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Research Report 19

Adoption and Impacts of Zero Tillage as a Resource Conserving Technology in the Irrigated Plains of South Asia

Olaf Erenstein, Umar Farooq, R.K. Malik and Muhammad Sharif

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Cover photograph: Zero-tillage wheat field in the rice-wheat belt of Haryana, India (photo credit: CIMMYT/RWC).

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Acronyms

CT	conventional tillage
IGP	Indo-Gangetic Plains
mt	metric ton/s (1,000 kg)
na	not applicable
ns	not significant
OFWM	On-Farm Water Management, Lahore
RCT	resource conserving technology
RWC	Rice-Wheat Consortium for the Indo-Gangetic Plains (www.rwc.cgiar.org)
s.d.	standard deviation
WP	water productivity
ZT	zero tillage
ZTD	zero tillage drill

Abstract

The recent stagnation of productivity growth in the irrigated areas of the Indo-Gangetic Plains of South Asia has led to a quest for resource-conserving technologies that can save water, reduce production costs and improve production. The present synthesis of two detailed country studies confirmed widespread adoption of zero tillage (ZT) wheat in the rice-wheat systems of India's Haryana State (34.5% of surveyed households) and Pakistan's Punjab province (19%). The combination of a significant "yield effect" and "cost-saving effect" makes adoption worthwhile and is the main driver behind the rapid spread and widespread acceptance of ZT in Haryana, India. In Punjab, Pakistan, adoption is driven by the significant ZT-induced cost savings for wheat cultivation. Thus, the prime driver for ZT adoption is not water savings or natural resource conservation but monetary gain in both sites. Water savings are only a potential added benefit.

ZT adoption for wheat has accelerated from insignificant levels from 2000 onwards in both sites. Geographic penetration of ZT is far from uniform, suggesting the potential for further diffusion, particularly in Haryana, India. Diffusion seems to have stagnated in the Punjab study area, and further follow-up studies are needed to confirm this. The study also revealed significant dis-adoption of ZT in the survey year: Punjab, Pakistan 14 percent and Haryana, India 10 percent. Better understanding the rationale for dis-adoption merits further scrutiny. Our findings suggest that there is no clear single overarching constraint but that a combination of factors is at play, including technology performance, technology access, seasonal constraints and, particularly in the case of Punjab, Pakistan, the institutional ZT controversy. In terms of technology performance, the relative ZT yield was particularly influential: dis-adopters of ZT reporting low ZT yields as a major contributor to farmer disillusionment in Punjab, Pakistan and the lack of a significant yield effect in Haryana, India. In neither site did the ZT-induced time savings in land preparation translate into timelier establishment, contributing to the general lack of a yield increase. Knowledge blockages, resource constraints and ZT drill cost and availability all contributed to non-adoption. This suggests that there is potential to further enhance access to this technology and thereby its penetration.

The study highlights that in both Haryana, India and Punjab, Pakistan ZT has been primarily adopted by the larger and more productive farmers. The structural differences between the adopters and non-adopters/dis-adopters in terms of resource base, crop management and performance thereby easily confound the assessment of ZT impact across adoption categories. This calls for the comparison of the ZT plots and conventional tillage plots on adopter farms.

ZT-induced effects primarily apply to the establishment and production costs of the wheat crop. Both the Haryana, India and Punjab, Pakistan studies confirmed significant ZT-induced resource-saving effects in farmers' fields in terms of diesel and tractor time for wheat cultivation. Water savings are, however, less pronounced than expected from on-farm trial data. It was only in Haryana, India that there were significant ZT-induced water savings in addition to significant yield enhancement. The higher yield and water savings in Haryana, India result in significantly higher water productivity indicators for ZT wheat. In both sites, there are limited implications for the overall wheat crop management, the subsequent rice crop and the rice-wheat system as a whole. The ZT-induced yield enhancement and cost savings provide a much needed boost to the returns to, and competitiveness of, wheat cultivation in Haryana, India. In Punjab, Pakistan, ZT is primarily a cost-saving technology. Based on these findings the study provides a number of recommendations for research and development in South Asia's rice-wheat systems.

