Environmental impact of resource conservation technology: the case of zero-tillage in the rice-wheat system of South Asia

Suresh Pal
I Sekar
Amit Kar

Division of Agricultural Economics

Indian Agricultural Research Institute, New Delhi

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1. Introduction

Evolution of the rice-wheat cropping system (RWS) in the Indo-Gangetic Plains in a way represents the path of agricultural development in South Asia. Although this system has been practiced since the 16th century, it spread widely with the expansion of canal and tubewell irrigation during the 1960s and 1970s (Woodhead et al., 1994). Availability of high-yielding varieties (HYVs) of rice and wheat has further expanded the area under RWS, ushering the Green Revolution in the region. Eventually, the system emerged as one of the most wide spread, intensively cultivated and extremely important for the food security and agricultural prosperity. It is estimated that RWS is followed on more than 14 million hectares of agricultural lands and nearly two-thirds of the existing cereal supplies comes from this system in the region.

Some recent analyses indicate that RWS in the Indo-Gangetic Plains is now faces a number of stresses. The growth in crop yields in the north-western plains (Punjab, Haryana and western UP) with higher crop yields is decelerating, and the system intensification is putting pressure on land and water resources and ecology. Micro-level parameters like properties and fertility of soil, pest infestations, nutrient balance, etc. indicate a deteriorating trend (Timsinha and Connor, 2001), while trends in the macro indicators like groundwater exploitation and total factor productivity are also a cause of worry. A similar tendency is appearing in other parts as well. The immediate consequence of these changes is reported to be a threat to long-term sustainability of the system (Paroda et al., 1993; Pingali 1993; Byerlee 1992, Fujisaka et al 1994). There is apprehension that food security of the region may be under pressure if these undesirable trends are not corrected in time through suitable technological and policy interventions.

The national and international research organizations and donors have made concerted efforts to improve productivity and environmental sustainability of RWS. Integration of research efforts of the CGIAR Centres and the national agricultural research systems in the region and mobilization of additional resources from international donors have been attempted through several programs and research consortia. In terms of research focus, major thrusts areas pursued were development of high yielding of rice and wheat, tillage and crop residue management, reclamation of salt-affected lands and water and nutrient management. Small-scale mechanization, system diversification, analysis of socio-economic issues and on-farm experimentations and demonstrations were also received considerable attention (Hobbs et al., 2000, RWC 2004). These programmes resulted into several important outcomes. In particular, resource conservation technologies like zero and reduced tillage made significant impacts.

Early impacts of these technologies using early adoption data have been documented. The results showed that there is significant reduction in the cost of production of wheat (Vijaylaxmi et al, 2007, and Erenstein et al, 2008). As a result, dissemination of these technologies was taken by the government departments. In addition to economic benefits through reduced tillage cost, the system also realized some environmental benefits like saving of irrigation water and lower carbon emission. This study analysed these benefits using farm level data. Economic impacts in newer areas, viz. Eastern IGP are also documented. These research impacts are analyzed in the context of changes taking place within RWS, especially new tillage and crop management technologies being introduced in the system.Attempts were also made to assess the value of environmental benefits like saving of irrigation water. Due to paucity of time and resources, empirical evidences were confined to the Indian region of RWS.

2. The rice-wheat system

The RWS in India is largely practiced in the states of Uttar Pradesh (UP), Punjab, Haryana, Bihar, Madhya Pradesh (MP) and West Bengal. However, much of the RWS area is concentrated in the states of UP, Punjab, Haryana and Bihar. Stability of the area under RWS or even expansion wherever possible indicates that rice and wheat crops still enjoy superiority over other crops, both in terms of economic returns and their stability. Infrastructure, market and price policy also favor rice and wheat crops, resulting widespread cultivation of the system and government market operations (Chand and Pal, 2003).

2.1 Agric characteristics and contributions

The states practicing RWS are primarily agrarian states. The share of agriculture in the state gross domestic product is higher than the national average of 18 percent. In Punjab this share is as high as 30 percent. In terms of area, these four states contribute nearly 30 million hectare to the national agricultural land of 140 million hectare. The RWS in India area is about 10 million hectare and nearly half of this is in Uttar Pradesh. Adding Bihar gives nearly 70 percent of the total RWS area. However, crop productivity is low and the combined yield of rice and wheat is 3-5 tonnes/ha in these states. This is against more than 7 tonnes/ha in Haryana and 8tonnes/ha in Punjab (Table 1). Thus, RWS in India can easily be characterized into high productivity region of Punjab and Haryana and the low productivity region of UP, Bihar and other eastern region. The eastern region is primarily rice grown region with high rainfall and productivity is now picking up. Another significant characteristic of agriculture in the low productivity region is that it is primarily smallholder agriculture. The current official statistics indicate that average size of holding is less than one hectare in UP and Bihar, where as it is 2.4 ha in Haryana and more than 4 ha in Punjab. In fact, average size of holding isincreasing in Punjab because of outmigration of population and changes in agrarian structure through consolidation of holdings and reverse tenancy. Infrastructure development like irrigation, rural roads and markets, input use and farm investment also echo these two diverse development trends.

