Impact of Zero Tillage in India's Rice-Wheat Systems

Vijay Laxmi, Olaf Erenstein and R.K. Gupta

Rice Wheat

CIMMYT

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The International Maize and Wheat Improvement Center, known by its Spanish acronym, CIMMYT® (www.cimmyt.org), is an international, not-for-profit research and training organization. With partners in over 100 countries, the center applies science to increase food security, improve the productivity and profitability of farming systems, and sustain natural resources in the developing world. The center¹s outputs and services include improved maize and wheat varieties and cropping systems, the conservation of maize and wheat genetic resources, and capacity building. CIMMYT belongs to and is funded by the Consultative Group on International Agricultural Research (CGIAR) (www.cgiar.org) and also receives support from national governments, foundations, development banks, and other public and private agencies.

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Acronyms

ACIAR	Australian Centre for International Agricultural Research
BCR	benefit-cost ratio
BHU	Banaras Hindu University
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center, Mexico (www.cimmyt.org)
HAU	Haryana Agricultural University
ICAR	Indian Council for Agricultural Research
IGP	Indo-Gangetic Plains
IRR	internal rate of return
NARS	National Agricultural Research System
NARES	National Agricultural Research and Extension System
NPV	net present value
NRM	natural resources management
NSC	National Seed Corporation
R&D	research and development
PAU	Punjab Agricultural University
RCT	resource conserving technology
Rs	Indian Rupee: US$ 1 = Rs 44.9 (average 2004–2006, RBI 2007)
RT	reduced tillage
RWC	Rice-Wheat Consortium of the Indo-Gangetic Plains (www.rwc.cgiar.org)
RWS	rice-wheat-based cropping systems
SAU	State Agricultural Universities
SPIA	Standing Panel on Impact Assessment
UP	Uttar Pradesh
ZT	zero tillage

Foreword and acknowledgements

The present report is an expanded version of Laxmi et al. 2007, and includes additional text, tables and references. The overall study benefited from support and reviewers' comments from the Standing Panel on Impact Assessment (SPIA) of the interim Science Council (iSC) of the Consultative Group on International Agricultural Research (CGIAR) as part of the initiative on Ex-Post Impact Assessment of Natural Resources Management (NRM) research in the CGIAR. It benefited from complementary funding from USAID. The valuable comments of Hermann Waibel, David Zilberman, John Dixon and various reviewers are gratefully acknowledged. While Parvesh Chandna helped generate the maps. Kingsley Kurukulasuriya edited the report. The usual disclaimer applies.

Abstract

To date, the most widely adopted resource conserving technology (RCT) in the Indo-Gangetic Plains (IGP) has been zero-tillage (ZT) for wheat after rice, particularly in India. This report reviews and synthesizes the experience with zero tillage in the Indian IGP. Zero tillage of wheat after rice generates significant benefits at the farm level, both in terms of significant yield gains (6–10%, particularly due to timelier planting of wheat) and cost savings (5–10%, particularly tillage savings). These benefits explain the widespread interest of farmers and the rapidity of the diffusion across the Indian IGP, further aided by the wide applicability of this mechanical innovation. The study subsequently reports on the findings of village-level focus-group discussions in Punjab, Haryana and Eastern Uttar Pradesh (UP). These typically corroborate the findings reported in the reviewed literature. They also highlight the significant extent and speed of ZT adoption in each village as well as the attendant substantial cost savings and yield increases. A conservative ex-ante assessment of supply-shift gains alone (excluding other social and environmental gains), shows that the investment in zero tillage/reduced tillage (ZT/RT) research and development by the Rice-Wheat Consortium of the Indo-Gangetic Plains (RWC) and the International Maize and Wheat Improvement Center, Mexico (CIMMYT) was highly beneficial with a benefit-cost ratio of 39, a net present value (NPV) of US$ 94 million and an internal rate of return (IRR) of 57%. The study highlights the potential gains from successful technology transfer and adaptation in natural resources management (NRM).

Chapter 1 Introduction

Rice-wheat systems provide the staple grain supply for about 8% of the world's population, making these systems critically important for global food security (Ladha et al. 2003b; Timsina and Connor 2001). In South Asia, rice-wheat systems produce more than 30% of the rice and 42% of the wheat consumed (RWC-CIMMYT 2003:24) and cover about 14 million hectares of cultivated land, with most of the area located in India and the IGP (Table 1).

During the 1950s and early 1960s, South Asia suffered frequent, severe food shortages. Beginning in the late 1960s, however, production of rice and wheat increased dramatically throughout the region during the 'Green Revolution,' spurred by new high yielding wheat and rice germplasm, a favorable resource base, rapid expansion of irrigation infrastructure, and an extremely supportive policy environment. The Green Revolution greatly reduced the incidence of hunger and starvation through rapid growth in agricultural production, particularly in India's rice-wheat systems.

Recent studies indicate a slowdown in the productivity of growth in the rice-wheat systems of India (Kumar et al. 2002a). Evidence from long-term experiments shows that crop yields are stagnating and sometimes declining (Duxbury et al. 2000; Ladha et al. 2003a). Current crop cultivation practices in rice-wheat systems degrade the soil and water resources thereby threatening the sustainability of the system (Ali and Byerlee 2000; Byerlee and Siddiq 1994; Duxbury et al. 2000; Fujisaka et al. 1994; Gupta et al. 2003; Hobbs and Morris 1996; Kumar and Yadav 2001; Ladha et al. 2003a). The prevailing policy environment has encouraged inappropriate land and input uses (Pingali and Shah 1999), and crop system constraints have encouraged unsuitable responses. At the same time, rapid urbanization decreases the land available for agriculture. As a result, food security in the region remains a challenge for the future. If the supply of food is to keep pace with the rapidly growing demand, rice-wheat farmers will have to produce more food from fewer resources while sustaining the environmental quality. This will require rapid changes towards technologies that are more productive but less resource-degrading.

During the early 1990s, with the emerging concern over the sustainability of productivity of growth in rice-wheat cropping systems, the need for the establishment of an international research consortium was felt. As a consequence, an eco-regional program of the CGIAR was launched in 1994, in the form of the RWC. This consortium involves national agricultural research systems from Bangladesh, India, Nepal and Pakistan and international centers including CIMMYT, the International Rice Research Institute (IRRI), and others (see http://www.rwc.cgiar.org). The RWC is a special kind of research network, which addresses natural resources management (NRM) issues and problems of agricultural productivity and sustainability within a geographically defined area. Over the past 10 years, the RWC has developed and promoted a number of resource conserving technologies that increase farm-level productivity, conserve natural resources, and limit negative environmental impacts (Gupta and Sayre 2007; Gupta and Seth 2007; Hobbs and Gupta 2003).

To date, the most widely adopted resource conserving technology in the IGP has been zero-tillage (ZT) wheat after rice, particularly in India. The present report reviews and synthesizes the experience with ZT in the Indian IGP to better understand and document the impact of this technology and related research.

The next chapter introduces the ZT technology in the context of India's rice-wheat systems including a brief historic overview of the related research and development (R&D). Chapter 3 presents the methodology of the study while chapter 4 reviews the reported ZT adoption and impacts. Chapter 5 presents the findings of focus-group discussions and chapter 6 estimates the welfare impacts of ZT. Chapter 7 presents the conclusion.

Table 1. Rice, wheat and rice-wheat systems in South Asia.

Country	Area under rice-wheat-based cropping systems (million ha)	Share of crop area under rice-wheat-based cropping systems (%)		Contribution of rice & wheat (%)	
		Rice	Wheat	Total cereal production	Total national calorie intake
India	10.3	23	40	85	60
Pakistan	2.2	72	19	92	62
Bangladesh	0.5	5	85	100	94
Nepal	0.6	35	84	71	63

Source: Adapted from Timsina and Connor 2001.

Chapter 2 Zero Tillage

The Zero Tillage Technology

Zero tillage (ZT) implies planting crops in previously unprepared soil. It is also known as zero till, no till or direct planting. This ancient practice continues to be followed by farmers in developing countries. The modern concept of ZT tends to imply seeding a crop mechanically in undisturbed soil-covered plant residues. "Though the name refers to only one practice, no till is actually a farm management system that involves many agricultural practices, including planting, residue management, weed and pest control, harvesting, and rotation" (Ekboir 2002). Zero tillage differs from RT in the sense that the latter still retains some minimal tillage prior to seeding, although this often still implies a significant reduction in tillage intensity compared to conventional farming practices. Data limitations sometimes imply that no clear-cut distinction can be made between ZT and reduced tillage, leading us to sometimes consider them jointly (ZT/RT).

Zero tillage in rice-wheat systems ranges from surface seeding to planting with seed drills drawn by four-wheel tractors (Hobbs et al. 1997). In surface seeding, wheat seeds are broadcast on a saturated soil surface before or after rice harvest (Tripathi et al. 2006). It is a simple technology for resource-poor farmers requiring no land preparation or machinery, but its use is still largely confined to low-lying fields that remain too moist for tractors to enter, particularly in the Eastern IGP. Mechanical seed drills typically open a hole, narrow slot, trench, or band of the smallest width and depth needed to obtain proper coverage of the seed. The prevailing ZT technology in the rice-wheat systems uses a tractor-drawn zero-till-seed drill to establish wheat in the rice stubble. This specialized seeding implement allows wheat seed to be planted directly into unplowed fields with a single pass of the tractor. Often, use is made of a zero-till-seed-cum-fertilizer drill: a conventional seed drill fitted with sharp-edged modified furrow openers, a calibrated engraved disc, and a cup mechanism for placing fertilizers. The machine opens a number (6–13) of narrow slits for placing seed and fertilizers at a depth of 7.5–10 cm into the soil (Mehla et al. 2000). The ZT drills are made domestically and cost around US$ 400 (Parwez et al. 2004).

'Conservation agriculture' is the term used for a diverse array of crop management practices that involve minimal disturbance of the soil, retention of residue mulch on the soil surface, and use of crop rotations (FAO 2007; Harrington and Erenstein 2005; Hobbs 2007). Within the context of conservation agriculture, ZT implies the retention of crop residues as mulch on the soil surface and its year-round application to all crops in the cropping cycle. In the Indian context, farmers still typically apply ZT only to the wheat crop; maintaining adequate residue levels for an effective mulch has proven problematic—in terms of both prevailing crop residue management practices (Erenstein et al. 2007d; Timsina and Connor 2001) and sowing wheat in the presence of significant rice residues with the current ZT drills (Pandey et al. 2003).

In the IGP, wheat is grown in the cold and dry weather from November to March while rice is grown during the warm humid/semi-humid season from June to October (Timsina and Connor 2001). Zero tillage of wheat is particularly appropriate for these systems and addresses four important constraints.

First, rice-wheat systems were often 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. The late harvest of the previous rice crop can be linked to both the late rice establishment and the duration of the rice crop. For instance, in some parts of the IGP, farmers grow fine-quality rice (especially basmati), which takes longer to mature. The long turn-around time often reflects intensive tillage operations, soil-moisture problems (too wet or too dry), unavailability of draft and mechanical power for plowing, and the urgency to store the rice crop before preparing land for wheat cultivation. Conventional tillage (CT) practices for wheat are very intensive and involve multiple passes of the tractor to accomplish plowing, harrowing, planking, and seeding operations. Farmers perceive the need for intensive tillage due to the difference in soil management practices for rice and wheat being grown under anaerobic and aerobic conditions, respectively. Zero tillage greatly reduces the turn-around time allowing wheat establishment in a single pass almost immediately after the rice harvest.

Second, continuous rice-wheat cultivation has led to the buildup of pests and diseases. The major weed affecting wheat in the IGP is Phalaris minor, which shows emerging resistance to isoproturon herbicide after repeated and widespread use. By reducing soil movement ZT serves as an effective control measure of P. minor (Malik et al. 2002c).

Third, rice-wheat systems have led to land degradation. Excessive groundwater pumping has led to lowering of the water table in some of the rice-wheat areas (Kataki et al. 2001; Malik et al. 2002a). Zero tillage potentially reduces irrigation water use—alleviating pressure on aquifers.