Adoption and Impacts of Zero Tillage as a Resource Conserving Technology in the Irrigated Plains of South Asia

Olaf Erenstein, Umar Farooq, R.K. Malik and Muhammad Sharif

Introduction[1]

In South Asia, rice-wheat cropping systems cover 13.5 million hectares (mha) and provide incomes and food to many millions of people (Gupta et al. 2003; Timsina and Connor 2001). The rice-wheat system is primarily irrigated, with 85 percent concentrated in the Indo-Gangetic Plains (IGP) (Timsina and Connor 2001). In the face of increasing competition for water from industrial, domestic and environmental sectors, concerns are being raised about the productivity of water used in agriculture (Kijne et al. 2003). Increasing water scarcity is also seen as a major contributor to stagnating productivity in the rice-wheat cropping systems of the IGP (Byerlee et al. 2003; Kumar et al. 2002). Due to the absence of efficient water-pricing mechanisms, the scarcity value of water is not reflected in water prices (Pingali and Shah 2001). In the face of unreliable canal water supplies, many farmers have increased their reliance on private tube wells, placing tremendous pressure on groundwater supplies (Abrol 1999; Ahmad et al. 2007; Qureshi et al. 2003). Negative environmental effects related to irrigation are increasing as overexploitation of groundwater and poor water management lead to the dropping of water tables in some areas and increased waterlogging and salinity in others (Harrington et al. 1993; Pingali and Shah 2001; Qureshi et al. 2003). In addition, tube-well irrigation has raised production costs in view of the energy expenses incurred (electricity or diesel) (Qureshi et al. 2003). Agricultural technologies that can save water, reduce production costs and improve production are therefore becoming increasingly important (Gupta et al. 2002; Hobbs and Gupta 2003b).

The Rice-Wheat Consortium (RWC) for the IGP (www.rwc.cgiar.org), which is made up of international agricultural research centers, national agricultural research organizations from Bangladesh, India, Nepal and Pakistan, and advanced research institutes has developed and promoted a number of 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 2003a). These resource-conserving technologies (RCTs) form the basis for conservation agriculture. “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).

Since the mid-1980s, researchers, farmers, extension specialists, machinery importers and local machinery manufacturers have been working to adapt RCTs to South Asia’s rice-wheat cropping systems (Ekboir 2002; Seth et al. 2003).

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[1] This section draws from Morris 2003.

The RCTs have been actively promoted in the IGP for about 10 years and recent evidence suggests that these efforts are beginning to bear fruit. Data collected from benchmark and farmer fields show that RCTs provide a wide array of benefits, including higher yields, lower production costs, improved water and fertilizer use efficiency, better control of pests and diseases and reduced greenhouse gas emissions (see Anwar et al. 2002; Hobbs and Gupta 2003a; Khan et al. 2002; Malik et al. 2002a, 2005a).

To date, the RCT that has been most successful in the IGP is zero-tillage (ZT) planting of wheat after rice (Laxmi et al. 2007). ZT 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 and no 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. Mechanized ZT has proven more popular in the IGP, but implies the need for a tractor-drawn ZT seed drill. This specialized seeding implement allows wheat seed to be planted directly into unplowed fields with a single pass of the tractor, often with simultaneous basal fertilizer application (Mehla et al. 2000). In contrast, conventional tillage (CT) practices for wheat involve multiple passes of the tractor to accomplish plowing, harrowing, planking and seeding operations. The use of ZT significantly reduces energy costs, mainly by reducing tractor costs associated with CT methods, and also because water savings reduce the time that tube wells must be operated. The use of ZT also allows the wheat crop to be planted sooner than would be possible using CT methods, which significantly reduces turnaround time. This is an important consideration in many parts of the rice-wheat belt, where late planting of wheat is a major cause of reduced yields: terminal heat implies that wheat yield potential reduces by 1-1.5 percent per day if planting occurs after 20th November (Ortiz-Monasterio et al. 1994; Hobbs and Gupta 2003a).

Of particular interest here is the impact of ZT on water use efficiency. Experimental evidence has shown that ZT reduces irrigation requirements in wheat compared to CT (Gupta et al. 2002; Hobbs and Gupta 2003b). ZT uses residual soil water more effectively. With ZT irrigation, water spreads faster across the surface, whereby irrigation can be stopped once the field is covered. ZT potentially improves the soil structure and facilitates the buildup of crop residue, which have been linked to increased water retention, better infiltration and reduced overall water use. In addition, the faster turnaround time made possible by ZT allows the wheat crop to be planted and harvested earlier, potentially reducing the need for one or more late-season irrigations in some areas. At the time this study was initiated, these benefits had yet to be conclusively documented in farmers' self-adopted fields, although now some such studies are available (Ahmad et al. 2007; Chandra et al. 2007; Jehangir et al. 2007; Malik et al. 2005b).

