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Economic and environmental impact of resource conserving technology: A study of zero tillage in the Indo-Gangetic Plains of India

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ABSTRACT

Zero till technology (ZT) is one of the promising resource conservation technologies promoted in the Indo-Gangetic Plains (IGP) of India. ZT is inherently embedded with an array of economic and environmental benefits. The study assessed the economic and environmental impacts including water saving benefits of ZT in the IGP region. Farm survey was conducted in Haryana and Bihar, which revealed that there is significant water saving due to ZT adoption and the saving of irrigation water ranges between 440 $m^3 ha^{-1}$ in Haryana and 200 $m^3 ha^{-1}$ in Bihar. Economic surplus method was used in assessing the economic impact of ZT in Haryana and Bihar. It was found that around 6% cost advantage in wheat production was realized at farm level and overall an economic surplus of US$ 142 million with a rate of return of 49% on the R&D investment was estimated. In addition, there has been reduction in carbon emission in the range of 50-60 kg ha^{-1} mainly due to less burning of diesel. Considering the water saving benefits of the technology, the farmers in the study area were willing to pay (WTP) ₹ 7,100 for its adoption. The accrued benefits of ZT suggested that ZT technology be promoted on a wider scale by removing the constraints in adoption and by providing support for less adoption regions.

1. INTRODUCTION

Indo-Gangetic Plain (IGP) of India is the heart belt of Green Revolution wherein Rice-wheat cropping system (RWCS) is predominantly practiced providing income and food to millions of people. IGP's contribution of rice and wheat to national pool is enormous due to the fact that this region supplies nearly 44 and 72% of total rice and wheat, respectively (Sekar and Pal, 2012). However, of late, there has been deceleration in rice-wheat (RW) productivity and spatial differences. Along with declining growth rate of rice and wheat production in recent times, the profitability of rice and wheat production is also not encouraging in many places of IGP because of steeper rise in production costs than crop prices. The rise in costs largely stem from input costs and indirect costs such as energy and ground water extraction costs. Declining water tables, increasing pumping costs, replacement of shallow gravity tube wells with submersible pumps at huge cost, adverse effects of water quality can have an impact on overall sustainability in the IGP. Intensification of the RWCS in the IGP may lead to declining soil carbon and emission of GHGs more specifically methane from rice crop, main contributor of GHGs, which can have implications on the environment. Intensive tillage results in soil erosion (Sharma *et al.,* 2013) The technologies that can conserve natural resources and improve environmental health assume greater significance. These kinds of resource conservation technologies seem to offer opportunities which would increase production and income (Sharma and Kumar, 2000).

Resource conservation technologies have been promoted in RWCS of IGP because of its potential economic and environmental benefits. Timely sowing under zero tillage improves crop yields and thus provides resilience against drought and other hazards (Mehta *et al.,* 2000). Zero till (ZT) technology was advocated as one of the promising technologies for resource conservation in the IGP region of India (Gupta and Seth, 2007). Rice Wheat Consortium has put in strenuous efforts to promote this technology in the IGP region in addition to several national and international agencies. ZT planting of wheat after rice has been the most successful resource-conserving technology to date in the Indo-Gangetic Plains (Erenstein and Laxmi, 2008). Inspite of the conscious efforts to promote this technology, there are mixed responses in its adoption. The diffusion of ZT technology has been mostly restricted to northwest Indo-Gangetic Plains of India, where wheat after rice is grown (Erenstein, 2009). ZT has far and wide prominence in Haryana, Punjab and Western UP and the uptake of this technology is slow in the eastern UP and Bihar. Secondly, this technology is confined to wheat crop and yet to make visible impact in paddy fields. Though plot level field experiments results had shown positive benefits of this technology, there were not many studies in India unearthing the facts on ZT through farm survey specifically in the state like Bihar and this study fulfilled the research gap. With this backdrop, this research was aimed at assessing the economic and environmental impact of ZT and studying the willingness to pay (WTP) for ground water saving.