The sources of growth in output also show a distinct pattern. The growth in total factor productivity (TFP) contributed about one-third to output growth in the Trans-Gangetic Plains of Punjab and Haryana, and the rest was contributed by the growth in inputs and area since 1980s. This trend was observed a bit later in the 1990sin UP and Bihar. The decomposition of growth in TFP showed that investment in agricultural R&D was the major source of growth in TFP (Kumar, 2004). This implies that, when the hope of output growth in future is pinned on the productivity growth, agricultural R&D should be targetted to provide technological solutions for binding system constraints.

2.2 Trends in productivity of rice and wheat

Trends in yield of rice and wheat in the high (Punjab and Haryana) and low (Bihar and UP) regions since the mid-seventies are shown in Figures 1 and 2. These figures show that crop yields in the low productivity states are almost half of that in the high productivity states of Punjab and Haryana. The gap in wheat yield widened between the two regions because of higher yield growth witnessed in Punjab and Haryana. However, wheat yields became stagnant in the current decade in both the regions, which is a cause of concern. Rice yields have maintained an uptrend since the mid-seventies but this was sharper in Punjab and Haryana. Further rice yield also stagnated in UP and Bihar during the last one decade or so but it showed significant increase in the recent period in Punjab and Haryana, which could be attributed to development and spread of high yielding superfine rice varieties.

A complete picture of trends in inputs and productivity is best given by total factor productivity (TFP), which is often used, along with other indicators, to assess sustainability of a production system. The study of the growth in input and output indices and TFP in the Indo-Gangetic Plains since 1981has slowed that during the 1990s as compared to that in the 1980s. Only in the South Bihar Plains there is an appreciable increase in TFP growth. Overall, the growth rate of TFP during 1981-96 has been around one per cent in the plains of Punjab, Haryana and south Bihar, and it is slightly lower than one per cent in other parts of Bihar. In fact, it is a matter of concern that the TFP growth is either negative or stagnant on about 35 percent of the entire RWS area, and on another 12 per cent of the area, the TFP growth is less than one per cent (Kumar, 2002). These trends are quite alarming. Efforts are made to provide technological options to reduce cost of production and enhance sustainability of land and water resources. Resource conservation technologies like zero-tillage have shown considerable success in this regard and some other like aerobic rice, laser leveling, and short duration rice are at on-farm experimentation stage. The experience of zero-tillage can be used to target these technologies and accelerate their adoption.

2.3 Irrigation and groundwater development

Irrigation development, coupled with HYVs, has been prime source of agricultural development in the region. In the early phase, the focus was on development of canal irrigation, but major expansion of irrigation occurred because of exploitation of groundwater. Since the beginning of the Green Revolution, there was significant increase in investments, mainly private, in tubewell irrigation because of manifold increase in crop productivity and impact of irrigation on cropping intensity. Now area irrigated by tubewell irrigation is as high as 68 percent in Punjab and 54 percent in Haryana (Table 2). Although the strategy of assured irrigation by tubewellspaid rich dividends in terms of rapid increases in crop productivity, there have been three notable ill-effects of irrigation. First and foremost is the rapid depletion and deterioration of groundwater, particularly in north-west India, largely practicing RWS. In majority of the districts of Punjab and Haryana, there is over exploitation of groundwater potential, and annual decline in groundwater level is more than 20 cm, resulting in a fall in water table more than 4 meters during the last twenty years. Three-fourths of the blocks in Punjab and half of the blocks in Haryana have been categorized as overexploited (groundwater exploitation more than 100 percent). The aggregate level of groundwater development has reached 145 percent of annual recharge in Punjab and 109 percent in Haryana. This is against an all India average of 58 percent (Table 2). This has made farmers to deepen their tubewells and install submersible pumps, leading to further mining of groundwater. This is not only making the system unsustainable and hastening the worrisome tomorrow, but also increasing inequality between small and large farmers, as investment in tubewell irrigation may soon reach beyond the capacity of small farmers. A similar trend is seen in other states also.

Development of tubewell irrigation also led to neglect of canal irrigation. This coupled with inadequate and uncertain supply of canal water and poor maintenance of canal system led to decrease in the proportion of area irrigated by canal. In other areas, mainly in canal head areas, land and water resources are deteriorating because of salinity, alkalinity and water-logging. These negative developments are also a serious threat to long-term sustainability of agriculture, in general RWS, in particular, and therefore, require immediate corrective measures. The former problem could be addressed by encouraging conjunctive use of surface and groundwater, while the latter require promotion of drainage system and adoption of technologies to reduce these abiotic stresses. Institutional aspects of surface irrigation focusing on maintenance of canal system and cost recovery should be accorded due importance.Also technological advancements like drip and sprinkler irrigation and water-saving practices for efficient use of irrigation water deserve high priority (Vaidyanathan, 1999). Some efforts have been made in this direction and the success is confined to zero-tillage and raised bed planting in wheat. These technologies are under some short of experimentation and adaptation and a breakthrough in terms of their successful application in rice will make desired impact.

The situation of irrigation development in Bihar is quite different from that in Punjab and Haryana. Groundwater exploitation is low and canal system is not that well developed. Since rainfall is high, not that many number of irrigations are required for paddy; supplementary irrigation is provided by deep and in some places shallow tubewells when there is deficit rainfall. Because of weak infrastructure of electric power and uncertain power supply, majority of the farmers use diesel-operated pumpsets. However, wheat is also grown on residual moisture with irrigation support of tubewells. In this region, irrigation development should be seen as part of overall management of water resources. This requires: (a) investment in land development to control floods, manage excess moisture and use of canal irrigation, (b) supply of electricity to encourage groundwater development, and (c) institutional development for use of water resources (Kumar and Jha, 2002).