Fourth, rice-wheat systems need to enhance their cost competitiveness in the context of trade liberalization. Zero tillage potentially includes savings in energy, water, labor, and other inputs. Zero tillage drastically reduces the use of machinery (less wear and tear and depreciation) and the cost of the tillage operation—a major cost of crop production in the IGP. Compared to broadcasting, the ZT drill saves seed and fertilizer, placing them at the desired depth and vicinity and in the right quantities.

The advantages of ZT technology are thus manifold. On the one hand, this practice generates higher yields at lower production costs and, on the other, it is an environment- friendly practice that saves water and soil (Hobbs et al. 1997).

A Brief History of Zero Tillage in India[1]

In India, research on ZT for wheat started almost three decades ago (Ekboir 2002). Several state agricultural universities tried ZT in the 1970s but their efforts failed due to technical difficulties, such as the lack of adequate planting equipment and the difficulty in controlling the weeds chemically. This line of research was soon abandoned by all except a handful of researchers working in isolation.

In 1990, CIMMYT's regional wheat agronomist introduced inverted-T openers to Indian researchers. These openers were originally developed in New Zealand by Aitchison Industries, and had been variously used in Pakistan in the preceding years—including the import of two inverters (1982), and one Aitchison drill (1984), and the local production of 20 copies of the Aitchison drill (1988). In 1991, a first prototype of the Indian ZT seed drill was developed at G B Pant University of Agriculture and Technology, Pantnagar. In 1992–93, a collaborative program for further development and commercialization of ZT was initiated with small-scale industries in Punjab (throughout this report, this means Indian Punjab). After considerable investment of resources and several design changes, the first ZT seed drill was made available for field-testing within 12 months. The RWC joined hands with the National Agricultural Research Systems and provided support to pursue farmers' participatory research and further adapt the zero-tillage technology to rice-wheat systems. To overcome bureaucratic hurdles, RWC acquired several zero-tillage drills and donated them to the Haryana Agricultural University for experimenting in farmers' fields. This provided the much-needed push to this program. In the late 1990s, Monsanto supported no-till research at the universities but soon reduced its activities as the potential market for their product, glyphosate, was perceived as small.

In 1997, after further refinement based on the feedback received from scientists and farmers, the private manufacturers supplied over 150 improved ZT drill machines to State Agricultural Universities (SAU) and the Indian Council for Agricultural Research (ICAR) institutions located in Haryana, Punjab, Uttar Pradesh, and Bihar. The manufacturers spent a great deal of their time in the fields with farmers and scientists to better understand the problems in machine operation which led to the rapid improvement of subsequent models. The manufacturers, scientists, and farmers shared their experiences with senior staff and officials of the Indian National Agricultural Research and Extension System (NARES, including State Agricultural Universities) to seek their support in promoting zero tillage. All were encouraged by the better results of ZT. The combined efforts of the NARES, private manufacturers, Rice-Wheat Consortium of the Indo-Gangetic Plains, and CIMMYT resulted in the widespread adoption of zero tillage at the turn of this century.

In India, the rapid and widespread adoption of ZT started in the Haryana State. Two drivers behind the success are the adequacy of the technology in meeting farmers' needs and the favorable institutional context. In Haryana, many farmers

1 This section draws heavily from Ekboir 2002:29-30 and Seth et al. 2003:65-67.

grow late-maturing fine-grained rice varieties (e.g., basmati) causing late sowing of wheat and the widespread incidence of the weed P. minor. Therefore, ZT was helpful not only in reducing the cost of tillage but also in increasing the wheat yield. Several actors played a key and complementary role in spreading the ZT technology, including the Haryana Agricultural University, the Directorate of Wheat Research (ICAR) and the State Agricultural Department aided by the various-sponsored research and development projects from the RWC, CIMMYT, the Indian Council for Agricultural Research, and the Australian Centre for International Agricultural Research. The State Government also supported ZT in the form of a subsidy of Rs[2] 3,000 per new ZT drill at a unit gross price of Rs 13,000, which has enhanced farmers' access to the machine (Ekboir 2002). Other than these, the drivers of the success were the timely congruence of technology interventions, liberalization, and participatory operational approaches provided by the RWC.

Seth et al. (2003:67) list the main reasons for the rapid success of ZT in India as:

- The initiative was responding to a strong farmer demand where the private sector could see substantial market opportunities for their products.
- The RWC played a crucial catalytic role in promoting the public-private partnership, nurtured it through its formative stages, and facilitated technology transfer from international and national sources. In addition, the RWC established a small revolving fund to facilitate delivery of machines at district points.
- Close linkages of scientists and farmers with the private manufacturers including placement of machines in villages for farmer experimentation allowed a rapid feedback and refinement of implements.
- Involvement of several manufacturers ensured competitive prices, good quality, and easy access to drills by farmers along with a guarantee for repairs and servicing.
- Strong support from state and local government officials helped with dissemination.

The importance of institutional support in India is also highlighted by neighboring Pakistan, where institutional rivalry has slowed the significant spread of ZT so far (Erenstein et al. 2007a).

The RWC played the innovative role of information provider, capacity builder, and technology clearing house. As research for a development network, the RWC works closely with international organizations, government organizations, the private sector and farmers. In doing so, it facilitates their collaboration, strengthens interlinkages, encourages information-sharing and feedback, circumvents institutional blockages, and mobilizes resources.

2 US$ 1 = Indian Rs 44.9 (average 2004–2006,; RBI 2007).

Chapter 3 Methodology

The present study comprised three components: a review, focus-group discussions, and modeling. For the first component, we compiled and reviewed information on zero-tillage wheat in India's rice-wheat systems in the IGP, including published literature, gray literature, and unpublished datasets. The available information tends primarily to report on the technical aspects of ZT at the plot level. Economic and environmental aspects are covered to a lesser extent. 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. The Indian IGP comprises a vast area that can be divided into four plains: Trans Gangetic Plains (TGP-Punjab and Haryana in the northwest), Upper Gangetic Plains (UGP-Western UP and Uttaranchal terai/plains), Middle Gangetic Plains (MGP-Eastern UP and Bihar), and Lower Gangetic Plains (LGP-West Bengal, Figure 1; Kumar et al. 2002a; Narang and Virmani 2001). Reference will be made to these subregions where relevant.

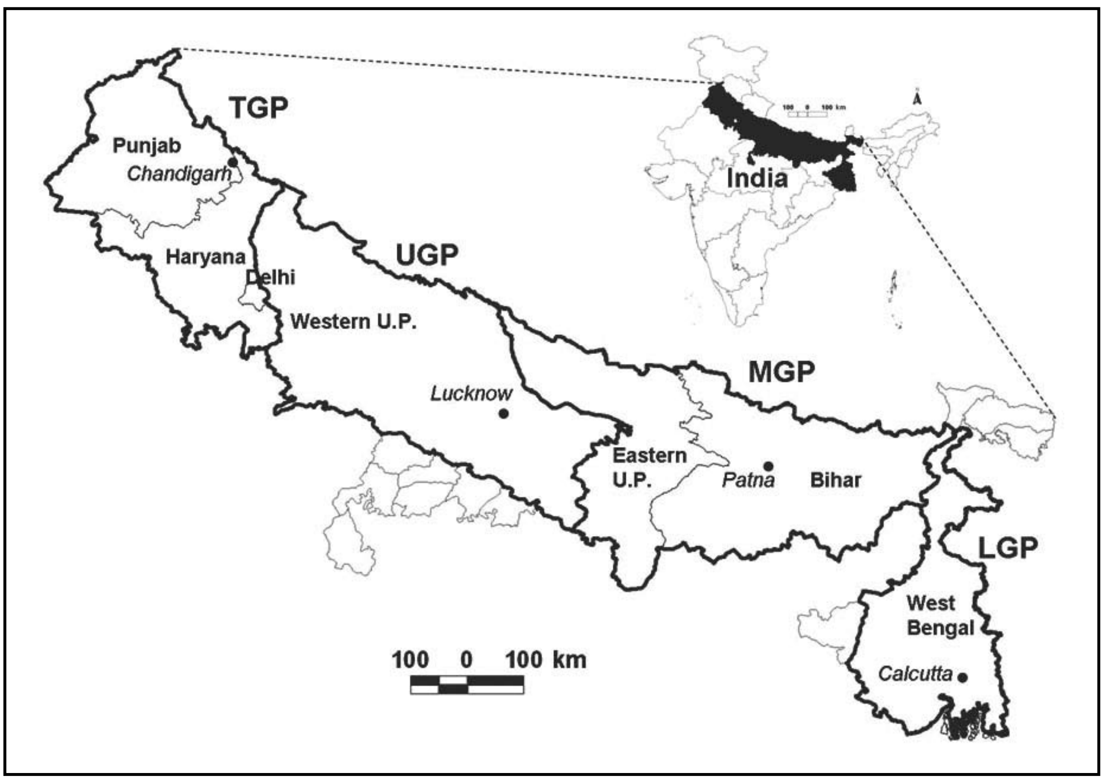
For the second component, we conducted village-level focus-group discussions in Punjab, Haryana, and Eastern UP in six villages (two in each state) during the 2003–04 winter season. Four of the six villages are located in the Northwestern IGP (Punjab and Haryana) where adoption of zero tillage is more widespread (Figure 2). Villages were chosen purposively for having reported adoption of ZT. The exercise in each village included both adopters and non-adopters (including dis-adopters, i.e., those who had discontinued the use of ZT). Where feasible, the group was divided into rich and poor farmers on the basis of landholding, and discussions were carried out separately for males and females. The focus groups were conducted to analyze the socioeconomic impact of ZT wheat firsthand and for validating the secondary data.

For the third component, we modeled the economic impact of research and development on zero-tillage wheat 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 R&D investment on zero-tillage wheat. Table 2 presents the main contrasts between the 'with' case (with the RWC and CIMMYT investments) and the 'without' case used to estimate the rate of return. The Annex provides further details on the estimation of the costs. The economic impact of R&D was calculated for two 'with' case scenarios to test for sensitivity of the findings. Table 3 presents the main parameters used and the differences between the conservative and optimistic scenarios. The assumption of "no other changes in the farming system" applies.

It is important to stress here that the modeled economic impact 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, and long-term and distributional effects). Reliable estimates of these effects are typically still scanty as apparent from the review. Compounding the issue, the extent and durability of the ZT wheat environmental gains are debatable with current farmers' practices for the subsequent rice crop and crop-residue management. Overall though, ZT typically implies positive environmental impacts, so that estimates of our economic impact can be seen as conservative underestimating the true social value of the technology and the social rate of return.

We can only make a reasonable assumption about the counterfactual in the absence of the efforts of the RWC and CIMMYT. As outlined in the previous section, they played key roles in adapting the ZT drills to the South Asian setting, facilitating the linkages between research, extension, drill manufacturers, and farmers and achieving the necessary momentum in terms of ZT interest and research and development resources. It can thus be assumed that CIMMYT's role and persistence constituted the key in getting the technology adaptation process through its slow and difficult start. In this process, CIMMYT has assumed the role of an 'honest broker' in building up confidence of the applied research and testing process. The RWC has been key in achieving and building on the initial gains for zero tillage in the Indian Indo-Gangetic Plains—through fostering prototype zero tillage equipment, farmer experimentation, and information sharing. The efforts of the RWC and CIMMYT thereby played an important role in accelerating the adaptation and uptake of ZT in India. As in Vincent and Quirke 2002:31, we assume that, without these efforts, ZT would have been introduced to the region, but with a lag of five years. This assumption seems consistent with the traditional diffusion pattern of successful technologies, whereby key interventions such as technology adaptation and facilitation can significantly accelerate uptake. The exact number of years remains ambiguous though, and we assume the five years to be a conservative lower bound as it could well be also up to 10 years.

Attribution also remains problematic. The RWC as a network could not have functioned on a stand-alone basis, but its presence and perseverance have generated synergies and a momentum that, otherwise, were unlikely to have been achieved. Indeed, success tends to generate an upward spiral of interest and additional resources. The RWC thereby takes shared credit for the successful spread of zero tillage. Here we attribute the gains of bringing the ZT uptake five years forward to the efforts of the RWC and CIMMYT in India, without further attribution to consortium partners.



Note: TGP: Trans Gangetic Plains; UGP: Upper Gangetic Plains; MGP: Middle Gangetic Plains; LGP: Lower Gangetic Plains.

Figure 1. The subregions of the Indo-Gangetic Plains in India.

