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Abstract

A conservative ex-ante assessment of supply-shift gains alone (excluding social and environmental gains), shows that the investment in zero tillage (ZT) R&D by the Rice-Wheat Consortium and CIMMYT was highly beneficial with a benefit-cost ratio of 39, a net present value of US$ 94 million and an internal rate of return 57%. Sensitivity analysis highlights the influential role of the yield gain, the contribution of reduced tillage (i.e. partial adoption) and the assumed time-lag. Significant positive spillovers of sunk ZT R&D costs – both previous and from elsewhere - also contributed to the high returns. The case thereby highlights the potential gains from successful technology transfer and adaptation. The case however also underscores that international NRM research can have a high return, particularly when it has wide applicability.

Keywords: natural resource management research; impact assessment; economic surplus; zero tillage

JEL: Q11, Q12, Q16

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1 Introduction

The productivity impacts and high returns to international crop genetic improvement research in developing countries are well documented (Evenson and Gollin, 2003; Byerlee and Traxler, 1995). Relatively less is known about the impacts and returns to international natural resource management (NRM) research. Part of the problem is that NRM research is often considered to be site specific. Yet appropriate NRM is increasingly recognized as critical to safeguard current and future food security.

The rapid spread of zero tillage (ZT) of wheat after rice in the Indian Indo-Gangetic Plains (IGP) therefore presents an interesting case. The prevalent rice-wheat systems are critically important for both Indian and global food security (Timsina and Connor, 2001). Recent studies indicate a slowdown in productivity growth in the rice-wheat systems of India (Kumar et al., 2002). To keep pace with rapidly growing demand India's rice-wheat farmers will have to produce more food from fewer resources while sustaining environmental quality – and ZT is one technology that fits that need.

The prevailing ZT technology in the rice-wheat systems uses a tractor drawn zero-till-seed drill to establish wheat in the undisturbed soil with rice stubble. Indian farmers typically apply ZT to the wheat crop only and maintaining adequate residue levels for an effective mulch has proven problematic – both in terms of prevailing crop residue management practices (Timsina and Connor, 2001) and sowing wheat in the presence of significant loose rice residues with the current ZT drills.

The ZT history in India has been variously documented (Ekboir, 2002:29-30 ; Seth et al., 2003:65-7). The mechanical technology originated outside the region, was adapted and produced locally and diffused successfully due to the concerted efforts of NARES, private sector, farmers, CIMMYT (http://www.cimmyt.cgiar.org) and the Rice-Wheat Consortium of the Indo-Gangetic Plains (RWC, http://www.rwc.cgiar.org). International agricultural research was instrumental in achieving success, but we can only speculate about the counterfactual in the absence of RWC & CIMMYT's efforts. CIMMYT's role and persistence were key in getting the technology adaptation process through its slow and difficult start. The RWC as a network could not have functioned on a stand-alone basis, but its presence and perseverance has generated synergies and momentum that otherwise where unlikely to be achieved. The RWC has been key in achieving and building on the initial gains for ZT in the Indian IGP – through fostering prototype ZT equipment, farmer experimentation and information sharing. In the absence of RWC & CIMMYT's efforts in India, widespread ZT adoption may have lagged by 5 to 10 years.

2 Methods

The present study comprised of three components: a review, focus group discussions and modeling. The review of available information based on published, grey and unpublished literature showed that information tends to primarily report on the technical aspects of ZT at the plot level. To a lesser extent economic and environmental aspects are covered. The available information was primarily derived from trial data (on-station and on-farm). Only occasionally did it include survey data. There was significant variation in the scientific rigor behind the various information sources, often lacking measures of variability or statistical analysis. Therefore, village level focus-group discussions were conducted in Punjab, Haryana and eastern Uttar Pradesh (UP) for validating the secondary data and for understanding the people's perceptions and practices of ZT. The exercise included both adopters and non-adopters in six villages (2 in each state). The group was divided in to rich and poor farmers on the basis of land holding and discussions were carried out for males and females separately.