3. Technology adoption pattern

3.1 Historical trends

A good deal of research efforts has been made by the national R&D system to develop and disseminate resource-conservation technologies (RCTs) for RWS in the Indo-Gangetic Plains. RWC has further strengthened these efforts by mobilizing additional resources and fostering research partnerships. As a result, zero-tillage wheat and other resource conservation technologies like raised bed planting, direct seeding of rice on puddled and unpuddled beds and laser land leveling were promoted through on-farm experimentation (Gupta and Seth 2007). Among these, ZT wheat is adopted by a large number of farmers in Haryana and Punjab. The technology involves direct sowing on wheat after paddy using zero-till seed drill in a single pass, whereas the conventional tillage involves several land preparation operations and therefore high cost of land tillage. The technology however initiallyfaced considerable resistance from the farmersas it was against traditional wisdom of intensive land tillage for sowing of wheat followed in India. This resistance was gradually overcomed with persistence demonstration of zero-tillage technology. A notable feature is that all categories of farmers are adopting zero-tillage. The advantages indicated by the farmers during field visits and surveys are: (a) cost saving and thus higher profit, (b) saving of irrigation water, especially in first irrigation, and (c) improvement in soil fertility due to decomposing of paddy stubbles in soil. The date of sowing is also advanced for a couple of days. In some cases, the technology helped in control of *Phalaris minor* weed in wheatbecause it does not provide conditions conducive for germination of seed. Consequently technology spread very fast in Punjab and Haryana. However, cost and water saving advantages are found to be rather uniformly across various categories of farmers and land type, improvement in fertility, reduction in weed infestation and advancement of date wheat sowing vary field to field and operations for rice establishment.

More visible adoption of ZT wheat started around 2000 and technology spread fast covering more than three million ha in IGP in 2005. Further reliable estimates are not available but RWC sources maintain that the adoption level remained around that level or improved moderately. The technology was also seen spreading in the middle Gangetic Plains, comprising the states of UP and Bihar. All sign points to larger coverage of wheat area in this part of the system. However, in the Trans-Gangetic Plains covering the states of Punjab and Haryana has witnessed some adjustments. This is primarily because of two reasons. First, some of the farmers were not sure about sustainability of wheat yield due to hardening of soil as a result of continuous use of ZT. This coupled with lower wheat yield in some years due to adverse weather during crop maturity also affected ZT. At the same time, reduced tillage method in wheat involving sowing of wheat with broadcasting method with single operation of rotavator replaced some of the ZT area. Some farmers were of the opinion that rotavator also involves one operation of sowing and there is only moderate increase in the cost of operation. This is more acceptable to farmers as crop residue is well incorporated in the soil. The cost of rotavator is however almost three times of ZT drill and therefore only large farmers owned this.

Box 1. Reasons for adoption of zero-tillage in wheat

Who are adopters: All categories of farmers

Drivers of adoption: (a) Cost reduction

(b) Good for late sown conditions

Other direct benefits:

Crop yield: A few farmers mention higher yield with zero tillage, but not sure about the long-term impact

Soil fertility: Positive because of incorporation of paddy stubbles, but it will take some more years to show visible impact on soil fertility

Irrigation water: Saves water in first irrigation

Major adoption facilitating factors:

(a) Refinement of zero-till drill
(b) Promotion of manufacturing of the drill and provision of subsidy by the government
(c) Integration of research efforts and large-scale demonstrations on farmers fields in a persistent manner

3.2 Present adoption pattern

Adoption of ZT wheat technology is currently uneven and there is no reliable information available giving aggregate adoption pattern. A farm survey was therefore conducted in Bihar and Haryana in late 2009 and early 2010, respectively, to analyse the present adoption scenario. Since this technology is spreading now in Bihar and undergoing changes in Haryana, the survey was confined to high ZT adoption areas. Therefore, the survey provides the pattern of adoption on farmers' fields and the results about regional adoption level should be interpreted with caution.

The results given in Table 3 show that 73 percent of the farmers follow ZT wheat and a good proportion of farmers (68 percent) also follow CT in wheat. The area sown on farms with ZT and CT is 49 and 35 percent, respectively. Further 41 percent of the farmers sow 16 percent of wheat area with reduced tillage using rotavator. In this method also one tractor pass is needed after broadcasting of seed in harvested paddy fields. During field survey it was found that a large number of farmers who were following ZT shifted to reduced tillage, as there is not much difference in the management and cost of sowing. At the same time, farmers also mentioned that reduced tillage is also under experimentation and its advantages will be established after few years of practice and status of soil. In case, farmers face problem with RT, area under ZT may increase in near future. Notwithstanding with these adjustments, the government is promoting ZT wheat under various schemes. ZT drill and rotavator continue to get nominal subsidy from the government. This is important when initial adoption studies have shown that income and resources of farm family are important determinant of ZT adoption (Erenstein et al 2008). In our sample also, one-third of the farmers in Haryana and 4 percent in Bihar owned ZT drill.