2. MATERIALS AND METHODS

The study was based on findings predominantly from the focused farm survey. The survey was conducted in Haryana and Bihar of the IGP region during 2011. Well-designed questionnaire was used for the collection of data on adoption, impact and benefits of water saving. Two districts each in Bihar and Haryana states were chosen where the technology has been actively promoted. Districts selection was therefore purposive and the selected districts were Karnal and Kaithal in Haryana, and Patna and Begusarai in Bihar. Sample villages and farmers were selected randomly to ensure that all categories of farmers were represented in the sample and no adjacent villages were chosen. In all, 70 farmers from five villages in Karnal and Kaithal districts and 72 farmers from five villages in Patna and Begusarai were taken for a detailed farm survey. On the whole, 142 farmers were selected to elicit information about the adoption and management practices and to evaluate economic and environmental impacts of ZT and water saving benefits. This primary survey was aptly bolstered by the secondary data collected from various sources of reported studies and documented sources.

The information about water management practices, number of irrigations, depth of water table, discharge rate, duration, and supply of water from tubewell was collected to estimate water saving benefits. The willingness to pay (WTP) for groundwater saving was estimated using the data obtained from the survey. Binary logit model was employed to determine the factors influencing WTP for groundwater saving. Adoption rate, yield gain, cost of cultivation of wheat was collected through farm survey to estimate the economic impact of ZT technology through economic surplus method. Research impact at commodity level is best measured by the 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 surpluses 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. Shift in the supply function, adoption level and value of production are the key parameters used in the analysis. Supply shift parameter 'k' was estimated using farm survey data. A ceiling adoption of 25% was used in the analysis. R&D cost is another important parameter considered for computing the rate of return. The program-wise R&D cost is not available and in this study, Vijaylaxmi *et al.* (2007) have compiled R&D cost for the national and international systems. These cost estimates have been used taking R&D lag of ten years. Economic surplus (Alston *et al*., 1995) is modeled as:

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

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

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

Where, $Z = K\,\varepsilon / (\varepsilon+)$; K is the vertical shift in supply function as a proportion of initial price; P= price; Q= quantity produced; η= elasticity of demand (absolute); and ε= elasticity of supply.

The environmental benefits were evaluated in specific reference to reduction in energy burning and groundwater saving. The reduction in emission was obtained through reduction in diesel use. Stated preference technique (Bennet, 2009), was used to assess the environmental benefits of water saving through willingness to pay approach for the stated environmental benefits.

3. RESULTS AND DISCUSSION

Economic Impact

The farm survey indicates a significant downward shift in the adoption level in comparison to earlier estimates maintained by Rice Wheat Consortia. The analysis was restricted to wheat area of about 6 m ha and total production of 26 Mt. The impact in monetary terms from the adoption of ZT technology was estimated with net present value of benefits US$ 142 million and the internal rate of return, 49%. The economic benefits were accrued out of ZT to the society as a whole inclusive of both producers and consumers surplus. These estimates are rather lower than those estimated by Vijaylaxmi *et al*. (2007) which might have been due to higher adoption ceiling (33%) used by those researchers. Much of these benefits will depend on how the adoption of technology is sustained in future. There are still a sizeable proportion of farmers who still prefer conventional technology. The constraints in adoption of ZT need to be removed specifically accessibility of machine through custom hiring services and public private partnership mode. The impact could be higher, if adequate steps are taken to promote ZT on high moisture content soils which form significant proportion of total area in the eastern

IGP. This needs strenuous and persistent efforts by the R&D organizations in spreading the ZT technology.

Environmental Benefits

Emission reductions

The environmental benefits of ZT in wheat are less quantified and documented. This study attempted to assess the environmental benefits in terms of reduction in carbon emission, which emanates mainly from burning of fuel (diesel) used for tractors for tillage operations. It is estimated that saving of diesel reduces CO_2 emission from 84.5 kg ha^{-1} under conventional technology to 21.6 kg ha^{-1} under zero till technology in Haryana (Table 1). The reduction in CO_2 emission in Bihar is comparatively lower than that of Haryana, however notable (52.4 kg ha^{-1}). 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 sequestrated under ZT in wheat is again released during puddling and other tillage operations for paddy. Studies have also indicated 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).