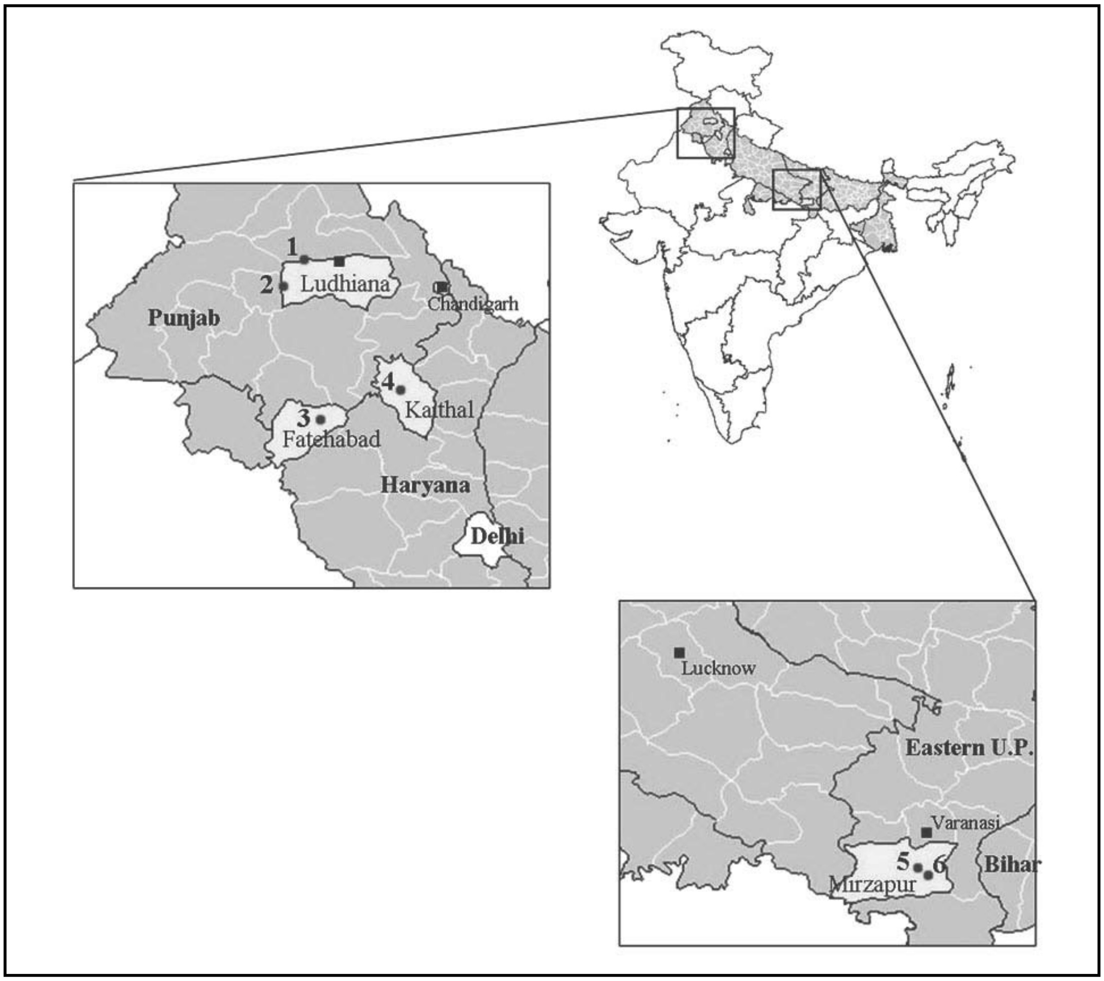


Figure 2. Locations of surveyed villages in the Indo-Gangetic Plains in India
(Names of the villages: 1. Gurusar Kaunke; 2. Kaunke Kalan; 3. Pirthala; 4. Teek; 5. Bhurkura; and 6. Karhat)

Table 2. Basic contrasts between 'with' and 'without' cases.

	With case (with RWC and CIMMYT investments)	Without case (without RWC and CIMMYT investments)
Adoption of zero/reduced tillage adoption	Extrapolation from observed diffusion curve to date to 33% in 2009	5-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
National Agricultural Research System 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

Note: For further cost details see the Annex.

Table 3. Selected parameters for impact calculations.

Indicator	Conservative scenario	Optimistic scenario
Elasticity of wheat demand	0.22	
Elasticity of wheat supply	0.40	
Social discount rate	5%	
Ceiling level of adoption zero /reduced tillage for wheat	33%	
Wheat yield advantage	6%	10%
Change in per ha cost of wheat cultivation	5%	10%
Produce prices	Social (Farm harvest price/Nominal Protection Coefficient-exportable basis)	
Time frame	1990 base year + 30 years	
Benefits:		
- Zero tillage	x 100% (27% of zero/reduced tillage area)	
- Reduced tillage	50% (73% of zero/reduced tillage area)	
Extension component	100% National Agricultural Research System	

Notes: The source for the first four items is Pal et al. 2003. Data on the fifth and sixth items are based on the literature review for this study (see below). Produce prices follow Gulati et al. 2003 as cited in World Bank 2005.

Chapter 4 Review of Adoption and Impacts of Zero Tillage

The present chapter reviews the reported adoption and impacts of zero tillage in the Indian IGP. In the first section, we look into the reported adoption of ZT and reduced tillage in India. The second section reviews the reported farm-level impacts of ZT in India, including (i) effects on land preparation and crop establishment; (ii) effects on water use; (iii) effects on soils, weeds, pests, and diseases; (iv) yield effects; and (v) cost savings and profitability. The third section reviews the socioeconomic and system impacts. The fourth and final section reviews the environmental impacts.

Adoption of Zero and Reduced Tillage in India

In India's rice-wheat systems, adoption of zero tillage is primarily in the wheat crop and concentrated in the Northwestern IGP. On an annual basis, the RWC compiles estimates of the scale of adoption of various resource conserving technologies (Gupta 2004; RWC 2004; www.rwc.cgiar.org). These estimates are primarily expert estimates at the state level using a range of indicators. Estimates of ZT area are often based on the sales of ZT drills and average area coverage per drill (e.g., Malik et al. 2005c:6–7). In these estimates, it is problematic to reliably separate ZT from reduced tillage so that these two technologies are typically lumped together. These estimates also primarily reflect tillage level and the use of ZT drill for individual crops—without explicit consideration of crop residue management.

In 2003–04, the total estimated wheat area under the combined zero and reduced tillage was approximately 820,000 hectares in the Indian IGP (Table 4). Most of the adoption was concentrated in Haryana (46% of 2003–4 ZT/RT area), Punjab (26%), and Western UP (21%). These areas are characterized by high agricultural productivity. The ZT/RT adoption has started to pick up in the eastern part of Uttar Pradesh and Bihar, where agricultural productivity is lower. So far, ZT has spread more widely in the better-endowed areas. For instance, the estimated rural poverty head count ratio in 1999–2000 was 44.3% in Bihar (second highest in India) and 31.2% in UP. The corresponding ratios for Punjab and Haryana were 6.4% and 8.3%, respectively (MoA 2004).

In 2004–05, the total estimated area under the combined zero tillage/reduced tillage was approximately 1.6 million hectares in the Indian IGP (Shoran 2005). The 2004–05 estimate for the first time disaggregated the estimated ZT and reduced-tillage areas, with ZT comprising 27% and reduced tillage 73%.

Figure 3 highlights the acceleration of the diffusion of ZT/RT over the recent years. In the second half of the 1990s, the technology was primarily in its testing phase, with farmers' interest in the Western IGP driven by late planting, herbicide resistance (P. minor), and labor scarcity. With the turn of the century the diffusion started to pick up, aided by the demonstration effect of early adopters and the participatory research for development initiatives by the consortium of international, national and state research organizations, private manufacturers and input agencies including farmers. The zero-tillage technology is currently in the mass adoption phase in the Indian IGP.

Table 4. Geographic distribution of the rice-wheat system and estimated zero and reduced tillage areas in the Indo-Gangetic Plains of India.

States	Area under rice-wheat rotation (1998–01) ('000 ha)	Area with zero/reduced tillage wheat ('000 ha)		
		2001–02	2002–03	2003–04
Punjab	2,190	20	50	215
Haryana	910	97	275	350
Uttar Pradesh*	5,130	12.6	45	235
Bihar	1,830	0.4	1	18
West Bengal	330	0	0	0
Total area	10,400	130	371	818

Source: Pal et al. 2003; RWC 2004.
* Includes Uttaranchal and Himalachal Pradesh.

The aggregate ZT/RT adoption estimates can be triangulated against other available adoption indicators. A recent random survey of 400 farm households in Haryana's rice-wheat belt included 34% ZT users in 2003–04 (Erenstein et al. 2007b). A random survey of 759 farm households in Punjab included 12% ZT users and 5% reduced-tillage users in 2003–04 (Joginder Singh, pers.comm.). These studies provide further support for the significant levels of ZT adoption in Haryana and Punjab.

The adoption estimates can also be contrasted with the reported sales of ZT drill machines. A recent study in Haryana and Punjab, where most of the adoption is concentrated, has compiled the number of ZT manufacturers and the number of ZT drills sold annually over the last 10 years (Parwez et al. 2004). Both indicators have shown a significant increase in recent years (Figure 4). These data highlight that, by the end of the year 2003, a cumulative total of 15,700 ZT drill machines had been sold in the two states.[4] If we assume all machines to be operational, and unreported sales to cancel out against eventual exported machines to other states, then the reported 565,000 hectares of ZT/RT in the two states in 2003–04 (Table 4) imply an average of 36 ha planted per zero-tillage drill. This compares well with the results of a survey of 153 ZT drill-owning farmers in Haryana, which showed that, on average, each ZT machine had planted 42 hectares of wheat in 2001–02 (Punia et al. 2002). However, this may only reiterate that some of the ZT area estimates are primarily based on drill sales.

In principle, the zero-technology technology could be extended to the entire mechanically tilled wheat area in the IGP. However, in the medium term this does not seem realistic due to a range of agro-climatic and socioeconomic factors that limit its applicability. A significant number of the current generation of farmers will likely adhere to their traditional preference for intensive tillage. There are also potential interactions between ZT and soil type, seasonal factors and cumulative effects that will cause farmers to adhere to intensive tillage in some plots or seasons (e.g., as preferred option to control a weed flush due to unseasonal rains and/or to control perennial weeds). A recent study on ZT adoption indeed found partial adaption to prevail, with an average of only half the ZT adopters' wheat area under ZT (Erenstein et al. 2007b). In any event, achieving blanket access to ZT knowledge and timely access to ZT drills will remain a challenge in the Indo-Gangetic Plains, whereas further adaptations may be needed to adapt ZT to the smallest of plots in the Eastern Indo-Gangetic Plains. As in Pal et al. 2003, we estimate the adoption ceiling for ZT/RT to be a relatively conservative 33% of the wheat area in the rice-wheat systems of the Indo-Gangetic Plains—a potential ZT/RT area of 3.43 million hectares. Figure 4 (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 contribution of the RWC and CIMMYT.

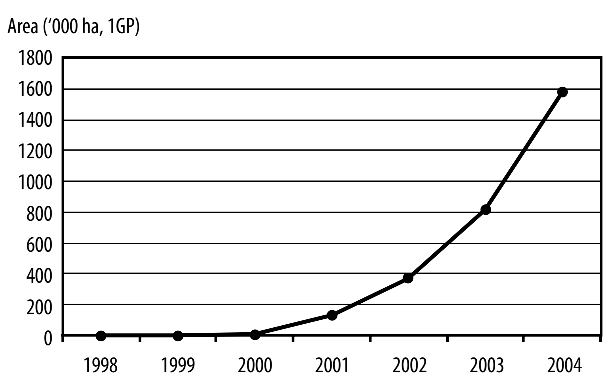


Figure 3. Estimated diffusion of zero/reduced tillage in the Indian Indo-Gangetic Plains.
Sources: 2004 Shoran 2005; 2001–03: RWC 2004:6; 1998–2000: Mehla et al. 2000:8 (Haryana only).