Adoption of ZT wheat is also quite significant in some parts of Bihar, where on-farm demonstration and government programs are in operation. The survey results show that 46 percent of the sample farmers sow half of their wheat area with ZT. The rest of the area is sown using CT but proportion of such farmers is 72 percent. This implies that there is partial adoption of ZT technology and there are areas which are suitable for CT, or farmers continue to follow CT for some reasons, including non-availability of ZT drill. In addition, there are areas where turn around time for tillage operation and sowing of wheat using CT is not sufficient and therefore farmers prefer ZT. These are lands which are comparatively heavy and have high moisture retaining capacity. ZT wheat is most suitable method if paddy is harvested bit late on these lands.

Notwithstanding with recent development in the adoption of ZT wheat in Haryana, there are some important lessons to be learnt from the experience of zero-tillage. *First,* small refinement of technology could lead to large-scale adoption. In this case small modification in ZT drill frame, tine and furrow opener blade made the use of the drill more convenient for the farmers. *Second,* active participation of the manufacturers has improved availability of ZT drill and thus facilitating the adoption process. Training and encouragement provided to the drill manufactures by the government and research organizations encouraged their participation. This means that input suppliers, whether in public and private sector, should be seen as partners in the technology dissemination process—an aspect which was not given due attention until now. *Third*, the provision of subsidy has not only reduced the cost of the drill and hence improved the access of farmers, but also helped convince farmers that the concept of zero-tillage is beneficial and therefore government support is provided. *Lastly*, persistence in the efforts to disseminate a technology can even take farmers out of outdated beliefs and help them embrace modern agricultural technologies and practices.

4. Impacts of zero-tillage

4.1 Wheat management under zero and conventional tillage

Crop management and input used indicators of ZT and CT wheat are shown in Table 4. As seen from this table, there is not major difference in crop management practices, except number of tillage operations done for sowing of wheat. In ZT farmers use one operation for sowing of wheat instead about four or more operations done conventionally. Farmers saw this advantage in ZT wheat both in terms of cost saving and therefore faster adoption of the technology. The planting wheat is also advanced few days or a week under ZT. In the absence of ZT, more turn around time for tillage would have delayed sowing of wheat.

There is no significant difference in other crop management practices like use of NPK and number of times wheat fields are irrigated. Farmers apply 230-250 kg/ha of NPK in wheat and the difference in NPK use is not very high between Haryana and Bihar, which seems to be rather in variation with general perception. This is because of location effect, i.e. initial spread of ZT in Bihar is in those areas which comparatively better-off and farmers owning ZT drill are resource rich. However, farmers apply three irrigations in Bihar against four irrigations in Haryana both for ZT and CT wheat. This means that water saving is largely accruing through amount of water use per irrigation and elimination of the need of pre-sowing irrigation. There is significant reduction in water use especially for the first irrigation. Wheat yields are also reported to be high under ZT but this difference may not be statistically significant.

These differences in non-tillage crop management practices, input use and yield may not appear to be high but there is some kind of under estimation of these differences. This is because wheat yield are likely to be further low under CT on the lands where now ZT is followed. These lands are clay loam and high duration paddy varieties are taken on these lands. Since these lands have high residual moisture, wheat can be sown using ZT. The sowing will be delayed considerably if CT is followed. The delay in the sowing will also have adverse impact on wheat yield. On-farm field experiment on these ZT clay-loam soils can better capture these differences.

4.2 Economic impact of zero-tillage

Economic impact of a new technology at a commodity level is best measured by application of economic surplus method. This method measures the generation of surplus in the economy and its distribution between producers and consumers. The producer and consumer surplus are generated through downward shift in the supply curve due to per unit cost reduction and thereby lower commodity prices. Different variants of economic surplus model are used in the literature but in this case closed economy model is best suited as there is not much trade in wheat. Following Alston et al (2005), economic surplus can be estimated as:

$\Delta CS = PQ\,Z\,(1+.5\,Z\eta)$

$\Delta PS = PQ(K-Z)\,(1+.5\,Z\eta)$

$\Delta TS = \Delta CS + \Delta PS = PQ\,K\,(1+.5\,Z\eta)$

where $Z = K\,\varepsilon / (\varepsilon + \eta)$; K is vertical shift in supply function as proportion of initial price;

η is elasticity of demand (absolute); and ε is elasticity of supply.

Shift in the supply function, adoption level and value of production are key parameters used in the analysis. Supply shift parameter 'k' was estimated using farm survey data but adoption level was rather difficult to assess as no official estimates are available. RWS maintains that adoption level reached close to three million hectare in 2005 but there are no further estimates. Our survey indicates significant adjustments in the adoption level. Based on the information compiled from various sources and our own assessment about the adoption level, a ceiling adoption of 25 percent was used in the analysis. The analysis was restricted to adoption in Punjab and Haryana with wheat area of about 6 million ha and production of 26 million tonnes.

R&D cost is another important parameter considered the rate of return. The program-wise R&D cost is not available and researchers have made their own assessment. In this case, Vijaylaxmi et al (2007) have compiled R&D cost for the national and international systems. We have used these cost estimates taking R&D lag of ten years.

The estimated net present value of benefits is 142 million dollars and the internal rate of return is 49 percent. These estimates are rather lower side than those estimated by Vijaylaxmi et al (2007) because of a higher adoption ceiling (33 percent) used by them. Much of these benefits will depend on how the adoption of technology is sustained in future. There are a vast majority of farmers who still prefer CT or RT on certain lands. But if ZT is followed on high moisture content soils which form significant proportion of total area in the eastern IGP, there could be further increase in the benefits of the technology. This needs persistence efforts by the R&D organizations and improving access of farmers to ZT drill. Farmers are convinced about cost benefits of ZT wheat. If efforts are made to demonstrate water and other environmental benefits, the spread of the technology will be much faster.