To modeled the economic impact of ZT wheat R&D in India's IGP, the aggregate welfare impact of ZT was estimated using the economic surplus approach in a closed economy framework with linear supply and demand functions and a parallel research induced supply shift (Alston et al., 1998). These welfare impacts were used to estimate the ex ante rate of return on investment in ZT wheat R&D. Table 1 presents the main contrasts between the "with" case (with RWC and CIMMYT investments) and "without" case used to estimate the rate of return. Table 2 presents the main parameters used and the differences between the conservative and optimistic scenario.

It is important to stress here that the economic impact thus estimated only reflects the ZT induced downward supply shift for wheat. Data limitations preclude us from including and valuing environmental and social impacts of ZT at this stage (e.g. externalities, intangibles, long term effects and distributional effects). Reliable estimates of these effects are typically still scanty. Compounding the issue, the extent and durability of the ZT wheat environmental gains is debatable with current farmers' practices for the subsequent rice crop and crop residue management. Overall though, ZT typically implies positive environmental impacts, so that our economic impact estimates can be seen as a conservative estimate that underestimates the true social value of the technology and the social rate of return. In view of space limitations we will emphasize the third component in this paper.

3 Adoption of ZT

In India's rice-wheat systems, adoption of ZT is primarily in the wheat crop and concentrated in the northwestern IGP (Table 3). On an annual basis, the RWC compiles estimates of the scale of adoption of various resource conserving technologies (RWC, 2004; www.rwc.cgiar.org). These estimates are primarily expert estimates at the state level using a range of indicators and typically lump together ZT and reduced tillage (RT). In 2004-05 the total estimated area under zero and reduced tillage combined was approximately 1.6 million hectares in the Indian IGP, with ZT comprising 27% and RT 73%.

The aggregate ZT/RT adoption estimates were triangulated against other available adoption indicators. Recent random surveys support the significant levels of ZT adoption in Haryana and Punjab. Although the focus groups conducted within the context of this study do not provide a representative sample (six villages from adoption areas), they did highlight the significant extent and speed of ZT adoption in each village. The adoption estimates also compare reasonably with the reported sales of ZT drill machines.

The ZT technology is currently in the mass adoption phase in the Indian IGP. Similar to Pal et al. (2003), we estimate the adoption ceiling for ZT/RT to be 33% of the wheat area in the IGP's rice-wheat systems – a potential ZT/RT area of 3.43 million ha. Figure 1 (leftmost line, with case) depicts a logistic curve fitted to the reported ZT/RT adoption estimates and the 33% ceiling – thereby highlighting the acceleration of the diffusion of ZT/RT over the recent years. In the same figure we have also included the same curve with a five year lag which corresponds with our counterfactual – the shaded area thereby highlighting the differential adoption attributable to the RWC and CIMMYT's contribution.

Rice-wheat systems of IGP are characterized by late planting of wheat, which significantly reduces wheat productivity. The delay in planting of wheat crop is mainly due to the late harvest of the previous crop and/or a long turn around time. Conventional tillage practices for wheat are very intensive in India’s rice-wheat systems. Due to the adoption of ZT technology the number of field operations for wheat crop establishment decrease from an average of seven to a single pass almost immediately after rice harvest. ZT implies significant tillage savings and a reduction in the turn-around time.

The present study has reviewed a wealth of information in relation to ZT and rice-wheat systems in the Indian IGP, supplemented by village-level focus group discussions. Although the various sources differed in rigor and detail, the same consistent messages comes through, validated by focus groups and farmer adoption. ZT of wheat after rice generates significant benefits at the farm level, both in terms of significant yield gains (6-10%, particularly due to more timely planting of wheat) and cost savings (5-10%, particularly tillage savings). The combined yield increase with cost saving implies returns to ZT adoption are pretty robust, thereby significantly reducing the risk of adoption.