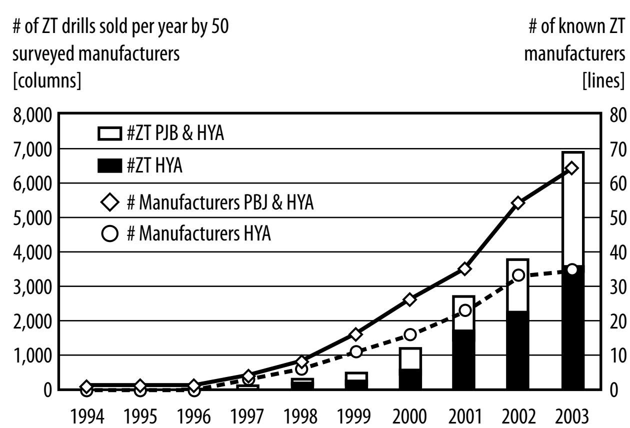


Figure 4. Number of zero-tillage drill manufacturers [lines] and number of zero-tillage drills sold per year by surveyed manufacturers [columns] in Haryana (HYA) and Punjab (PJB), India, 1994–2003.
Source: Erenstein et al. 2007b.

4 Adoption of ZT technology moved from Haryana to Punjab but manufacturers were initially located in Punjab and machines were transported from there in the early years of adoption.

The current stage of mass adoption calls for ongoing analysis of the experiences of adopters and making the necessary modifications in the technology and diffusion process to suit the local needs and enable even wider adoption and adaptation. This calls for a good understanding of farmers' perceptions and practices and the drivers and modifiers behind these. Some farmers use the ZT drill, but maintain a limited degree of tillage—i.e., RT (or partial adoption). Some adopters continue to use ZT and conventional tillage side by side on the same farm (Erenstein et al. 2007b; Pandey et al. 2003). Of the 400 randomly surveyed farm households in Haryana's rice-wheat belt, 10% had dis-adopted ZT in the survey year (Erenstein et al. 2007b) including 'temporary' dis-adoption, whereby farmers had reverted to reduced tillage for various reasons (e.g., to control a rainfall-induced flush of weeds).

The ZT technology is dependent on affordable and timely access to ZT drills and their correct operation—an issue particularly in the early stages of adoption. Custom-hiring of ZT drill services have thereby been a key ingredient for the rapid diffusion of ZT. A survey of ZT drill-owning farmers has highlighted that 69% of the wheat area planted with each drill was under custom-hiring (Punia et al. 2002). Similarly, another survey found 60% of ZT adopters in Haryana to have relied on contracted ZT drill services (Erenstein et al. 2007b). Surveyed dis-adopters in Haryana mentioned the nonavailability of ZT machinery as the main reason for dis-adoption (Nagarajan et al. 2002). The focus groups in Eastern Uttar Pradesh also included cases of dis-adoption due to untimely availability of ZT drills, reflecting the inability of a few ZT service providers to meet the demand during wheat establishment time. Availability of machinery is still likely to restrain adoption in the eastern plains in the near future.

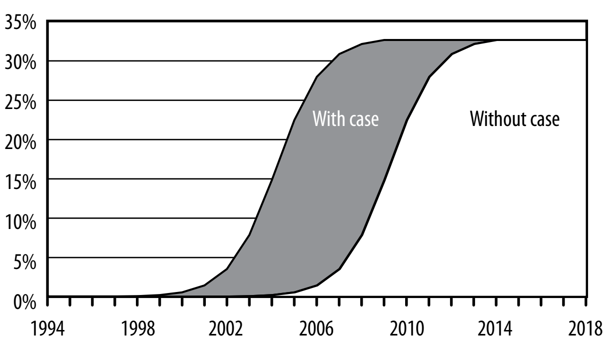


Figure 5. Expected adoption pattern of zero/reduced tillage in the Indian Indo-Gangetic Plains with and without cases.

Farm-Level Impacts of Zero Tillage in India

The present section reviews the direct farm-level impacts of adoption of zero-tillage wheat in rice-wheat systems in the Indian IGP, based on the available literature. The emphasis here is on the reported direct, immediate, and pecuniary effects attributable to the ZT technology at the plot/farm level—i.e., the on-farm impact on productivity and production costs. Most of the available literature relates to the northwestern parts of the IGP—the Trans Gangetic Plains and the Upper Gangetic Plains—which are characterized by areas of intensive agriculture.

Effects on land preparation and crop establishment

Conventional tillage practices for wheat are very intensive in India's rice-wheat systems (Table 5). For instance, tillage alone encompasses around 25% of the total cost of conventional wheat production (Karnal, Haryana). Due to the adoption of ZT technology, the number of field operations for the establishment of the wheat crop (including tillage) decreased from an average of seven to only one (Sharma et al. 2002a). Due to this, about 8 to 12 hr/ha of tractor operational time were reportedly saved (an 80–88% savings—Malik et al. 2004; Sharma et al. 2002a; Yadav et al. 2002b; Table 6).

The corresponding seasonal savings in diesel for land preparation is reported to be in the range of 15–60 liters/hectare (l/ha), representing a 60–90% savings (Hobbs and Gupta 2003; Laxmi et al. 2003; Malik et al. 2002a; Malik et al. 2004; Yadav et al. 2002b; Table 6). In Haryana, ZT saved 59 l/ha of fuel, 8 hr/ha of tractor time, and approximately 3,000 Mega Joules/ha of energy in tractor operations as compared to

Table 5. Number of field operations performed in conventional tillage in rice-wheat system in the Karnal District, Haryana.

	Percentage of farmers					
Number of operations	Wheat Hired	Owned	Total	Paddy Hired	Owned	Total
<6	0	0	0	4	4	7
6 to 9	31	15	46	27	42	69
10 to 13	7	31	38	9	12	21
>14	2	14	16	0	0	0

Source: Sharma et al. 2002a.

CT (Sharma et al. 2002a). Such potential savings are not limited to the IGP bur have also been reported in Central India (Madya Pradesh), where zero tillage had saved 75 l/ha of fuel by reducing tillage operations from seven to one (Yaduraju and Mishra 2002).

Zero tillage does not generate significant savings in labor use in land preparation and crop establishment, especially as mechanization is already widespread in the Indian IGP. A few studies reported marginal labor savings, for instance, labor savings of 4.3% in farmers' fields in Haryana (Sharma et al. 2002a). Laxmi et al. (2003) reported savings of approximately 5 person-days/ha in Haryana and 4 person-days/ha in Bihar.

The reduced turn-around time was reported to have allowed wheat planting to be advanced by 7–10 days in Haryana and by 8–25 days in Bihar (Gautam et al. 2002; Nagarajan et al. 2002; Singh et al. 2002c).

Effects on water use

Zero tillage is reported to save irrigation water in the range of 20–35% in the wheat crop. In Haryana, ZT saved an average of 7.5 cm-ha of water in pre-sowing irrigation (Karnal District; Nagarajan et al. 2002). Commonly, ZT reduces water usage by about 10 cm/ha, or approximately 1 million l/ha (Mehla et al. 2000). The savings arise because, with ZT, it is possible to sow wheat just after rice harvest making use of residual moisture for wheat germination. Moreover, irrigation water advances faster in untilled soil than in tilled soil. The savings are generally reported for the first irrigation (e.g., 8–10 hr. with ZT and 13–17 hr with conventional tillage; Hobbs et al. 1997). The problem of waterlogging and yellowing of the wheat plants after the first irrigation is thereby reduced (RWC-CIMMYT 2003:95). Zero tillage can also imply savings of one irrigation (Hobbs et al. 1997; Laxmi et al. 2003; Malik et al. 2002b; Malik et al. 2002a; Mehla et al. 2000). The irrigation savings tend to translate into immediate cost savings whenever farmers rely on lift irrigation, as in the case of electric- or diesel-operated wells.

Table 6. Diesel and tractor time use in zero tillage and conventional tillage.

	Fuel use (l/ha)			Tractor time (hr/ha)		
	Zero tillage	Conventional tillage	Savings (%)	Zero tillage	Conventional tillage	Savings (%)
1. Ludhiana (Punjab)	12.5	33	62	2.25	11.2	80
2. Karnal (Haryana)	6	65	91	1.6	9.4	83
3. Kaithal (Haryana)	7	21	67*	-	-	-
4. Pantnagar (Uttaranchal)	7.1	67.8	89.5	1.6	13.7	88
5. Begusarai (Bihar)	3.5	18.5	81*	-	-	-
6. Jabalpur (Madhya Pradesh)	9	84	89	3	24	87.5
7. Indo-Gangetic Plains	11	72	84			

Notes: Source for sites 1, 4 and 6 is Yaduraju and Mishra 2002; source for site 2 is Sharma et al. 2002a; source for sites 3 and 5 is Laxmi et al. 2003; source for 7 is Malik et al. 2004.
* Significant at 5%.

Effects on soils, weeds, pests, and diseases

Zero tillage typically improves soil quality in various dimensions, including soil structure, soil fertility, and soil biological properties. Rice-wheat systems typically have low soil organic carbon (Duxbury et al. 2000). The ZT soils reportedly have higher organic carbon contents than CT soils—but they also have a lower pH (due to nitrification; Chauhan et al. 2002). The same study reported that the higher stability of soil aggregates under ZT (due to accumulation of organic matter) results in reduced soil erosion (due to wind and rain). Studies have also reported that the upper soil surface for ZT was comparatively soft and had a higher moisture content and that there was no significant difference in bulk density under both tillage systems (Kumar et al. 2002b; Malik et al. 2002c; Yadav et al. 2002a). However, such gains during the wheat crop will only present seasonal gains as long as the subsequent rice crop remains intensively cultivated and anaerobic. For enhancement of the structural soil quality the whole cropping system would need to shift to aerobic and ZT conditions with adequate residue management.

With the adoption of ZT in rice-wheat systems in the IGP, comparatively less weeds were found in the wheat crop (Chauhan et al. 2002; Franke et al. 2007; Malik et al. 1998a; Malik et al. 2002c; Malik et al. 2004; Prasad et al. 2002; Sen et al. 2002; Singh et al. 2002a; Singh et al. 2002d; Yaduraju and Mishra 2002). With ZT, the early emergence of wheat and no or less soil disturbance in the uncropped area resulted in less and late emergence of weeds (especially P. minor). Therefore, weed competition to the wheat crop is greatly reduced. Malik et al. (1998a) reported that in fields with problematic weeds the saved time in ZT could be used for stimulating weed emergence followed by effective control with a nonselective herbicide.

Both long-term trials and farmer surveys suggest a change in the weed spectrum in ZT wheat fields. Malik et al. (1998a) found a change in the weed spectrum in ZT wheat fields, particularly an increase in the population of broad-leaved weeds. Singh et al. (2002b) conducted a long-term experiment in Haryana (Karnal District) and found that the intensity of P. minor decreased by 30–40% in ZT when compared to CT, while the intensity of broad-leaved weeds increased. Yadav et al. (2002a) in their long-term study in Haryana (1997–98 to 2001–02) also found less infestation of P. minor under ZT. Laxmi et al. (2003), reported that 51% of farmers in Haryana and 85% of farmers in Bihar perceived that weed infestation had decreased due to the adoption of ZT in wheat.

Zero tillage also alters the dynamics of selected pests and diseases (Chauhan et al. 2002; Laxmi et al. 2003) and has reportedly no harmful effect on the population density of insect pests in general and the yellow stem borer of rice in particular (Chauhan et al. 2002; Jaipal et al. 2002). In fact, ZT enhanced the earthworm population in rice fields and predator diversity and density in wheat. Dabur et al. (2002) reported a reduction in the population of nematodes in the wheat crop due to ZT adoption.

Yield effects

The generally positive yield effects of ZT on wheat are mostly due to (i) timely sowing and (ii) efficiency of increased input use and weed control (Mehla et al. 2000). Terminal heat implies that the potential of wheat yield decreases by 1–1.5%/day if planting occurs after 20 November (Hobbs and Gupta 2003; Ortiz-Monasterio et al. 1994; Randhawa et al. 1981). Approximately 30% of wheat cultivation is under late sowing in the Indian IGP, and zero tillage allows for timelier establishment.