5. Environmental impact of zero-tillage

Besides economic impact in the form of cost saving, there are other environmental benefits which are less quantified and documented. These are saving of groundwater and reduction in carbon emission through tractor diesel saving. As noted above, saving of irrigation water is mainly through reduction in the requirement of irrigation water and consequently reduction in loss of water due to evapotranspiration. Since wheat can be sown on residual moisture after paddy, pre-sowing irrigation can be avoided. Further water requirement for first irrigation of wheat is much less under ZT wheat as compared to CT. Thus there is substantial reduction in water requirement. Experimental data have sown that water saving with ZT in wheat could be 36 percent, on an average.Reduction is water use in first irrigation is 30-50 percent and 15-20 percent in subsequent irrigation (Gupta and Seth 2007). Water use could be further reduced if ZT is used in combination with other technologies like raised bed planting and laser land leveling. Erenstein et al (2008) have shown that reduction in water use was 140 m^3/ha in Haryana and 280 m^3/ha in Pakistan Punjab. The estimates could be as high as 340 m^3/ha when measured through focused water survey.

This study has also quantified reduction in use of groundwater in ZT wheat. This is done based on farm survey where farmers were asked to indicate number of irrigation applied, tubewell hours per irrigation and capacity of tubewell. These parameters along with discharge capacity of the tubewell were used to compute actual water applied by farmers. The average estimates thus arrived are given in Table 4. This table shows that though Haryana farmers apply only one additional irrigation, total water use is almost double of that in Bihar. This is true for both ZT and CT. There is a saving of 440 m^3/ha water in intensively irrigated state of Haryana and 202 m^3/ha in Bihar during the entire crop season. Given the nature of technology, this is an important impact, especially when the technology was not initially targeted as water saving. The water saved under ZT should be adequate to provide two thin irrigations to summer pulses –an option often being considered to promote sustainability of RWS in the region. This will further enhance the environmental and economic benefits.

What explains the variation in saving in use of irrigation water due to ZT. Obviously, one can accurately measure irrigation water in field experiments and therefore reduction in water requirement is high. However, assessment of on-farm water saving is largely influenced by farmers' ability of recall irrigation application and estimate of discharge of a tubewell which may be in variance with the actual discharge. Secondly, water requirement is also influenced by soil type—clay loam soils require less water than loamy and now ZT wheat is followed mostly on clay loam soils. Therefore, it is quite likely that estimates of water productivity and saving vary considerably due to soil type and farmers' practices.

Is reduction in use of irrigation water is saving of groundwater? The answer to this question is yes and as seen subsequently, this is an environmental service. Since there is significant reduction in water requirement, less groundwater is extracted and therefore direct saving of water. Furthermore, not entire water applied is recycled back to aquifer because of evapotranspiration losses. It is obvious that evapotranspiration losses are high in IGP and therefore water table is going down. Studies have also shown that evapotranspiration losses is as high as 1000 mm both for rice and wheat, and wheat alone accounts for nearly one-third of the water loss. These losses are against water requirement of 1800 mm (Ambast et al, 2006). Studies have further shown that evaporation losses could be reduced by reduction in duration of land preparation (Tuong 1999) and ZT essentially meet this objective.

There are several other important environmental impacts of ZT wheat. There is reduction in carbon emission due to less burning of tractor diesel. It is estimated that saving of diesel reduces CO_2 emission from 84.5 kg/ha under CT to 21.6 kg/ha under ZT in Haryana. The reduction in CO_2 in Bihar is comparatively low but significant (52.4 kg/ha). Carbon emission is also reduced through carbon sequestration by incorporating crop residue into soil. However, scientific evidence on this is rather limited. Whatever, carbon is sequenced under ZT is again released during puddling and other tillage operations for paddy. Studies also indicate that carbon sequestration is high under continuous practice of ZT for a long-time with cultivation of at least one legume crop (Sisti et al, 2004).

Experimentation is underway to further enhance incorporation of paddy residue through use of improved ZT drill with disk furrow opener. In this method entire paddy straw can be left on surface and wheat can be sown under ZT. This has several added advantages. First there is coverage of land surface which reduces evapotranspiration losses and therefore maintains soil moisture and temperature, which are conducive for plant growth. Secondly, mulching effect suppresses weed, particularly *P. minor*(about 40 percent less weed infestation) and increases plant population. Also there is saving of weedicide, resulting into additional economic and environmental benefits. Finally, farmers may not burn paddy straw for sowing of wheat, as done under CT, and therefore generating significant environmental benefits. It is estimated that reduction in burning of one paddy straw can reduce 3 kg of particulate matter, 60 kg CO, 1,460 CO_2 , 199 kg ash and 2 kg SO_2. This amounts to reduction in the emission ofCO_2 about 15 tonnes/ha(Gupta and Seth 2007).

5.1 Valuation of groundwater benefits

Saving of groundwater is an important and significant impact of ZT in Haryana where the rate of depletion is very fast. Value of such benefits can best be assessed using non-market valuation tools. Since benefits of water saving are not directly realized by farmers and community, it would be appropriate to apply stated preference technique for this purpose. The contingent valuation method (CVM) is one of such methods and it involves asking the respondents the amount of money they are willing to pay for the stated environmental benefits (Bennett 2009). In our case, saving of groundwater not only provides environmental benefits in terms of more availability of water but also some economic benefits in terms of reduction in the cost of water extraction and sustainability of production system and hence farm income.