These benefits explain the widespread farmers’ interest and the rapidity of the diffusion across the Indian IGP, further aided by the wide applicability of this mechanical innovation. Small-scale machine manufacturers played a key role in meeting and creating an increasing demand. Service providers have enhanced technology access by making it divisible and are key promoters having the expertise and personal interest to successfully spread the technology. It all required a timely congruence of a profitable opportunity and the willingness to adapt by several key champions.

ZT tends to be adopted first by the better-endowed farmers. ZT rental services have however made the technology relatively scale neutral and divisible. Time and resources saved through ZT are variously used by the adopting farm households – including productive, social and leisure purposes. Thus adoption of ZT enhances farmers’ livelihoods. The challenge remains to extend these gains to the less endowed areas of the IGP, where it has significant potential and can contribute to poverty alleviation.

4 Impact of ZT

4.1 Welfare impacts

The significant farm level impacts of ZT in terms of yield increase and cost savings translate into a downward shift of the supply curve. The aggregate welfare effect of this shift was estimated through the economic surplus approach and used to estimate a rate of return to the "with" case (with RWC & CIMMYT investments), using various assumptions and parameters as outlined earlier (Table 1,2 and 3). A fundamental assumption is that the observed adoption levels (and NARES expenditures) would have lagged five years in the without case (Figure1). We attribute the differential benefit stream (primarily consumer and producer surplus and some saving of NARES cost) to the investments made by RWC and CIMMYT. The estimates of the benefits are conservative in the sense that they only include the welfare effects attributable to the tangible direct benefits. The environmental impacts addressed in the next section would only add to the social value of the technology.

For the conservative scenario we assume 6% ZT induced yield gains and 5% cost savings. The results show that even with these relatively conservative values, the ZT research program is highly beneficial with a benefit-cost ratio of 39 and a net present value (NPV) of US$ 94 million. The internal rate of return (IRR) was 57% (Table 4). The discounted economic surplus (US$ 96 million) indeed dwarfs the discounted cost of the "with" case (US$ 2.5 million). The economic surplus primarily benefited consumers (65%) compared to producers (35%). For the more optimistic scenario we assume ZT induces 10% yield gains and 10% cost savings. In this case the estimated NPV is US$ 164 million with a benefit cost ratio of 68 and an IRR 66% (Table 4).

Results of sensitivity analysis of the conservative scenario to changes in various key indicators are presented in Table 5. For each indicator, two alternative values were imputed, ceteris paribus. For the discount rate a 10% and 0%-value were imputed. But even under a discount rate of 10% the returns to ZT R&D remained highly beneficial – albeit that NPV was halved. Four other indicators altered are the yield gain, the cost saving, the contribution of reduced till and the assumed time-lag. For these indicators scenarios were typically computed without and with only half the original values. The calculations are most sensitive to variations in the assumed yield. Without any yield increase, NPV is reduced by 77% but even so the "with" case still proves beneficial with a BC ratio of 10 and an IRR of 37%. The results are relatively less sensitive to the assumed cost savings – without any costs savings NPV is reduced with 25%. The assumed contribution of RT also proofs influential, mainly as result of the significant area share under RT relative to ZT. Without any contribution from RT, NPV is reduced with 59% but the investments remain favorable. Finally, the results are also relatively sensitive to the assumed time lag. In the case of only a one-year lag, NPV would be reduced by 81% but BC-ratio and IRR again remain favorable.

ZT thus generated high welfare gains from a relatively small investment by the RWC and CIMMYT. These gains are relatively robust and persist even under more stringent assumptions. The investment was relatively small in view of the positive spillovers and sunk costs of previous research both in the region and elsewhere. This drastically reduced technology development time and cost towards relatively cheap adaptive research and allowed for rapid institutional learning.