On-station trials across the Indian IGP reported significant increases (3–73%) in wheat yields under **zero tillage** (Dhiman et al. 2003; Prasad et al. 2002; Sen et al. 2002; Yadav et al. 2002b). The few exceptions without an increase in ZT yield tend to be in Punjab (e.g., Chahal et al. 2002), which may reflect that planting of wheat in Punjab is already timely (Hobbs 2001). On average, an 11% (400 kg/ha) increase in wheat yield was reported with **zero tillage** in each year (2000–01 and 2001–02) across six research centers in the IGP (Dhiman et al. 2003)—ranging from a marginal 1% (50 kg/ha) decrease in the Punjab to a maximum of 26% (600 kg/ha) increase in Eastern UP for the two years combined (Table 7). Table 7 shows some variation in the relative yield increases in each year but, per site, the ZT advantage tends to be consistent and of a similar order of magnitude. The increase in yield was reported significant in the Middle Gangetic Plains and insignificant in the Trans Gangetic Plains.

On-farm trials across the IGP have also highlighted the higher yields with ZT, with increases ranging from 1–15% in the Northwest to 9–36% in the East (Gautam et al. 2002; Malik et al. 2004; Nagarajan et al. 2002; Sharma et al. 2002b; Yadav et al. 2002b). Table 8 shows increases in wheat yields in farmers' fields under ZT across sites, ranging from a marginal 1% increase in Punjab to a maximum 12% increase in Bihar (Malik et al. 2004). On average, a 280-kg/ha increase in wheat yield was reported in 112 farm trials (46 in 2000–01 and 66 in 2001–02) across five states in the IGP (Dhiman et al. 2003)—average increases ranging from 110 kg/ha in Punjab to 490 kg/ha in Bihar. Both on-station and on-farm trials thereby highlight significant yield gains with ZT—with the gains increasing from Punjab towards the middle Gangetic plains reflecting the increasing

Table 7. On-station yield of wheat (t/ha) under zero tillage and conventional tillage in research centers in different regions of the Indo-Gangetic Plains.

Research center	Zero tillage		Conventional tillage		Gain (%)	
	2000–01	2001–02	2000–01	2001–02	2000–01	2001–02
Ludhiana, Punjab	4.34	4.13	4.46	4.11	-2.7	0.5
Kaul, Haryana	4.77	4.74	4.58	4.63	4.2	2.4
Pantnagar, Uttaranchal	4.83	4.16	4.05	3.68	19.3	13.0
Faizabad, Eastern Uttar Pradesh	3.75	4.77	3.33	4.02	13.5	18.7
Varanasi, Eastern Uttar Pradesh	2.87	2.88	2.18	2.48	36.2	16.1
Patna, Bihar	3.47	3.52	2.95	3.02	17.6	16.6

Source: Dhiman et al. 2003.

importance of timeliness. Long-term monitoring of six sets of farmer fields over eight years in Haryana has shown that ZT had consistently higher or similar yields to CT (Malik et al. 2005d:16).

As yet, relatively few farm surveys are available to document yield effects of zero-tillage adoption in the IGP. In one adoption survey of 34 farmers in Uttaranchal, zero-tillage adopters significantly outyielded conventional tillers with 5% (=200 kg/ha, 4.4 vs 4.2 t/ha; Pandey et al. 2003). One survey of approximately 400 farmers in 2003 contrasted zero-tillage adopters with non-adopters in Haryana and Bihar (Laxmi et al. 2003). In Bihar, zero tillage significantly outyielded CT with 9% (220 kg/ha; Table 9). In Haryana, the 6% difference in yields was not statistically significant. Another study of 398 farmers over three years in Haryana reported a significant 153 kg/ha yield increase for ZT adopters (Malik et al. 2005b). Yet another survey of 400 farmers, again in Haryana, revealed a similar significant yield advantage of 170 kg/ha (or 4.0%) for zero tillage over CT plots of adopters in the survey year (2003–04), although not in the preceding years (Erenstein et al. 2007b).

Cost savings and profitability

Most of the available studies concur in highlighting the profitability of ZT wheat production over conventional practice. Two factors contribute to the overall profitability of ZT: the value of the yield increase and the savings in production cost—particularly savings in land preparation and crop establishment. Savings in irrigation pumping and inputs may add to this. Comparison of the various studies is somewhat complicated by their site-specificity and methodological differences—including the source of the data and costs included. Most calculations typically use the local cost of hiring ZT services as the opportunity cost of the ZT drill (e.g., Rs 715/ha; Punia et al. 2002).

A number of profitability estimates have been derived from on-station and on-farm trial data. These typically comprise savings derived from partial budgeting and the value of the yield increase (Table 10). On-station cost savings for ZT have been reported to range from Rs 1,700 to 2,300/ha (Dhiman et al. 2003; Prasad et al. 2002; Singh et al. 2002c; Yadav et al. 2002b). For on-farm trials in Bihar and Haryana, slightly lower savings of Rs 1,400/ha have been reported, which together with the value of the additional yield (Rs 3,000/ha) provided an overall net profit of Rs 4,400/ha for ZT (Gautam et al. 2002;

Table 8. On-farm trial yield of wheat (t/ha) under zero tillage and conventional tillage in farmers' fields in different regions of the Indo-Gangetic Plains.

Places	Zero tillage	Conventional tillage	Increase in yield	Increase (%)
Punjab	5.06	5.01	0.05	1
Haryana	5.03	4.71	0.32	6.8
Western UP (Bagpat, Meerut and Saharanpur districts)	4.90	4.61	0.29	6.3
Bihar (Patna, Rohtas, Nalanda and Vaisali districts)	3.83	3.41	0.42	12.3

Source: Malik et al. 2004.

Table 9. Farmer-reported yield of wheat (t/ha) under zero tillage and conventional tillage in farmer surveys in Haryana and Bihar.

District (State)	Zero tillage	Conventional tillage	Gain (%)
Kaithal (Haryana)	5.2	4.9	6 (Not significant)
Begusarai (Bihar)	2.7	2.5	9 (Significant at 5%)

Source: Laxmi et al. 2003.

Table 10. Comparative economic indicators (Rs/ha) of wheat under zero tillage and conventional tillage in different regions of the Indo-Gangetic Plains.

Area	Source	Indicator	Zero tillage	Conventional tillage	Change
Haryana	Nagarajan et al. 2002	Total cost	22,845	24,235	-1,390
		Net benefit	5,415	1,035	4,380
	Sharma et al. 2002b	Total cost			-1,794
		Net benefit			4,072
	Laxmi et al. 2003	Net benefit			2,186
	Malik et al. 2005b	Net benefit			2,636
	Erenstein et al. 2007b	Total cost	26,200	28,100	-1,900
		Net benefit	4,300	1,200	3,100
Uttaranchal	Pandey et al. 2003	Total cost	20,569	24,474	-3,904
		Net benefit	12,464	7,258	5,206
Western Uttar Pradesh	Malik et al. 2004	Monetary gains	2,520+920		3,440
		(savings in tillage)	2,268+2,500		4,768
		+ (yield benefit)	2,808+1,500		4,308
Eastern Uttar Pradesh	Malik et al. 2004	Total cost			-4,368
Bihar	Singh et al. 2002c	Total cost			-2,320
	Gautam et al. 2002	Total cost			-1,400
		Net benefit			4,350
	Laxmi et al. 2003	Net benefit			1,014
Indian IGP	Dhiman et al. 2003	Tillage cost	1,650	3,515	-1,865
	Hobbs 2002	Total cost			-2,500

Note: Studies 3–6 and 11 relate to farm survey findings.

Nagarajan et al. 2002). In the Haryana trials, the savings amounted to 6% of the total cost (zero tillage, Rs 22,800 vs CT, Rs 24,200/ha; Nagarajan et al. 2002). For on-farm trials in Western UP, savings ranged from Rs 2,300 to 2,800/ha, which together with the value of the additional yield (Rs 900–2,500/ha) provided an overall net profit of Rs 3,400–4,800/ha for zero tillage (Malik et al. 2004). For Eastern UP, higher cost savings were reported (Rs 3,500–4,900/ha for ZT; Malik et al. 2004). Some of these findings were subsequently also reported by Malik et al. (2005a).

The limited farm surveys also report significant cost savings (Table 10). Compared to conventional tillers, ZT adopters saved Rs 1,700 and 2,200/ha in Haryana and Bihar, respectively (Laxmi et al. 2003). Zero-tillage adopters in Uttaranchal reportedly saved Rs 3,900/ha (24%), which together with the value of the additional yield (Rs 500/ha) provided an overall net profit of Rs 4,400/ha (43%; Pandey et al. 2003). Another survey in Haryana reported the net benefit for ZT adopters to be a significant Rs 2,600/ha higher than that for those who practiced CT (Malik et al. 2005b). Yet another survey of 400 farmers, again in Haryana, revealed a conclusive advantage of zero tillage over CT plots of adopters amounting to Rs 3,100/ha in the survey year (2003–04), composed of a 'yield effect' of Rs 1,200 and a 'cost-saving effect' of Rs 1,900 (Erenstein et al. 2007b).

Socioeconomic and System Impacts

Both large and small landholders adopt ZT (Laxmi et al. 2003; Malik et al. 2005c). This is facilitated by the ability of smallholders to contract ZT drill services—just as they do for their tillage services in general. Malik et al. (2004) have highlighted the benefits of ZT to be relatively scale-neutral: smallholders achieving similar gains in net returns (zero tillage 7,700 vs CT 6,000 Rs/ha) as large landholders (zero tillage 9,000 vs CT 7,100 Rs/ha). In terms of the yield gains and cost savings reviewed above, the areas with less intensified agriculture conceivably gain more from ZT than the highly intensified agricultural areas, thereby potentially reducing regional inequality. For now though, the technology has spread far more significantly thereby primarily benefiting the better-endowed areas. In much the same way, the early adopters of ZT tend to be better endowed (e.g., larger landholdings, better educated; Erenstein et al. 2007b; Pandey et al. 2003).

The use of ZT in wheat opens the scope for new technologies including the application of ZT to other crops (e.g., pulses and cereals) and permanent beds and the diffusion of new varieties. Most varieties in use in farmers' fields have been selected under conditions of conventional tillage and variety-ZT interactions have been reported (Erenstein 2006; Mehla et al. 2000). Conceivably, varieties selected under ZT conditions are likely to enhance the benefits of ZT. Zero tillage also has the potential of increasing cropping intensity and diversity in selected areas of the IGP (e.g., moving towards double cropping in rice-fallow systems; introducing triple cropping in rice-wheat systems). The benefits of ZT wheat would also be significantly enhanced when the subsequent rice crop is cultivated under aerobic and ZT conditions—as well as opening the scope for further diversification.

Beyond the farm level, ZT opens a new service industry—be it for machinery manufacturers or custom hiring services (Dixon et al. 2007). The potential multipliers associated with these changes—particularly intensification, diversification, and service industries—are likely to more than compensate for the relatively limited, direct ZT-induced labor displacement, particularly in view of the prevailing mechanization levels. However, time, monitoring, and further studies are needed to substantiate such potential impacts.

Environmental Impacts

The ZT/RT wheat has several environmental benefits. Foremost amongst these are fossil fuel savings and reduced greenhouse gas emissions (Grace et al. 2003; Hobbs and Gupta 2003; Malik et al. 2002a). Using a conversion factor of CO_2 emission of 2.6 kg/l of diesel (Grace et al. 2003) and a relatively conservative estimate of 35 l/ha diesel savings, we estimate an annual ZT savings in CO_2 emission of 91 kg/ha. Adoption of ZT on a potential area of 3.43 million hectares of wheat would annually reduce emissions by 0.31 million tons of CO_2 and save 120 million liters of diesel. At the current price of diesel (or crude oil equivalents) this saving alone would imply US$ 50 million of benefits annually. Other greenhouse gas emissions, including methane and nitrous oxides, have an even greater effect on global warming. Grace et al. (2003) have highlighted that ZT with residue-retention and with 50% of the recommended NPK application, could effectively halve the total carbon equivalent emissions to 14 t $C0_2$/ha/yr compared to a high-input conventionally tilled cropping system with residue burning and organic amendments due to improved nutrient use and environmental efficiency.

In the Northwest IGP crop residues are often burnt, creating severe seasonal air pollution/smog and human health hazards in the area. Zero tillage is being further adapted so as to maintain crop residues as mulch without burning or incorporation. The burning of crop residues is not considered as a CO_2 source to the atmosphere by the Intergovernmental Panel on Climate Change (IPCC), as on an annual basis there will be no change in the C stock. Zero tillage does reduce CO_2 emissions by slowing oxidation of the carbon soil stock due to reduced soil disturbance (Grace et al. 2003; Hobbs and Gupta 2003).