Table: 1
Environmental impact of ZT wheat in Haryana and Bihar

S. No.	Particulars	Haryana		Bihar	
		ZT	CT	ZT	CT
1.	Diesel consumption for tillage operations (L ha^{-1})	10.0	39.1	10.0	34.3
2.	Total CO_2 emission (kg ha^{-1})	21.6	84.5	21.6	74.0

Source: Based on farm survey data, 2011

For enhancing incorporation of paddy residue through the use of improved ZT drill with disk furrow opener, experimentation is underway, which can have several added advantages. Firstly, 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 *Phalaris minor* (about 40% 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 of CO, 1,460 kg of CO_2, 199 kg of ash and 2 kg of SO_2. This amounts to reduction in the emission of CO_2 about 15 t ha^{-1} (Gupta and Seth, 2007).

Water saving benefits

Zero till technology is widely perceived as a resource conservation technology. Water saving benefits from the use of technology is less quantified and documented. Saving of irrigation water is mainly through reduction in the use of irrigation water and consequently, reduction in water losses due to evapotranspiration. Since wheat can be sown on residual moisture after paddy, pre-sowing irrigation can be avoided. Further water-use for first irrigation of wheat is much less under zero tillage as compared to conventional tillage method. Thus, there is substantial reduction in water use.

Water saving benefits in this study was quantified using magnitude of reduction of groundwater use in ZT wheat. The actual water applied by farmers was computed based on the data obtained from farm survey wherein data on number of irrigations applied, tubewell hours per irrigation, capacity of tubewell, HP of engine, diameter of suction pipe *etc.* were elicited. The estimates thus arrived are given in Table 2. Total water-use in Haryana is almost double than that of Bihar although Haryana farmers apply only one additional irrigation, which is true for both ZT and CT. This implies that Haryana farmers apply more water per irrigation than that of Bihar farmers. There is a saving of 440 m^3 ha^{-1} water in intensively irrigated state of Haryana and 202 m^3 ha^{-1} in Bihar during the entire crop season. Erenstein *et al*. (2008) reported that reduction in water use was 140 m^3 ha^{-1} in Haryana and 280 m^3 ha^{-1} in Pakistan Punjab. Experimental data have shown that on an average, water saving with ZT in wheat could be 36%. Reduction in water use in first irrigation is 30-50% and 15-20% in subsequent irrigation (Gupta and Seth, 2007).

Table: 2
Irrigation water use in ZT and CT wheat in Haryana and Bihar

S. No.	Particulars	Haryana			Bihar	
		ZT	RT	CT	ZT	CT
1.	Number of irrigations	3.8	4.1	4.3	2.9	2.7
2.	Total irrigation hours (ha)	34.2	40.7	43.0	15.5	18.9
3.	Total water use (m^3 ha^{-1})	1710	2036	2150	932	1134

Source: Farm survey
Note: ZT, RT, and CT denote zero tillage, reduced tillage and conventional tillage, respectively.

Given the nature of technology, this is a significant impact, especially when the technology was not primarily targeted for 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. Thus, the farmers and other stakeholders in the society can make a choice in terms of environmental benefits whether to continue adopting this technology or not.

These savings in use of irrigation water are in deviation from the actual use and are variable from farm to farm depending upon availability and demand. The savings in water use may be substantially higher which needs to be assessed. The assessment of on-farm water saving is subject to farmers' ability of recall irrigation water 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.

It is often debated if reduction in use of irrigation water could be considered as groundwater saving. Since there is a significant reduction in water requirement, less groundwater is extracted and therefore direct saving of water. Secondly, the extracted water is not entirely recycled back to aquifer but a proportion goes as evapotranspiration losses. Such evapotranspiration losses are high in IGP and there is a decline in water table. Studies have also shown that evapotranspiration losses are as high as 1000 mm for both 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 the duration of land preparation (Tuong, 1999) and ZT essentially meets this objective.