A prerequisite for any ex-post adoption and impact study is that the technology of interest must have moved beyond the research station and into farmers' fields. While a number of resource-conserving technologies were being developed and tested in the northwest IGP at the time of initiating this study (PARC-RWC 2003; RWC 2002), most had yet to be widely promoted, and uptake by farmers was minimal, although more recently technologies like laser leveling and bed planting have also shown promise (Connor et al. 2003; Jat et al. 2006). For this reason, the current study focuses on ZT wheat, which is known to have spread into farmers' fields.

The extent to which ZT has diffused across the IGP is also not known exactly. Field observations and knowledgeable experts estimate that the area under ZT is significant and is rapidly increasing, particularly in India (Laxmi et al. 2007). Area estimates are often based on the sales of ZT drills and average area coverage per drill (e.g., Malik et al. 2005b, 6-7). There was thus a need to verify the extent of adoption and its impact through structured empirical surveys. Without such data, the technical and economic benefits actually realized by farmers also remain unknown, since scaling up from plot-level experimental data to arrive at aggregate measures of impact is problematic and misses eventual adaptations of farmers in terms of fine-tuning and modifying the technology to their circumstances.

To promote faster and extensive adoption of RCTs in general and ZT in particular, a better understanding is needed not only of their impacts at various levels of aggregation (field, farm and region), but also of the factors that influence the adoption and diffusion. Research has indicated the potential technological benefits, but experience suggests that successful adoption depends on a favorable confluence of technical, economic, institutional and policy factors (CIMMYT 1993; Feder et al. 1985). It is only by understanding these factors that researchers, extension specialists, machinery manufacturers and policymakers will be able to modify the technology, delivery mechanisms and policy environment to stimulate successful adoption and diffusion.

The overall objective of the present study is to enhance our understanding of the adoption and impacts of ZT as a resource-conserving technology in farmers' rice-wheat fields in the IGP. The specific objectives of the present study are to:

1. Document the diffusion of ZT in the rice-wheat belt of the western irrigated IGP, particularly in Haryana, India and Punjab, Pakistan.[2]
2. Identify technical, economic, institutional and policy factors that affect ZT adoption and diffusion in the study area.
3. Evaluate impacts of ZT adoption on productivity and profitability of rice-wheat systems in the study area, including impacts stemming from water use savings.
4. Identify research and extension needs, policy interventions and institutional changes needed to accelerate adoption and diffusion of ZT.

This report synthesizes the findings of the two detailed country studies (Erenstein et al. 2007a; Farooq et al. 2007) and is organized into eight chapters. In the second chapter we review the methodology. In the third we document the diffusion of the technology. In the fourth we analyze the factors affecting ZT adoption. In the fifth we analyze and evaluate the technical plot-level impact of the technology and in the sixth the financial plot-level impacts. In the seventh chapter we analyze the farm and regional impacts. In the eighth and final chapter we give the conclusions and recommendations.

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[2] In this report, Haryana means Haryana State, India; Punjab means Punjab Province, Pakistan.

Study Area and Research Methodology

Study Area

The study focuses on two irrigated rice-wheat areas in the northwest IGP (figure 1). The first is the rice-wheat zone in Haryana, located in the northwest of India and falling in the Trans-Gangetic Plains. The second is the rice-wheat zone in Punjab, located in the northeast of Pakistan close to the Indian border and falling within the Indus Plains. In the Haryana study area the average annual precipitation ranges from 300 mm yr^{-1} (Sirsa district) to 1,100 mm yr^{-1} (Yamunanagar district) (Central Ground Water Board 2007). In the Punjab study area the average annual precipitation ranges from 400 mm yr^{-1} (Sheikhupura district) to 800 mm yr^{-1} (Sialkot district) (Byerlee et al. 1984). The semiarid climate is continental monsoonal, with some 80 percent of the total precipitation during the monsoonal season from June to September. Wheat is grown in the cold and dry weather from November to March, whereas rice is grown during the warm humid/semi-humid season from June to October (Timsina and Connor 2001). With an annual potential evapotranspiration of at least 1,400 mm (Harrington et al. 1993; Jehangir et al. 2007), rice and wheat are dependent on irrigation, which includes the conjunctive use of surface water and groundwater. Both study areas are served by a developed canal irrigation system, although groundwater now provides the major share of total water supply at the farm gate (Harrington et al. 1993; Jehangir et al. 2007) making up for the inadequate volume, frequency and timing of canal water (Ahmad et al. 2007). The soils in the study areas are predominantly alluvial, calcareous, very low in organic carbon and weakly structured, with light to medium texture (sandy loam to clay loam) (Harrington et al. 1993; Jehangir et al. 2007).