Water is becoming an increasingly important constraint to agriculture in the IGP as competition for domestic and industrial uses increases and water use efficiency is poor (Hobbs and Gupta 2003). Zero-tillage wheat enhances water use efficiency, reduces irrigation requirements, and thereby helps save irrigation water. This benefit is especially important for the Northwest where water shortage is already acute, leading to interstate political conflicts. In Haryana and Punjab, irrigation through tube wells meets around 60–65% of the total irrigation requirement. Due to excessive exploitation, groundwater resources are depleting at an alarming rate. In Punjab, 59% of blocks are critical (with groundwater exploitation >85% of the annual recharge) and in Haryana 69% districts have declining water tables (Minhas and Bajwa 2001). Zero-tillage farming on 0.25 million hectares in the IGP reportedly saved 75 million m^3 in 2002–03 (Malik et al. 2004). On paper, the adoption of ZT on a potential area of 3.43 million hectares of wheat would save an estimated 1,029 million m^3 of water each year. Empirical measurement and modeling are needed to better quantify these savings scientifically and estimate the value of these water savings (Ahmad et al. 2007; Erenstein et al. 2007a; Jehangir et al. 2007).

Thus, ZT primarily has positive environmental impacts and this would enhance the social returns to the research and development investment. However, further research, some of it already initiated, is needed to substantiate 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.

Chapter 5 Results of Village-Level Focus-Group Discussions

This chapter presents the findings of the focus-group discussions conducted within the context of this study. The first three sections report the findings for Punjab, Haryana, and Eastern UP, respectively. Each section synthesizes the findings from the two surveyed villages in each state, putting particular emphasis on the ZT technology, its diffusion, its impact on stakeholders, and some of the underlying constraints within the communities. The fourth section summarizes the three survey locations.

Focus-Group Discussions in Punjab

The two survey villages in Punjab were Gurusar Kaunke and Kaunke Kalan in the Ludhiana District (Figure 2). The village lands are irrigated with fertile clay loam soils. Rice and wheat are the main crops. Other crops include potato, mint, mung, and maize. The average farm size amounts to 2.25 hectares in Kaunke Kalan (1,000 farm households, 2,250 hectares) and 5.2 hectares in Gurusar Kaunke (110 farm households, 572 hectares). Agricultural operations are carried out primarily with tractors and for the cereal harvest the use of combine harvesters prevails.

In each village, separate focus group discussions were held with the male adopters, male non-adopters and women. The male participants were further split in terms of rich and poor farmers. Table 11 presents some of the characteristics of the groups and their members. There were some differences between the group composition of adopters and non-adopters. There was also no apparent consistency between the two villages that suggested a clear association with ZT adoption. The group members in Punjab typically fell in the medium-to-large farm category, a characteristic of the state that is in contrast to the lower IGP region of Eastern UP and Bihar, where most of the farmers have very small landholdings (Erenstein et al. 2007c).

Zero tillage has been used since 1999–00 in Kaunke Kalan and since 2000–01 in Gurusar Kaunke. In both villages, ZT diffusion was relatively slow at first, but started picking up rapidly since 2002–03. In Kaunke Kalan, the ZT wheat area amounted to 54% of the total village area and involved 80% of the farmers and 11 ZT drills by 2003–04. In the smaller Gurusar Kaunke village, the ZT area amounted to 85% of the area and involved 91% of farmers and 7 ZT drills by 2003–04. Table 12 shows the diffusion of ZT in these villages.

Despite the number of ZT drills some villagers still reported a shortage of these drills. If we assume no other drills were operational in the villages (i.e., the village ZT area to be sown by village drills only), it would indeed imply a coverage of 69 ha/ZT drill in Gurusar Kaunke and up to a hefty 110 ha/drill in Kaunke Kalan. Despite the advance of ZT there were still reports of a lack of awareness amongst some of the non-adopters. Other farmers faced some constraints or remained to be convinced to adopt ZT.

Table 11. Focus group characteristics in the two Punjab survey villages.

	Gurusar Kaunke		Kaunke Kalan	
	Adopters	Non-adopters	Adopters	Non-adopters
Male participants (number)	15	10	19	6
- Rich	10	4	10	
- Poor	5	6	9	
Female participants (number)	9		12	
Average age (years, male)	44	38	45	52
Average size of holding (ha)	5.22	7.4	7.39	4.12
Average annual income rice-wheat (Rs/ha)	37,500	37,500	45,000	49,400

Table 12. Zero-tillage adoption in the two Punjab survey villages.

	Gurusar Kaunke (110 farm households, 572 ha)			Kaunke Kalan (1,000 farm households, 2,250 ha)		
Rabi season	Zero-tillage area (ha)	Zero-tillage farmers (number)	Zero-tillage drills (number)	Zero-tillage area (ha)	Zero-tillage farmers (number)	Zero-tillage drills (number)
1999–00	0	0	0	40.5	2	1
2000–01	11.3	1	2	40.5	2	1
2001–02	20.25	3	3	40.5	2	1
2002–03	121.5	6	5	405	100	5
2003–04	486 (85%)	100 (91%)	7	1215 (54%)	800 (80%)	11

For instance, some non-adopters reported deriving satisfaction from the traditional way of cultivation, feared crop failure or lesser yield, and disliked the disheveled appearance of the ZT field.

Both villages largely concurred on the sources of ZT dissemination, which included the Punjab Agricultural University, State Agricultural Department, demonstrations in friends' fields, and newspapers. However, in Gurusar Kaunke the National Agro Industry (a major ZT drill producer) reportedly played a major role, and farmer fairs (Kissan mela) were specifically reported in Kaunke Kalan.

Farmers, and particularly adopters, were generally appreciative of the ZT technology. The direct economic benefits of ZT adoption as perceived by the farmers are savings of time, money, water, and fuel, and an increase in the wheat yield (Table 13). The two villages generally concur in terms of the type of savings, although there can be quite some variation in their magnitude. The villages concur that ZT decreases tractor use time by 4–5 hr/ha as there is less field preparation under ZT. The less wear and tear of the tractor also resulted in less tractor depreciation under ZT. Both villages also concur on diesel savings, but the estimated savings vary from 15 to 42 l/ha. Some farmers reported an increase in fuel consumption for some operations because of heavier tractor load and perceived soil compaction. Total time savings for ZT were estimated at 20 hr/ha in one village and 7 hr/ha in the other. One village reported that ZT saves one irrigation compared to conventional tillage; the other village reported some labor savings. Zero tillage allowed for more timely sowing of wheat, which normally gets delayed under CT tillage due to the long turn-around time after the rice harvest due to elaborate land preparation. Despite some of the differences, the two villages concur that ZT in wheat:

- saved Rs 2,000–2,500/ha in expenditures;
- increased the yield by 0.5 ton/ha; and
- increased income by Rs 4,400–5,000 /ha.

Zero tillage reportedly decreased the weed population of P. minor but increased the population of broad-leaved weeds such as Rumex maritimus. Some weeds that emerge late under ZT conditions were problematic to control and some farmers were afraid of a weed outburst. Some farmers reported that if the weed problem arises, the cost of weed control will increase to Rs 1,500/ha. A few farmers reported an increase in chemical requirements, including an increase in fertilizer use (49 kg/ha in diammonium phosphate [DAP] and 123.5 kg/ha in urea). Some farmers also reportedly perceived an increase in the rodent population in the ZT fields.

Sowing difficulties associated with the remaining rice residues in the field were reported by some farmers. Some farmers were of the view that a cutter was needed on the drill for its easy movement in the field. Some other farmers opined that ZT drill maintenance and repair mechanisms should be better. Yet others reported lack of proper germination in the heavy soils, weak establishment of wheat crop, an increase in the seed rate of 5 kg/ha, and a decrease in straw quality.

Farmers reportedly used the time savings for various income-generating activities such as involvement in other agricultural operations, giving more time to livestock rearing, and repair and maintenance of farm equipment and machineries. Women in both the villages were of the view that there was a decrease in the workload with ZT, which helped them concentrate on childcare and education. The shortening of the turn-around time with ZT has reduced the time pressure which usually prevails between the paddy harvest and sowing of the wheat crop. Some of the women reported that ZT reduced the mental and physical pressure on the men and thereby reduced their consumption of liquor. Yet other women disagreed, reporting that the free time and less expenditure increased the habit of drinking and playing cards among men, especially for large farm holders.

Table 13. Direct economic benefits of zero tillage wheat reported by adopters in the two Punjab survey villages.

	Gurusar Kaunke	Kaunke Kalan
Land preparation savings		
- Tractor time savings (hr/ha)	4	5
- Diesel savings (l/ha)	15	42
- Total time savings (hr/ha)	20	7
- Labor savings (Rs/ha)	370	-
Irrigation savings	-	One irrigation
Cost savings (Rs/ha)	2,500	2,000–2,500
Increase in yield (t/ha)	0.5	0.5
Total benefit in income (Rs/ha)	4,400	4,400–4,500

Note: No responses were recorded from labor savings in Kaunke Kalan and from irrigation savings in Gurusar Kaunke.

Focus-Group Discussions in Haryana

The two survey villages in Haryana were Pirthala in the Fatehabad District and Teek in the Kaithal District (Figure 2). Both villages have a similar number of farm families, but Pirthala is a large village (total population 10,800) while Teek is smaller (total population 4,500). The village lands are irrigated with fertile loam and clay loam soils. Rice, wheat and cotton are the major crops grown in this area. The average farm size is 1.2 hectares. Use of the tractor and combine harvesting are widespread.

In each village, separate focus group discussions were held with the adopters and non-adopters, further split between rich men, poor men, and women. Table 14 presents some of the characteristics of the groups and their members. No major age difference was apparent between adopters and non-adopters. However, in Teek, the farm size of ZT adopters was a multiple of the farm size of non-adopters, reflecting the lack of rich non-adopters in the focus groups in Teek (Table 14).

Zero tillage has been used in Teek since 1996–97 and since a subsequent year in Pirthala. Both villages saw a rapid diffusion of ZT up to the survey year of 2003–04. In Teek, the ZT wheat area amounted to 85% of the total village area and involved some 30 ZT drills by 2003–04. In Pirthala, the ZT wheat area amounted to 80% of the total village area and involved some 300 farmers and 50 ZT drills by 2003–04 (Table 15). Assuming no other drills were operational in the villages, this would imply a coverage of 32–34 ha/ZT drill.

Both villages concurred on the importance of the Haryana Agricultural University and the State Agricultural Department as major sources of ZT dissemination. In Teek, the Krishi Vigyan Kendra (outreach stations of NARS at district level) reportedly played a major role, whereas in Pirthala what was reported was the role of demonstration effects of early adopters and private company agents.

Farmers reported savings of time, fuel, water, and money and an increase in yield as immediate economic benefits of ZT adoption (Table 16). As in Punjab, the two villages generally concur in terms of the type of savings, although there again can be quite some variation in their magnitude. Zero tillage farmers reported tillage savings of 5–10 tractor hours, diesel savings of 27–62 l/ha, and cost savings totaling Rs 2,500–3,000/ha.

In Pirthala, farmers reported irrigation savings of 2.5 hr/ha with ZT over conventional tillage, whereas in Teek there was a 50% water saving in the first irrigation and a 25% water saving in the subsequent irrigations. These water savings relate to irrigation water advancing more rapidly over an untilled field, thereby reducing the time needed to irrigate the entire field. Farmers reported that ZT helped achieve good drainage in the field and that with ZT there was less yellowing of the wheat crop after the first irrigation.

In Pirthala, yields reportedly increased with 0.5 ton/ha under ZT, whereas in Teek a yield increase was reported for the initial years of adoption only (two years according to the men, 3–4 years according

Table 14. Focus group characteristics in the two Haryana survey villages.

	Pirthala		Teek	
	Adopters	Non-adopters	Adopters	Non-adopters
Male participants (number)	12	10	12	12
- Rich	7	5	6	0
- Poor	5	5	6	12
Female participants (number)	8	5	6	10
Average age (years, male)	47	45	43	40
Average size of holding (ha)	2.73	2.5	3.69	0.25
Average annual income rice-wheat (Rs/ha)	37,100		22,200	

Table 15. The adoption of zero tillage in the two Haryana survey villages.