In our farm survey, farmers were explained likely environmental and other benefits of water saving and implications of current trend in groundwater use. The strategy to reduce irrigation water use through system diversification, adoption of water-saving technology, less water use options etc were also explained to them. Adoption of these methods may involve some direct expenditure or low farm income. Respondent farmers in Haryana were asked how much they are willing to pay (WTP) or spend or compromise farm income for promoting water saving strategy. Five payment amounts starting from Rs 2000 were asked along with maximum amount WTP in case response was positive. These five amounts were randomly distributed among the respondent while conducting the survey. Farmers were also asked about main considerationinfluencing their response and also their choice for water saving strategy.

As seen from Table 6, two-thirds of the respondent farmers were WTP for water saving benefits and most of them were in the range of Rs 2000-6000, but a few farmers were WTP as high as Rs 15,000. The average amount WTP worked out to be Rs 7100 which is quite impressive considering low level of farm income. More importantly, farmers with comparatively small size of holding were willing to pay and the maximum amount mentioned by them was even higher thansome of medium and large farmers. This is because of their understanding about severity of the problem and likely adverse impact on their income if current trend of water depletion continues. Small farmers will be affected first as investment requirement for installation of deep tubewellmay soon go beyond their capacity.

The factors influencing WTP are given in Table 7. Those who are WTP were convinced about importance of groundwater in sustaining the productivity and payoffs of the cropping system and therefore were WTP. Of course, current level of farm income is an important determinant of WTP. Other environmental benefits like reduction is soil salinity also influenced the response. The farmers who are not WTP were of the opinion that all sections of the society are benefited from water saving and therefore government should bear the cost of water saving strategy. Low farm income and uncertainly about effectiveness of water saving strategy were the factors which influenced negative response of the farmers.

AS regards possible options for reducing groundwater use, a vast majority (62 percent) of the farmers think that improved management of canal system can reduce pressure on groundwater for irrigation. Diversification of the system towards less water using crops and promotion of irrigation water saving technologies are options suggested by 40-52 percent of the farmers. Legal measure and enhancing electricity price to restrict water use were preferred by a small proportion of the farmers. But considering seriousness and scale of the problem, perhaps a combination of all measures will be suitable for reducing groundwater use. For example, restriction on early transplanting of paddy, system diversification and water saving technologies have showed positive results in Punjab.

6. Conclusions

The RWS in IGP is critical for food security in south Asia. In order to enhance productivity, profitability and sustainability of this system several technological interventions focusing on resource conservation are made and ZT in wheat is one of them. This study has analysed the spread of this technology in Indian IGP and its economic and environmental benefits. It is found that the technology is still under experimentation by farmers owing to introduction of other tillage method, namely reduced tillage with rotavator. Nevertheless, considerable area is still under ZT wheat, mostly in Haryana and Punjab. This technology is at initial stage of adoption in Bihar. A wider adoption in eastern IGP may require interventions by the government and arrangements for custom hiring to ZT machine which is largely owned by rich farmers. There are farmers adopting a combination of tillage methods (ZT, RT and CT) in both the regions, indicating that there are other factors like soil type which influenced technology adoption.

The economic benefits are mainly accruing due to saving in the cost of tillage operations for sowing of wheat. In some instances of higher yield due to less weed infestation and advancement of sowing date were also found. Taking all these factors into consideration, a per tonne cost advantage of six percent was observed, which applied to the wheat production in north-west Indian IGP resulted annual gross benefit of 142 million dollars and a rate of return of 49 percent on entire R&D investment. These returns are quite high by any standard and therefore placed ZT as one the most successful technological interventions in recent times.

In addition to economic benefits, the technology has generated substantial environmental benefits of saving of groundwater and reduction in carbon emission. Saving of irrigation water ranges from201 m^3/ha in Bihar to 440 m^3/ha in Haryana. Reduction in carbon emission due to less burning of diesel is in the rage of 50-60 kg/ha, depending upon land type. In addition, there are environmental benefits because of incorporation of paddy straw in soil. These are extremely useful environmental benefits. But groundwater savings are far more important because of rapid depletion of this resource and consequently greater importance attached to water saving by farmers, policy makers and environmentalists. Our survey has shown that all categories of farmers are willing to pay for or adopt water saving strategy and the average amount is Rs 7,100, which is quite high considering low farm income. However, farmers were of the opinion that a strategy focusing on water-saving technologies, system diversification towards less water using crops and improved management of canal irrigation system will be more effective. Concerted efforts in this direction with adequate institutional, financial and policy support will go a long way in addressing water and other sustainability issues of RWS.