4.2 Environmental impacts

ZT wheat has several environmental benefits. ZT implies significant fossil fuel savings and reduced greenhouse gas emissions (Grace et al., 2003; Hobbs and Gupta, 2003). In the Northwest IGP crop residues are often burned, creating severe seasonal air pollution/smog and human health hazards in the area. ZT is being further adapted so as to maintain crop residues as mulch without burning or incorporation. Water is becoming an increasingly important constraint to agriculture in the IGP as competition for domestic and industrial use increases and water use efficiency is poor (Hobbs and Gupta, 2003). ZT wheat enhances water use efficiency, reduces irrigation requirements and thereby helps save irrigation water. This benefit is especially important for the Northwest where due to excessive exploitation, ground water resources are depleting at an alarming rate.

ZT thus primarily has positive environmental impacts and this would enhance the social returns to the R&D investment. However, further research, some of it already initiated, is needed to substantiate and value these impacts more rigorously. At the same time the current use of ZT only for wheat limits the extent of some of the potential environmental gains. More significant environmental gains are likely when the whole rice-wheat system converts to year-round conservation agriculture.

5 Conclusion

A conservative ex-ante assessment of supply-shift gains alone (excluding social and environmental gains), shows that the investment in ZT R&D by RWC and CIMMYT was highly beneficial with a benefit-cost ratio of 39, a net present value of US$ 94 million and an internal rate of return 57%. Sensitivity analysis highlights the influential role of the yield gain, the contribution of reduced tillage (i.e. partial adoption) and the assumed time-lag. Significant positive spillovers of sunk ZT R&D costs – both previous and from elsewhere - also contributed to the high returns. The case thereby highlights the potential gains from successful technology transfer and adaptation. The case however also underscores that international NRM research can have a high return, particularly when it has wide applicability.

The present study has valued impact based on tangible yield gains and cost savings alone, with environmental and social gains as added non-valued benefit. To a large extent this was dictated by data limitations. Still the approach has merits. Such tangible gains correspond more closely with farmers' and private sector interest and therefore with potential and rapid adoption. The challenge for NRM research thereby is to generate technologies that are privately attractive in their own right with environmental gains as added benefit. The present case also highlights the potential of a phased approach, building on the easy-wins to subsequently use the momentum to address second generation problems. In some instances, such an approach may be more successful than tackling NRM issues head on.

Significant knowledge gaps still exist. Most studies either focus on the plot level or the macro level. Gaining a better understanding of the intermediate levels and potential interactions is needed to assess the degree to which the gains are actually realized on the ground and the scope for scaling up from plot level impacts. Available information on the cost of ZT R&D and attribution also proved problematic. Most studies report on the technical and private financial gains of ZT at plot level – with limited documentation of socio-economic, livelihood and environmental impacts. Addressing these knowledge gaps would significantly strengthen future impact assessment endeavors.

There also remain significant challenges, not least in terms of actually realizing ZT's potential economic and environmental gains on the ground. This implies moving beyond mere production cost savings to natural resource savings and using ZT as stepping stone to conservation agriculture. ZT is also no panacea – and complementary resource conserving technologies that are privately and socially attractive are needed. At the same time technological intervention can only go so far. Indeed, policy reform to create an enabling environment for sustainable agriculture could easily prove even more significant, but implies addressing some of the more thorny policy issues such as the subsidy and taxation schemes that currently undermine the sustainability of rice-wheat systems.

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Table 1: Basic contrast between with and without case

	With case (with RWC & CIMMYT investments)	Without case (without RWC & CIMMYT investments)
ZT/RT adoption	Extrapolation from current To 33% in 2009	Five year lag (of current rate and extrapolation)
CIMMYT cost	US$ 600,000 over 12 years	0
RWC cost	US$ 2,900,000 over 19 years	0
NARS cost	US$ 3,900,000 over 23 years	US$ 4,100,000 with 5 year lag
Extension cost	US$ 4,100,000 over 26 Years	US$ 4,200,000 with 5 year lag