FIGURE 1.
Survey locations.

The rice-wheat systems in the study areas are highly mechanized, input-intensive, commercial and with relatively large farm holdings, particularly when compared to the eastern IGP (Erenstein et al. 2007b; Gupta et al. 2003). Another distinguishing feature of both study areas within the IGP is the popularity of basmati rice (Timsina and Connor 2001), an aromatic fine-quality rice which takes a longer time to mature. Wheat has traditionally been, and continues to be, the mainstay of food security in the northwest IGP, and the introduction and widespread cultivation of rice have only occurred in recent decades (Erenstein et al. 2007d). The introduction of rice has, thereby, put increasing pressure on the ability to plant wheat timely without incurring yield losses. The delay in planting the wheat crop is mainly due to the late harvest of the previous crop and/or a long turnaround 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, particularly basmati. The long turnaround time often reflects intensive tillage operations, soil-moisture problems (too wet or too dry), nonavailability of traction power for plowing, and the urgency to store the rice crop before preparing land for wheat cultivation. Farmers perceive the need for intensive tillage due to the difference in soil management practices for rice and wheat – the former being grown under anaerobic conditions and the latter under aerobic conditions (Laxmi et al. 2007).

Data Sources

This study interprets ZT as the planting of wheat with a tractor-drawn ZT seed drill directly into unplowed fields with a single pass of the tractor. Although prototype ZT seed drills were first introduced into South Asia during the mid- to late 1980s, significant adoption of ZT by farmers began only in the late 1990s. The two study areas in Haryana and Punjab were purposively chosen for this study as they comprise the locations where ZT promotion was initiated and adoption was most significant (Khan et al. 2002; Malik et al. 2005c). Each study draws from two similar primary data sources: the survey of ZT drill manufacturers and a formal adoption survey of rice-wheat farmers. The Punjab study was complemented with a village survey (Farooq et al. 2007) and the Haryana study with a water-use survey of rice-wheat farmers (Erenstein et al. 2007a).

This study focuses on ZT through the use of the tractor-drawn ZT seed drill, i.e., ZT as a crop management technology that is embodied in unique agricultural machinery. As a result, it is possible to assess the advent of the technology through a supply-side analysis. For this purpose, a survey of ZT drill manufacturers was implemented in December 2003 (Anwar et al. 2004; Parwez et al. 2004). Altogether 35 ZT manufacturers were identified in Haryana and 43 in Punjab, of whom about two-thirds were directly interviewed for this study (table 1).

The main primary data source for this study was a formal survey of rice-wheat growers from the rice-wheat zones of Haryana and Punjab. The adoption survey used a stratified sampling frame. Within each country study, the districts (and subdistricts) with predominantly rice-wheat systems were purposively chosen (figure 2), comprising at least four (sub)districts where ZT has been widely promoted and at least two where promotion of ZT has been less extensive. The two country studies varied somewhat in the exact sampling approach (for details see Erenstein et al. 2007a; Farooq et al. 2007). In the case of Haryana, altogether five villages per district were randomly chosen from 10 districts. Within each selected village, eight farm households were chosen randomly. This gave a total of 50 villages and 400 farm households. In the case of Punjab, 51 villages were selected comprising 24 ZT-promoted and 27 non-promoted villages. From each selected village typically some 8-10 farmers were interviewed giving a total of 458 farmers (table 1).

Each selected household was visited twice during 2003-04 to collect detailed information using a structured questionnaire covering various

FIGURE 2.
Surveyed districts within: (a) Haryana; (b) Punjab.