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Table 1. Main characteristics of agriculture in the states practicing the rice-wheat system

Sl. No.	Particular	Punjab	Haryana	Uttar Pradesh	Bihar	All India
1.	Share of agriculture in GDP (%), 2007-08	30.5	19.6	26.3	23.2	17.8
2.	Net sown area (M ha, 2007)	4.2	3.6	16.7	5.5	140.3
3.	Average size of holding (ha, 2001)	4.03	2.32	0.83	0.58	1.33
4.	Rice area (M ha), 2007-08	2.6	1.1	5.7	3.5	43.9
5.	Rice yield (t/ha), 2007-08	4.0	3.4	2.1	1.2	2.2
6.	Wheat area (M ha), 2007-08	3.5	2.5	9.1	2.1	28.0
7.	Wheat yield (t/ha), 2007-08	4.5	4.1	2.8	2.1	2.8
8.	NPK use (kg/ha, 2008)	209.9	187	149.6	162.8	117.1

Table 2. Sources of irrigation and status of groundwater use in Punjab and Haryana

	Punjab	Haryana	All India
1. Percentage area irrigated, 2005-06	95.2	82.3	42.4
2. Sources of irrigation, 2005-06			
2a.Area irrigated by canal (%)	32.0	45.3	25.7
2b. Area irrigated by groundwater (%)	68.0	54.2	58.8
2c. Other sources (%)	-	0.5	15.6
3. Groundwater use as % of annual recharge	145	109	58
4. Percentage of the blocks with >100% utilization, 2004	75	49	15
5. Percentage of the blocks with 90-100% utilization, 2004	4	10	4

Table 3. Adoption of Zero-tillage wheat in the rice-wheat system

Sl. No	Particular	Haryana	Bihar
1.	Proportion of farmers adopting ZT	72.7	46.0
2.	Proportion of wheat area under ZT	49.3	50.5
3.	Proportion of farmers adopting RT	40.9	-
4.	Proportion of wheat area under RT	15.8	-
5.	Proportion of farmers adopting CT	68.2	72
6.	Proportion of wheat area under CT	34.8	49.5

Note: Rotavator has not been promoted on large scale in Bihar

Source: Farm survey

Table 4. Crop management indicators and inputs use in ZT and CT wheat

Sl. No.	Particular	Haryana			Bihar	
		ZT	RT	CT	ZT	CT
1	Total number of tillage operations	1	1	3.9	1	3.06
2	NPK use (kg/ha)	250	254	257	234	239
3	Weedicide use (gm/ha)	436.9	445.2	496.4	-	-
4	Number of irrigations	3.8	4.1	4.3	2.9	2.7
5	Total irrigation hours (ha)	34.2	40.7	43.0	15.5	18.9
6	Total water use (M^3/ha)	1710.0	2035.7	2150.0	932.4	1134.0
7	Crop yield (tonne/ha)	5.0	4.9	4.8	3.4	3.1

Source: Farm survey

Table 5. Environmental impact of ZT wheat in Haryana and Bihar

		Haryana		Bihar	
Sl. No.	Particular	ZT	CT	ZT	CT
1.	Diesel consumption for tillage operations (l/ha)	10.0	39.1	10.0	34.3
2.	Irrigation water use (m^3/ha)	1710.0	2150.0	932.4	1134.0
3.	Soil organic carbon				
4.	Total Co_2 emission (kg/ha)	21.6	84.5	21.6	74.0

Source: Based on farm survey data

Table 6.Willingness to pay for groundwater water saving strategy

Amount Rs	Number of respondents WTP	Number of respondents not WTP	Max. amount WTP Rs
2000	13	1	6,154
4000	9	5	5,333
6000	11	2	7,273
8000	8	5	7,500
10,000	3	9	15,000
All	44	22	7,100
WTP by size of holding(Acre)			
<5	2	2	7,500
5-10	21	7	7,714
10-15	4	3	6,000
15-20	6	3	6,833
21-25	4	3	5,000
>25	7	4	8,429
All	44	22	7,100

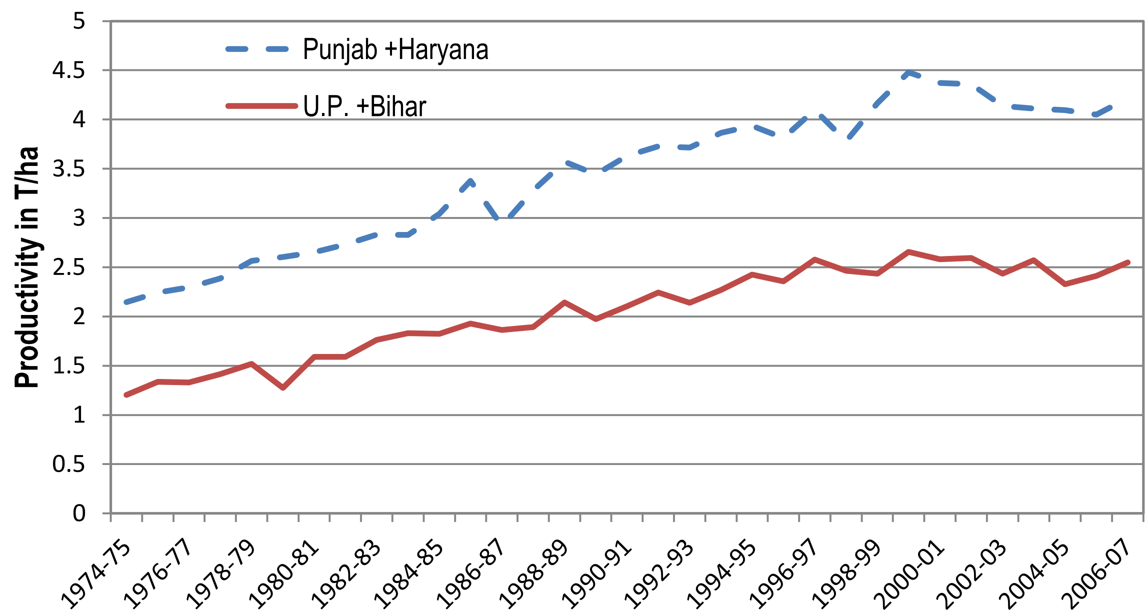
Source: Farm survey, One US dollar = Rs **