	Pirthala (2,025 ha)			Teek (1,191 ha)		
Rabi season	Zero-tillage area (ha)	Zero-tillage farmers (number)	Zero-tillage drills (number)	Zero-tillage area (ha)	Zero-tillage farmers (number)	Zero-tillage drills (number)
1996–97	0	0	0	2	-	1
1997–98	1.2	1	1	10	-	1
1998–99	202.5	100	7	-	-	3
1999–00	-	-	20	607.5	-	10
2000–01	-	-	30	-	-	-
-	-	-	-	-	-	-
2003–04	1,620 (80%)	300	50	1,012.5 (85%)	-	30

Note: No response was recorded in items marked '-'.

Table 16. Direct economic benefits of zero tillage wheat reported by adopters in the two Haryana survey villages.

	Pirthala	Teek
Land preparation savings		
- Tractor time savings (hr/ha)	5	10
- Diesel savings (l/ha)	27–40	62
- Other	Rs 1,200/tractor tillage/ha	5 labor days
Irrigation savings	2.5 hr/ha	50% first irrigation 25% subsequent irrigations
Cost savings (Rs/ha)	2,500–3,000	2,500
Increase in yield (t/ha)	0.5	Increase in yield in the first two years

to the women). Farmers attributed the higher wheat yield under ZT to a number of factors, including less lodging, improved soil health, and better and more homogeneous crop establishment. At the same time, some farmers reported a poorer quality of bhusa (wheat straw used as livestock feed) due to a stiffer stem with ZT, particularly in the case of wheat after basmati rice.

ZT reportedly decreased the P. minor weed population which was beneficial for yield. The lower weed population under ZT also drastically reduced the consumption of herbicides, which saves costs and reduces soil and water pollution. This reflects the problems farmers face in controlling P. minor and its emerging herbicide resistance, particularly in Haryana (Malik et al. 2002c). However, the population of broad-leaved weeds reportedly increased (e.g., Rumex retroflex ['Jungli palak'] and 'buton buti'). Some farmers also feared a drastic yield reduction in the event of a weed outburst.

Some farmers were afraid of the risk of soil compaction, and there was a general perception that the soil needed at least one plowing after 3 to 4 years of ZT adoption. Some farmers also reported that an extra plowing was required for the subsequent field preparation for rice after ZT wheat although a separate farmer survey in Haryana found no such evidence (Erenstein et al. 2007b). The danger of crop failure in case of heavy rain after seeding but before germination was also flagged. An increase in the rodent population due to the presence of loose straw in the fields was reported. Some farmers reported difficulties in operating ZT drills in fields with loose residue and suggested that the need for a straw cutter on the ZT drill to remove the stubbles in the field while sowing. Other farmers pointed out the difficulty in using zero tillage practices in former cotton fields which were perceived to harbor large numbers of insects and pests.

Farmers reported that, with CT, timely sowing of wheat was problematic in view of the needed turn-around time after the rice harvest. With ZT, timely sowing became easier as it involved no tillage for the wheat crop, with ample time being available between rice harvest and wheat sowing. Consequently, ZT adopters felt that less tension prevailed at the time of wheat sowing. Women of adopting households also reported that ZT assures timely sowing and more peace at home due to ZT decreasing the tension that normally prevails at home because of the hectic schedule of field operations under conventional tillage. Some adopters also reported that ZT facilitated planning and participating in ceremonies and social events. The time savings are reportedly utilized in other agricultural activities, maintenance of agricultural implements, and animal care. Women also acknowledged that ZT helped save time and that some of their men helped them more in animal care and children's education due to the extra time available. Some women believed that ZT would lead to overall prosperity in the village. But other women reported that their men used the saved time and money in unproductive ways such as playing cards, gossiping, and smoking hookahs (water pipes).

In Teek, the focus group of non-adopting women was primarily composed of landless daily-wage laborers. The discussions on the impacts of ZT shed some light on some of the implications for the landless poor who primarily depended on daily wages for their livelihoods. Zero tillage reduced the demand for labor and some male laborers thereby lost seasonal work opportunities in land preparation while women laborers lost work opportunities in weeding and other inter-cultural operations. Some women estimated they had lost work at least 10 days/year because of the introduction of ZT. Some of the landless men work as permanent laborers for large farmers earning some Rs 12,000–15,000/year. The landless felt that, over time, the scope of finding daily or permanent labor was waning. Some alluded that half of the landless had left the village because of a reduction in employment opportunities. The available data do not allow for a closer assessment of the livelihood perspectives of the landless poor or of the relative role of ZT diffusion and the overall economic trends therein. Still, even such an incomplete assessment reminds us of the varying implications of agricultural technology for different stakeholders.

Focus-Group Discussions in Eastern UP

The two survey villages in Eastern UP were Bhurkura and Karhat from the Mirzapur District (Figure 2). Bhurkura is a large village (total population 5,000) while Karhat is a small village (total population 700). The soil types are loam and clay in Bhurkura and black loam in Karhat. Irrigation prevails and rice and wheat are the major crops grown in this area. Other commonly grown crops are lentil, pea, and pigeon pea. The average farm size is 0.4 hectare in Bhurkura and 1.0 hectare in Karhat. Land preparation is largely by tractor, with non-tractor owners relying on providers of tractor services.

In each village, separate focus group discussions were held with the adopters and non-adopters, further split between men and women and the rich and poor. Table 17 presents some characteristics of the groups and their members. Again no major differences were readily apparent between adopters and non-adopters.

Zero tillage has been used since 1998–99 in Karhat and since the subsequent year in Bhurkura. Both villages saw a rapid diffusion of ZT in the subsequent 4–5 years. In Karhat, the ZT wheat area amounted to 75% of the total cultivated area and involved some 50 farmers and three ZT drills by 2003–04. In Bhurkura, the ZT wheat area amounted to 61% of the total cultivated area and involved some 100 farmers and three ZT drills by 2003–04 (Table 18).

The limited number of ZT drills was reportedly still a major constraint for ZT adoption as it constrained its timely availability. Assuming no other drills were operational in the villages, this would imply a coverage of 51 ha/ZT drill in Bhurkura and 81 ha/ZT in Karhat. Timely access is likely further exacerbated by the relatively small farm sizes. Rich farmers in the Bhurkura village even opined that ZT was not cost-effective for small farmers. Lack of awareness about ZT was not a constraint and reflects the significant spread of ZT in the two villages.

Both villages concurred on the importance of the Banaras Hindu University, the State Agricultural Department, and fellow farmers as major sources of ZT dissemination. The same two villages were also covered in a different study (Joshi et al. 2007).

As in Punjab and Haryana, farmers again reported savings of time, fuel, water, and money, and yield increase as immediate economic benefits of ZT adoption (Table 19). However, there was again quite some variation in the reported magnitude of savings. Zero-tillage farmers reported tillage savings of 5–7 tractor hours and also seed savings of 20–40 kg/ha. In Karhat, ZT implied diesel savings of 10–20 l/ha. Farmers reported irrigation savings amounting to 7 hr/ha in the first irrigation and 2–5 hr/ha in the subsequent irrigations. The reported cost savings amounted to a relatively high Rs 5,500–7,500/ha. Farmers also reported yield increases of 0.2–0.4 t/ha as compared to CT.

Farmers were of the view that due to the adoption of ZT in wheat the weed population of P. minor had decreased. At the same time, there was a reported increase in the population of broad-leaf weeds and some other species (e.g., tipatiya and genhu mala). Women concurred that the population of weed had decreased.

Farmers' views on the implications of ZT for fertilizer and chemical use diverged. Whereas some ZT adopters reported fertilizer savings of up to 20 kg/ha, others reported hefty increases. One farmer even alluded to the doubling of fertilizer use, although it remains unclear to what extent this is attributable to ZT. Women also gave inconclusive accounts on the eventual changes in fertilizer use. Some farmers reported increases in herbicide use (e.g., 2,4 D), whereas others reported reduced insecticide and pesticide use.

Table 17. Focus group characteristics in the two Eastern Uttar Pradesh survey villages.

	Bhurkura		Karhat	
	Adopters	Non-adopters	Adopters	Non-adopters
Male participants (number)	15	6	9	8
Female participants (number)	23		17	
- Rich	5		7	
- Poor	4 with lands + 14 landless		10	
Average age (years, male)	46	48	48	40
Average size of holding (ha)	1.24	1.13	0.95	0.91

Table 18. Adoption of zero tillage in the two Eastern Uttar Pradesh survey villages.

	Bhurkura (250 ha)			Karhat (324 ha)		
Rabi season	Zero-tillage area (ha)	Zero-tillage farmers (number)	Zero-tillage drills (number)	Zero-tillage area (ha)	Zero-tillage farmers (number)	Zero-tillage drills (number)
1998–99	0	0	0	10.1	3	1
1999–00	12.7	5	1	40.5	10	2
2000–01	12.7	5	1	162	30	2
2001–02	25.3	5	1	202.5	35	3
2002–03	76	50	1	223	40	3
2003–04	152 (61%)	100	3	243 (75%)	50	3

Table 19. Direct economic benefits for zero-tillage wheat reported by adopters in the two Eastern Uttar Pradesh survey villages.

	Bhurkura	Karhat
Land preparation savings		
- Tractor time savings (hr/ha)	5	7
- Diesel savings (l/ha)	-	10–20
- Other	10-day earlier sowing	-
Seed savings (kg/ha)	20	20–40
Irrigation savings (hr/ha)	First irrigation: 7 subsequent irrigations: 2	First irrigation: 7 Second irrigation: 5 Third irrigation: 2
Cost savings (Rs/ha)	5,500	9,500
Increase in yield (t/ha)	0.4	0.2–0.3

Note: No response was recorded in the two items marked '-'.

The farmers in the Karhat village reported improvements in the soil quality, whereas those in the Bhurkura village expressed concerns about soil compaction. In the latter village, farmers opined that the rear tractor wheel compacted the soil thereby making the seed drilling difficult. In the Karhat village, poor farmers suggested that the distance between the drilled rows should be reduced and that the width of the tines should be less.

Male and female respondents of adopting households concur on the higher income with ZT. The additional income is variously used, including for children's education, agricultural production (e.g., buying better seeds and more fertilizer), consumptive purchase (e.g., household articles, clothing and luxuries), and social functions (e.g., marriages). Some farmers reported that the enhanced income increased their creditworthiness.

Both male and female respondents in the two villages concurred that ZT was time-savings. In Bhurkura, this allowed for a 10-day earlier sowing. The time savings reduce the work pressure and thereby the tension that usually prevails during the wheat sowing time—both for farm operations and within the home. Zero tillage also implies less work in the field, and the corresponding labor savings are variously used for other productive (income-generating) and consumptive activities, including more time for children, relatives and friends, social activities, recreation, and rest.

The ZT labor savings are a boon to the farmers, but imply a decrease in employment opportunities for agricultural laborers. In the Burkura village, poor farmers reported reductions of up to two thirds in wage employment. In the same village, landless laborers— particularly women—perceived that the employment opportunities at the time of land preparation reduced from 10–12 days earlier to 2–3 days now due to ZT. With ZT there was also reduced wage employment for manual removal of weeds. Some women opined that ZT had contributed to an increase in out-migration.

Again, the available data do not allow for a closer assessment of the livelihood perspectives of the landless poor or of the relative role of ZT diffusion and the overall economic trends therein. Furthermore, it merits mentioning that both villages have received considerable outside support and interventions (e.g., Joshi et al. 2007). For instance, village farmers had received training in seed production from the National Seed Corporation and scientists from BHU. These farmers are now producing wheat seed which is being procured by the NSC. The seed production is generating additional income to farmers with large holdings and employment opportunities for agricultural laborers. For instance, landless women revealed that some of them got an additional five days of employment during seed preparation time. According to one seed producer, ZT played an important enabling role in seed production as he is now able to sow in time, and the quality of his wheat crop has improved.

Synthesis of Focus Group Discussions

The focus groups conducted within the context of this study do not provide a representative sample (six villages from adoption areas). Still they typically corroborate the findings reported elsewhere and as reviewed in the previous chapter. All villages highlight the significant extent and speed of ZT adoption in each village. The focus groups also found some farmers who discontinued ZT due to problems including the perceived need for occasional tillage, formation of hardpan and weed control.

