Vincent and Quirke (2002) did a complete economic analysis of the benefits of controlling Phalaris minor weeds and use of zero-tillage in Haryana State of India and based on various sources used a Fig. of \$50 savings per hectare using zero-till. Additional savings are obtained from less pumping or water charges, labor and less wear on equipment. The savings in fuel results in significant reductions in greenhouse gas emissions. In the rice-wheat system, wheat weeds differ from rice weeds and as such zero-till results in less soil disturbance and less (30-60%) wheat weeds germinating (Malik *et al.* 2002). Less water is used for the first irrigation because water flows faster across a zero-till field than a plowed field. Less water is needed in zero-till (15-25%) and bed planting (25-50 %) and in fact water logging of wheat is not seen after irrigating zero-till and bed planted wheat but is commonly seen in conventionally plowed wheat. In zero-till, the drill places the seed and fertilizer in sub-surface bands resulting in better germination. It was found that adoption RCTs in India and Pakistan resulted net benefits, higher yields and lower land preparation costs, of more than US\$150 million in winter 2003 alone. Use of zero-tillage for wheat saves about 50 liters of diesel per hectare, representing a savings of 75 million liters, worth more than US\$ 37 million, regionwide (RWC-Highlights 2003-04).

ENVIRONMENTAL BENEFITS

The intensification of rice-wheat rotations has resulted in a more dependence on irrigation, amplified fertilizer usage, and crop residue burning, which all have a direct effect on the variable that most affects global climate change-emissions of greenhouse gases. It has been estimated that the Co_2 equivalent emissions from a high-input, conventionally tilled cropping system with residue burning and organic amendments would equate to 8 Mg C or 29 Mg CO_2 per year if applied to 1 million ha of the Indo-Gangetic plains. In a no-till/residue-retained system, with 50% of the recommended NPK application, the total emissions would equate only to 3.7 Mg C or 14 Mg CO2 per year, an effective halving of emissions as we move from a high to low input system with improved nutrient use and environmental efficiency (Gupta *et al.* 2005). The transition to intensified zero-tillage systems, with recommended fertilizer levels, can be both productive and environmentally sound in a world that is rapidly becoming aware of the significant effects of global climate change in both the short and long term. Early results indicate that 1 ha of wheat planted using zero-tillage requires up to 1 million liters less irrigation water than the same crop grown under conventional tillage.

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