Table 7.Factors influencing WTP and not WTP for groundwater saving strategy

Sl. No.	Factor	Number of respondents (N=66)
A.	*Factors influencing WTP*	
	Level of income	28
	Likely economic benefits	11
	Sustainability of production system	37
	Likely reduction in water extraction cost	28
	Environmental benefits like reduction in soil salinity	24
B.	*Factors influencing not WTP*	
	Low income	22
	Don't know much about water crisis	4
	Uncertain about effectiveness of water saving strategy	11
	Government should bear the cost	28
	Other beneficiaries should bear the cost	7
C.	*Possible options to reduce groundwater use*	
	Control supply of electricity and increasing tariff	20
	Promotion of water saving technologies	40
	System diversification towards less water requirement crops	52
	Improved management of canal system	62
	Legal options like limits on water use	31

Source: farm survey

Fig 1. Trends in wheat yields in Punjab-Haryana and UP-Bihar



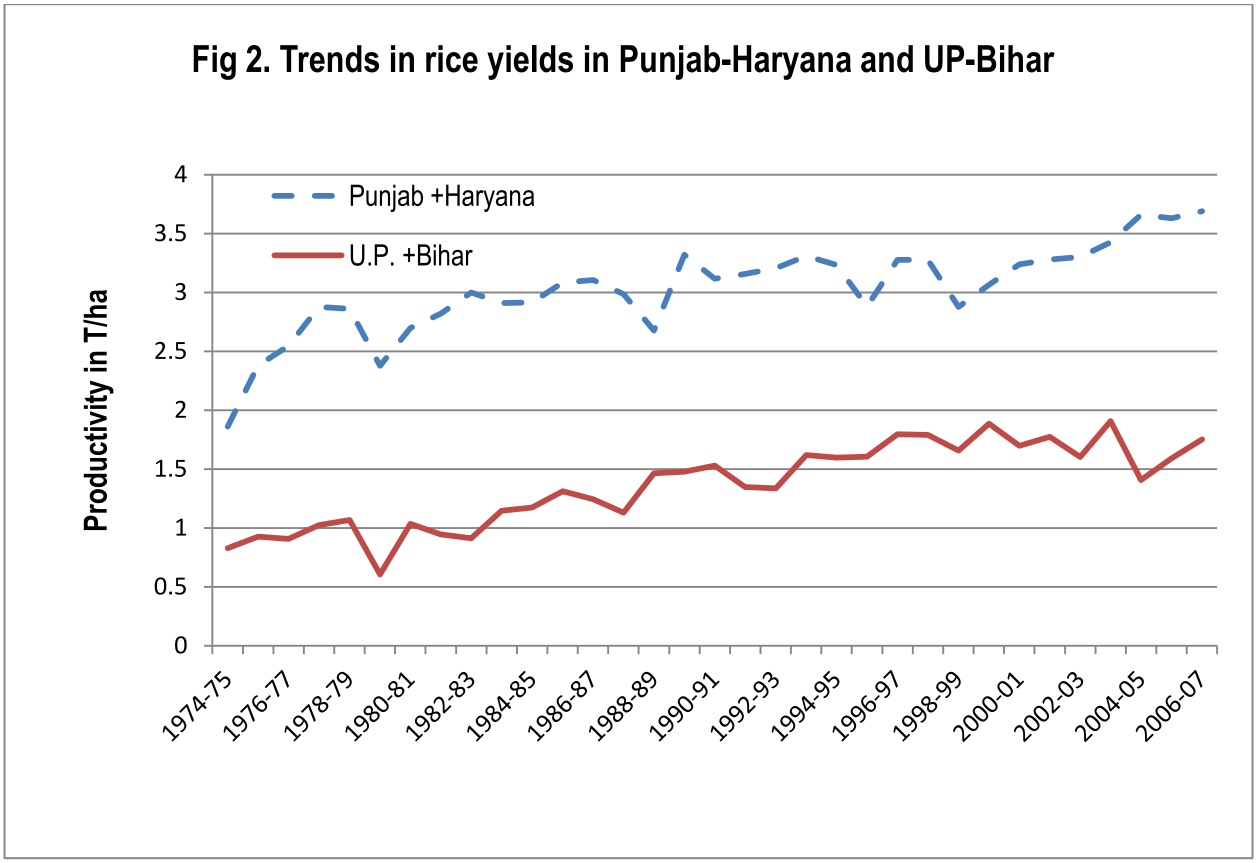


Fig 2. Trends in rice yields in Punjab-Haryana and UP-Bihar
Productivity in T/ha
Punjab +Haryana
U.P. +Bihar
4
3.5
3
2.5
2
1.5
1
0.5
0
1974-75
1976-77
1978-79
1980-81
1982-83
1984-85
1986-87
1988-89
1990-91
1992-93
1994-95
1996-97
1998-99
2000-01
2002-03
2004-05
2006-07