Farmers were stated about current trend in groundwater use, likely implications if the current trend continues, and also the environmental and other benefits of water saving. The adoption of water-saving technologies and subsequent benefits were enumerated to the farmers. The adoption of such technology may involve some direct expenditure or foregoing part of the farm income. The respondent farmers were asked how much they were willing to pay (WTP) or spend or compromise farm income for promoting ZT. Five payment amounts starting from ₹ 2,000 were stated along with maximum amount of WTP in case response was positive. The amounts for WTP were randomly stated among the respondents and the factors influencing their response were determined.

As seen from Table 3, two-thirds of the respondent farmers were willing to pay or spend for water saving benefits and most of them were in the range of ₹ 2,000-6,000, but a few farmers were WTP as high as ₹ 15,000 annum^{-1}. The average amount of WTP worked out to be ₹ 7,100 which is quite impressive considering low level of farm income.

Table: 3
Willingness to pay for water saving technology

Amount (₹)	No. of respondents WTP	No. of respondents not WTP	Max. WTP (₹)
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

It is important to note that farmers with comparatively small size of holding were also willing to pay and the maximum amount to pay was even higher than some of the 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 tubewell may soon go beyond their capacity.

The willingness to pay for water saving technology is influenced by several factors and the determinants of WTP were empirically examined using binary logit model and the estimated results are given in Table 4. Economic, attitudinal and other individual characteristics variables were considered but all of them were not found to be significant in explaining the WTP. The non-significant variables in the model were age and years of schooling, which might be because the water problem widely experienced by all the farmers irrespective of level of schooling and age. The variables appearing in the model had the expected sign and reconfirmed earlier observation about WTP. Farmers' understanding about long-term sustainability implications of excessive use of groundwater influenced WTP positively. Long-term environmental impacts were less clear to farmers and therefore their influence, though positive, was non-significant. Farmers also opined that the current level of farm-income was rather inadequate to sustain the family

Table: 4
Logit model estimates of the determinants of the willingness to pay

Variable	B	S.E.	Wald	Sig.	Exp (B)
1. Farm holding size	-.019	0.039	0.237	0.627	0.981
2. Sustainability of production system	3.530	1.463	5.821	0.016	34.137
3. Potential environmental benefits	22.158	6441.532	0.000	0.997	4.199E9
4. Farm income	-2.985	1.670	3.196	0.074	0.051
5. Govt bearing cost	-1.686	1.717	0.964	0.326	0.185
Constant	.382	1.298	0.086	0.769	1.465

-2 log likelihood 14.18
Cox and Snell R^2 : 0.66 (Chi-square, 71.16 significant at 1% level)

and therefore, it negatively influenced the WTP. The similar effect was also observed on opinion of the farmers about government's responsibility to bear the cost of water saving technology.

4. CONCLUSIONS

ZT technology is one of the resource conservation technologies showing promises in the IGP. The spread of the technology is poised towards middle and upper Gangetic Plain. The technology is however confined to wheat crop alone although it was promoted for the RWS. ZT has been embraced by the farmers of IGP because it is embedded with both economic and environmental benefits. It is estimated that the economic benefits that are mainly accrued out of this technology are saving in the form of cost reduction in tillage and marginally higher yield, which resulted in annual gross benefit of US$ 142 million and a rate of return of 49% on the entire R&D investment. These returns are quite high and therefore places 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. Reduction in carbon emission due to less burning of diesel is in the rage of 50-60 kg ha^{-1}, depending upon land type. Although this technology is not targeted for water saving, the study revealed that it has the potential of water saving benefits. Saving of irrigation water ranges from 200 m^3 ha^{-1} in Bihar to 440 m^3 ha^{-1} in Haryana. Groundwater savings are far more important because of rapid depletion of this resource in IGP. All categories of farmers are willing to pay (WTP) for or adopt water-saving strategy and the average amount is ₹ 7,100 and the WTP is greatly influenced by the farmers' understanding about long-term sustainability implications of excessive extraction and use of groundwater. For large scale adoption in the lower IGP, the study suggested for interventions by the government and arrangements for custom hiring of ZT machine which is currently owned by largely rich farmers. Considering the benefits of ZT, the technology may be further upscaled to lower IGP through concerted efforts of institutional and financial support.

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