Table 2: Selected parameters for impact calculations

Indicator	Conservative scenario	Optimistic scenario
Elasticity of demand	0.22	id.
Elasticity of supply	0.40	id.
Social discount rate	5%	id.
Ceiling level of ZT/RT adoption	33%	id.
Yield advantage	6%	10%
Change in per ha cost of cultivation	5%	10%
Produce prices	Social (FHP/NPC)	id.
Timeframe	1990 base year + 30 years	id.
Benefits:		
- Zero till (ZT)	100% (27% of ZT & RT area)	id.
- Reduced till (RT)	50% (73% of ZT & RT area)	
Extension component	100% NARS	id.

FHP: Farm harvest price; NPC: Nominal Protection Coefficient – exportable basis. Sources: elasticity - Pal et al., 2003; NPC - Gulati et al 2003 as cited in World Bank, 2005

Table 3: Geographic distribution of rice-wheat systems and estimated zero and reduced till area in the Indo Gangetic Plains of India

States	Area under rice-wheat rotation (1998-01) (m ha)	Area with Zero/Reduced Tillage Wheat ('000 Ha)		
		2001-02	2002-03	2003-04
Punjab	0.91	20	50	215
Haryana	2.19	97	275	350
Uttar Pradesh, Uttaranchal & Himalachal Pradesh	5.13	12.6	45	235
Bihar	1.83	0.4	1	18
West Bengal	0.33	0	0	0
Total Area	10.4	130	371	818

Source: Pal et al., 2003; RWC, 2004

Table 4: Conservative and optimistic ZT impact scenarios

	Conservative scenario	Optimistic scenario
Net present value (NPV, million US$, 1990)	94	164
Benefit/Cost ratio	39	68
Internal rate of return (IRR)	57%	66%

Figure 1: Expected adoption pattern of ZT/RT in Indian IGP in with and without case

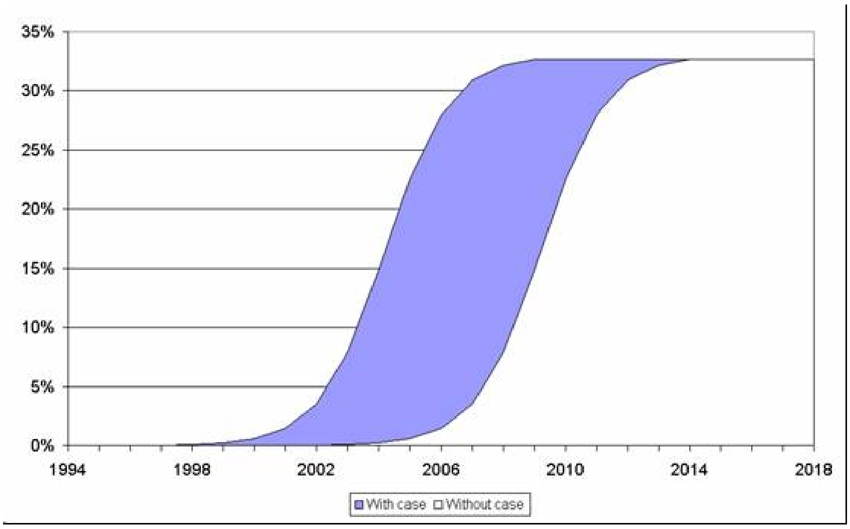

Table 5: Sensitivity analysis to variations of conservative ZT impact scenario

	Discount rate 0-10%	**Yield gain 0 - 3%**	**Cost reduction 0 – 2.5%**	**RT contribution 0 – 25%**	**Lag 1 - 3 years**
NPV (US$, million 1990)	214 - 43	22 - 58	71 - 82	39 - 66	18 - 57
B/C ratio	69 - 26	10 - 24	30 - 34	17 - 28	10 - 26
IRR	58 – 58%	37 - 51%	53 - 56%	45 - 53%	45 - 55%