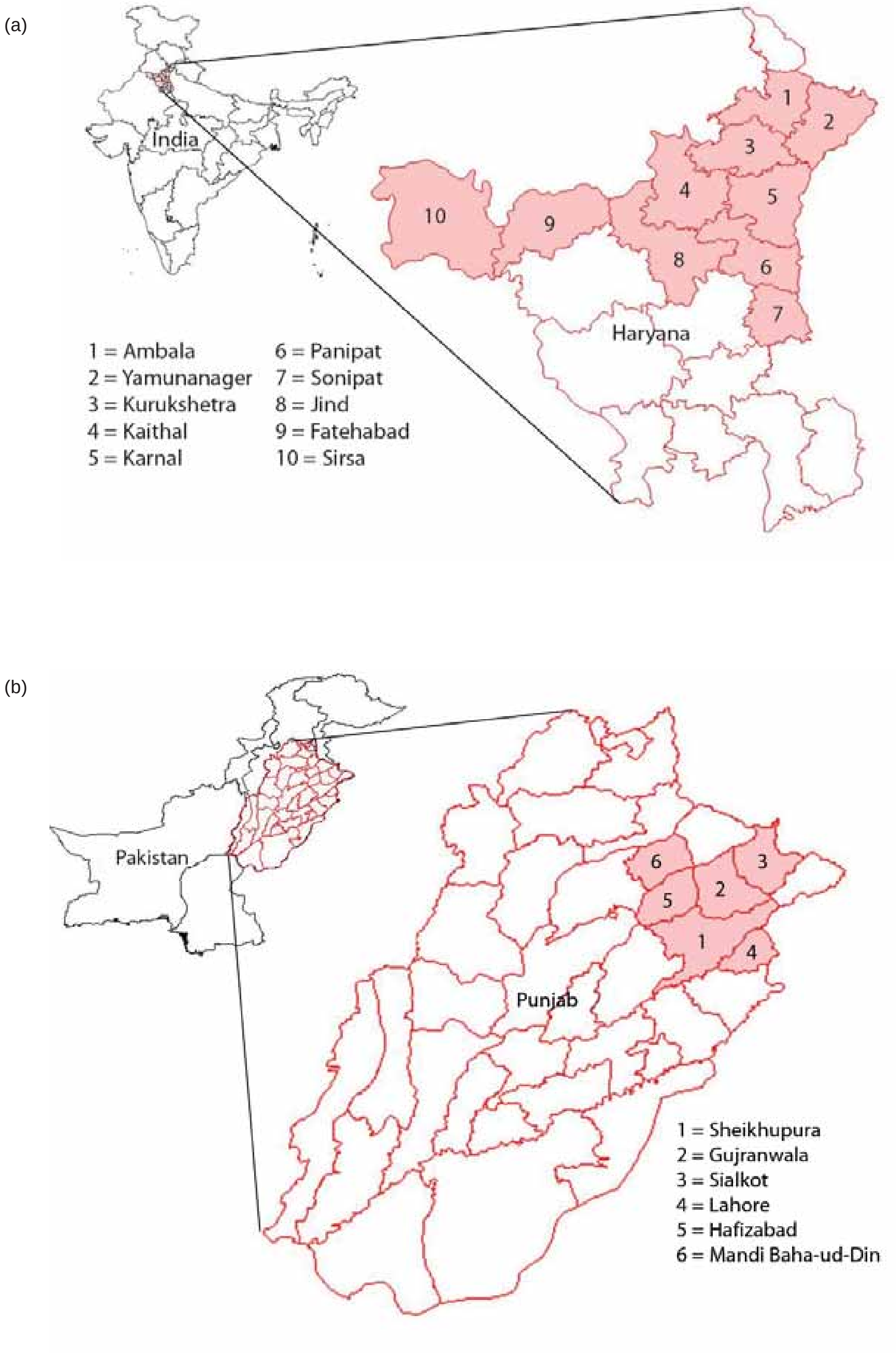


TABLE 1.
Sample characteristics by study site.

	Haryana	Punjab
ZT drill manufacturers survey		
- ZT drill manufacturers surveyed	25	31
- Additional ZT drill manufacturers identified	10	12
- Total ZT drill manufacturers	35	43
Farm household survey		
- Districts surveyed	10	6
- Subdistricts (Tehsils) surveyed	10	11
- Villages surveyed	50	51
- Farm households surveyed	400	458
- Wheat plots surveyed	499	522
- Rice plots surveyed	468	528

indicators at the farm and plot levels. The farm-level indicators covered a range of farmer and household characteristics and experience with, and perceptions of, ZT. The field-level indicators covered plot-level details on crop management for both rice (kharif [June to October] 2003) and wheat (rabi [November to April] 2003-04). Where farmers had used both ZT and CT for their wheat crop, both plots were surveyed giving a total of 499 wheat plots from 400 farm households in Haryana and 522 wheat plots from 458 farm households in Punjab. Similarly, depending on the preceding wheat crop, 468 and 528 rice plots (from Haryana and Punjab, respectively), were surveyed (table 1). To put the rabi 2003-04 season in perspective, the study also traced the adoption history of each farmer. Specifically in the case of Punjab, the surveyed villages were also revisited in the subsequent year to ascertain the extent of ZT area in rabi 2004-05 and related indicators.