Compared to the review, which is one of the thee components of this study, the focus group meetings revealed similar savings in tractor operational time for land preparation (13, 7 and 6 hr/ha in Punjab, Haryana and Eastern UP, respectively) and in corresponding diesel use (27, 35 and 14 l/ha, respectively). The lesser quantity of diesel savings in UP is due to the lower level of mechanization in this area. In UP, people reported advancement of wheat sowing by 10 days. The focus groups reported similar water savings as reported elsewhere—be it in terms of one irrigation savings or reduced duration of primarily the first irrigation. The focus group meetings also reported a perceived increase in soil quality, a decrease in P. minor, and an increase in broad-leaf weeds. Rodent damage was occasionally reported and is seemingly associated with residue retention, which calls for closer monitoring.

The focus group meetings confirmed the positive yield effect of ZT. The discussions reported a ZT yield gain of 500 kg/ha in Punjab and Haryana and 325 kg/ha in Eastern UP— an approximate 10% yield gain in each site.

The focus group meetings in Punjab and Haryana reported cost savings of Rs 2,000–2,500/ha and an overall net profit of Rs 4,400–5,000/ha for ZT. In Eastern UP, reported cost savings were significantly higher with Rs 7,500/ha, with an overall net profit of Rs 9,500/ha for ZT. These last estimates seem somewhat high compared to the other estimates but, in general, the focus groups confirm the significant cost savings and increase in profitability attributable to ZT. The similarity of reported savings and profits attributable to ZT are striking, providing support to the relatively wide applicability of this technology.

The focus group discussions also showed that both large and small landholders had adopted ZT. The large landholders benefited due to less risks of delays in wheat establishment. The smallholders reported that they could also reap the advantages of ZT wheat if they were able to get the machines in time on custom hiring. The rate of hiring a zero-tillage drill with tractor is Rs 300/day in Haryana and Rs 320/day in Eastern UP.

Although the authors perceive the labor-saving nature of ZT wheat to be relatively limited, landless laborers, both men and women, are reported to have been adversely affected, some commenting they lost their seasonal wage employment. Migrant and landless laborers raised concerns about the possible adoption of ZT in paddy, as they fear the more significant loss of earning during paddy transplantation.

The time and resource savings were variously used by the adopters. Both males and females reported having more time to undertake other income-generating/-saving activities (such as livestock raising, carpentry, electrician work, tailoring, etc.) as well as leisure (e.g., social ceremonies).

Women generally appreciated ZT. They acknowledged that after the adoption of ZT in wheat there was less tension, which normally prevailed because of the hectic schedule of field operation under CT, and this has resulted in more peace at home. Women also reported that, with ZT, their drudgery was reduced and that their male counterparts were helping them in animal care and children's education. Women in the low-productivity areas were less informed about ZT than those in high-productivity areas. Zero tillage as such has not played any role in school enrollment or dropout rates of children, especially of girls.

Chapter 6 Estimating Rates of Return on Investment

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 was used to estimate a rate of return to the 'with' case (with the RWC and CIMMYT investments), using various assumptions and parameters as outlined in the methodology (Chapter 3, Table 2 and Table 3). A fundamental assumption is that the observed adoption levels (and NARES expenditures) would have lagged five years in the 'without' case (Figure 4). We attribute the differential benefit stream (primarily consumer and producer surplus and some savings of the National Agricultural Research and Extension System cost) to the RWC and CIMMYT investments. The estimates of the benefits are conservative in the sense that they only include the welfare effects attributable to the tangible direct benefits. The positive environmental impacts addressed in the section on Socioeconomic and system impacts 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, and half of these values for reduced tillage. The results show that even with these relatively conservative values, the ZT/RT research program is highly beneficial with a benefit-cost ratio of 39 and a net present value of US$ 94 million. The IRR was 57% (Table 20). The discounted economic surplus (US$ 96 million) indeed dwarf 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 that ZT induces 10% yield gains and 10% cost savings (and half these values for reduced tillage). In this case, the estimated NPV is US$ 164 million with a benefit cost ratio of 68 and an internal rate of return of66% (Table 20).

Results of a sensitivity analysis of the conservative scenario to changes in various key indicators are presented in Table 21. For each indicator, two alternative values were imputed, ceteris paribus. For the discount rate 10%- and 0%-values were imputed. But even under a discount rate of 10% the returns to ZT/RT research and development remained highly beneficial—albeit that net present value was halved. Four other indicators altered are the yield gain, the cost savings, 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 benefit cost ratio of 10 and an internal rate of return of 37%. The results are relatively less sensitive to the assumed cost savings—without any cost savings NPV is reduced by 25%. The assumed contribution of reduced tillage (estimated at 50% of ZT values) also proves influential, mainly as result of the significant area share under reduced tillage relative to zero tillage. Without any contribution from reduced tillage, NPV is reduced by 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 the benefit cost ratio and internal rate of return again remain favorable.

Zero tillage and reduced tillage thus generated high welfare gains from a relatively small investment of 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.

Table 20. Conservative and optimistic zero tillage/reduced tillage impact scenarios.

	Conservative scenario	Optimistic scenario
Net Present Value (million US$, 1990)	94	164
Benefit-Cost Ratio	39	68
Internal Rate of Return	57%	66%

Note: Exchange rate—US$ 1.00 in Rs: 17.9 in 1990 and 44.9 in 2004-06.

Table 21. Sensitivity analysis to variations of conservative zero tillage/ reduced tillage impact scenario.

	Discount rate 0–10%	Yield gain 0–3%	Cost reduction 0–2.5%	Reduced-tillage contribution 0–25%	Lag 1–3 years
Net present value (US$ million, 1990)	214–43	22–58	71–82	39–66	18–57
Benefit cost ratio	69–26	10–24	30–34	17–28	10–26
Internal rate of return (%)	58–58	37–51	53–56	45–53	45–55

Chapter 7 Conclusion

To keep pace with the rapidly growing food demand, South Asia's farmers will have to produce more food from fewer resources while sustaining environmental quality. Zero tillage is one technology that fits this need and is being rapidly adopted in the Indian IGP in wheat after rice. The successful diffusion of zero tillage is due to the concerted efforts of the National Agricultural Research and Extension System (including State Agricultural Universities) and the private sector. CIMMYT and the RWC have played a pivotal and innovative role as facilitator and information provider, technology-clearing house, and capacity builder. Zero tillage 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). These benefits explain the widespread interest of farmers and the rapidity of the diffusion across the Indian IGP, further aided by the wide applicability of this mechanical innovation. Small-scale machine manufacturers have played a key role in meeting and creating an increasing demand. Service providers have enhanced technology access by making it divisible and they 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.

A conservative ex-ante assessment of supply-shift gains alone (excluding other social and environmental gains), shows that the investment in ZT/RT research and development by the Rice-the Wheat Consortium of the Indo-Gangetic Plains 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 of 57%. The 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 research and development 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 in NRM.

The present study has valued impact, based on private gains alone, with environmental and social gains as added non-valued benefit. To a large extent, this was dictated by data limitations, and yet the approach has merits. Private gains correspond more closely with the interest of farmers and the private sector 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 an 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.

Zero tillage primarily has a positive environmental impact (savings of fossil fuel, reduced emissions of greenhouse gas, water savings), and this would enhance the social returns to the R&D investment. The water savings in the wheat crop are particularly interesting in view of excessive groundwater exploitation in intensive rice-wheat growing areas. Further research to substantiate and value the environmental impacts is needed. There is also significant scope for enhancing the environmental impact of ZT in rice-wheat systems. Two areas that merit particular attention in this respect are management of crop residue and shifting towards direct- seeded aerobic rice. However, leaving more crop residues as mulch has implications for both ZT drill functioning and potential trade-offs between residue use for livestock feed and conservation agriculture (Erenstein et al. 2007d).

Zero tillage tends to be adopted first by the better-endowed farmers. Rental services of ZT have however made the technology relatively scale-neutral and divisible. Time and resources saved through ZT are variously used by the adopting farm households—for productive, social, and leisure purposes. Thus adoption of ZT enhances farmers' livelihoods. So far, ZT has spread more widely in the better-endowed areas. 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.

The present study has reviewed a wealth of information in relation to zero tillage 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 come through, validated by focus groups and farmer adoption. The combined yield increase with cost savings implies that returns to ZT adoption are pretty robust, thereby significantly reducing the risk of adoption. Still, significant knowledge gaps 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 research and development and attribution also proved problematic. Most studies report on the technical and private financial gains of ZT at plot level—with limited documentation of socioeconomic, livelihood, and environmental impacts. Addressing these knowledge gaps would significantly strengthen endeavors on future impact assessment.

Zero tillage therefore offers high potential economic, environmental, and social gains in the Indian IGP. Nonetheless, significant challenges remain, not least in terms of actually realizing these potential gains on the ground. This implies moving beyond mere production cost savings to natural resources savings and using ZT as a stepping stone to conservation agriculture. Zero tillage is also no panacea, and complementary resource conserving technologies that are privately and socially attractive are needed. Technological intervention also needs to be complemented with policy reform to create an enabling environment for sustainable agriculture. This 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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Annex

Assumptions for Estimation of Research and Development Costs

For accounting purposes we take 1994 as the base year. The spread of ZT in India benefited from investments made elsewhere and earlier. These are considered as positive spillovers of sunk costs and are not accounted for in the current calculation thereby somewhat inflating our estimated returns. For the cost side we consider two main cost components: RWCand NARES.

RWC Component

For the RWC total annual cost data are available from its inception in 1994 till 2003. However, available cost data are generally aggregated and a number of assumptions are needed to derive estimates for the specific cost of RWC ZT research and development activities in India.

The Review Panel Report (Seth et al. 2003) estimates RWC investment patterns in donor funded projects by research themes. These estimates show that, at the time, the largest investment was for tillage, crop establishment, diversification, and machinery-development work (29%) followed by Human Resource Management (HRD, 21%) and knowledge management (19%). We assume that the first category primarily relates to ZT-related work. In addition, we assume that 29% of the generic but contributing themes such as HRD, knowledge management, and socioeconomics are related to zero tillage. Taken together, 42.6% of the total RWC cost is assumed to be related to zero tillage.

The zero tillage investment of the RWC relates to all the four countries of the consortium. Singling out the share attributable to India needs further assumptions. Attributing these costs equally among the four countries underestimates India's share, India having the largest rice-wheat area (75% of the South Asia area, Table 1) and being host to the RWC facilitation unit. Attributing these costs solely on the national share in the regional rice-wheat area overestimates India's share, as resources tend to be shared more equitably and transaction costs are higher for the smaller three partners. Therefore, we assume an intermediate value of 50% of the RWC zero-tillage-related costs to be attributable to India. Taken together, we thus assume 21.3% of total RWC costs to be attributable to zero tillage in India.

For 1994 to 2003, we assume 21.3% of RWC total annual cost to be attributable to zero tillage in India (increasing from U$13,000 in 1994 to US$ 257,000 in 2003). For 2004 to 2008, we assume a similar investment as the average for 2002–03 (US$ 251,000/annum). For 2009 to 2013, we assume a linear decline to zero as ZT-related activities are phased out.

National Agricultural Research and Extension System Component

The Indian National Agricultural Research and Extension Systems have made significant investments in ZT. However, data limitations imply a number of assumptions are needed to derive estimates for the specific cost of ZT research and development activities in India. The review panel of the RWC (Seth et al. 2003) estimated that the total rice-wheat-related research expenses (operational plus staff) of Indian NARS were approximately US$ 5 million/annum during 2000–2003. Pal et al. (2003) estimated that approximately 5.4% of total expenditure is incurred on tillage and residue management. Taken together, we thus assume the Indian NARS to invest US$ 270,000/annum in zero tillage for 2000–2003. For 1994 to 1999, we assume a linear increase to the reported levels in 2000. For 2004 to 2008, we assume continuation of investments at the same level as for 2000–03. For 2009 to 2013, we assume a linear decline to zero as ZT-related activities are phased out.

Estimating the extension component of ZT in India is even more problematic. We therefore simply assume the same pattern as the NARS costs, but with a five-year lag. In the conservative scenario, extension costs are assumed to be at the same level as NARS. In the optimistic scenario, extension costs are assumed to be 50% of the NARS costs.

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