Analytical Methods

For the subsequent analysis and reporting, farm households were classified based on their use of ZT in wheat. The farmers who used ZT for wheat during rabi 2003-04 were classified as adopters. Those who never used ZT for wheat on their farm were classified as non-adopters. Finally, those farmers who had used ZT in the past, but not in rabi 2003-04, were classified as dis-adopters.

We hypothesize that there are a number of differences between the three types of adopters, and that these may help explain the observed adoption decision. The adopters, non-adopters and dis-adopters were found to have inherently different crop management practices, irrespective of the use of ZT. This primarily appears to be a reflection of their inherently different asset bases. The plot-level comparisons in this synthesis will therefore focus on the comparison of the ZT and CT plots of adopters only (for details for all plots see detailed country studies - Erenstein et al. 2007a; Farooq et al. 2007). This comparison is more objective in view of the underlying resource base and management differentials. This may underestimate the impact of ZT in the event that adopters reduced the intensity of their “conventional” crop management practices after having used ZT. However, compared to the other adoption categories (see Erenstein et al. 2007a; Farooq et al. 2007) and previously reported tillage intensities (Byerlee et al. 1984; Harrington et al. 1993), no reduction of tillage intensity in the CT plots of adopters was apparent; so according to the survey data this bias is relatively minor.

The significance of all bivariate contrasts between adopter categories and plot types was calculated using the relevant statistical tests (e.g., ANOVA with post-hoc test; t-test). The factors affecting the farm-level decision to adopt ZT were analyzed using the logit regression model, a standard limited-dependent variable approach (CIMMYT 1993). The dependent variable is dichotomous, and takes the value of one when ZT is used and zero if it is not. The independent variables included in the adoption models covered a range of relatively fixed and exogenous characteristics of farm households that were expected to be associated with the ZT adoption decision. Not all variables originally hypothesized could be included in the final models: some variables proved to be highly correlated (e.g., tractor ownership and farm size), and some were not unambiguously measured or proved nondiscriminating. For consistency reasons, we retained the same explanatory variables in the two country studies. The descriptive statistics of the independent variables included in the models and further details are given in the respective country case studies (Erenstein et al. 2007a; Farooq et al. 2007).

The water productivity analysis follows the water productivity framework developed by Molden and associates (Molden 1997; Molden et al. 1998; Seckler 1996), which is increasingly being applied (Ahmad et al. 2004; Cabangon et al. 2002; Jehangir et al. 2007). The main inflow components of the study area and considered in this study are irrigation from the canal and tube-well sources and rainfall. Water productivity was estimated on the basis of the yield and monetary value per unit of the gross inflow (irrigation + rain) and irrigation inflow.

The water inflow indicators draw from farmer recall plot-level data for number and duration of irrigations by source (canal and tube well). These were converted into water volumes using average irrigation volumetric rates and seasonal rainfall in the study area. For the Haryana study area we used the average irrigation rates from the water survey conducted within the context of this study (Erenstein et al. 2007a: 52.5 m^3/hour for tube well and 69.4 m^3/hour for canal) and seasonal rainfall (93 mm in rabi 2003-04 and 509 mm in kharif 2003, Office of the Deputy Director, Agriculture, Kurukshetra, unpublished data). For the Punjab study area we used the irrigation rates and rainfall data reported by Jehangir et al. (2007) within the same area (102 m^3/hour for tube well [i.e., 1 cusec] and 117 m^3/hour for canal; seasonal rainfall of 103 mm in rabi [average 2001-03] and 239 mm in kharif 2003).

The financial analysis was done per individual surveyed household using the reported physical input/output levels and local farm prices that prevailed at the time of the survey. Prices are reported financial market prices, including eventual taxes and subsidies. These market rates are assumed to be a reliable reflection of opportunity costs, irrespective of ownership (e.g., in case of land and tractors) and facilitate comparison. Missing values have been substituted with the corresponding average for the locality. Local currency was converted to US dollars at the average conversion rate at the time.

The gross revenue from crop cultivation comprises the value of all the grain and the value of the residues/straw. The total production cost includes:

1. Land preparation (all tillage plus eventual post-sowing pass to cover seed).
2. Crop establishment (cost of seeding operation only, includes seed, labor and machinery).
3. Fertilizer cost (includes chemical fertilizer and farm yard manure).
4. Plant protection cost (includes herbicides, manual weeding, pesticides/fungicides).
5. Irrigation cost (flat area-based rate for canal and variable time-based cost for tube well).
6. Harvesting expenditures (includes labor and machinery for harvesting and threshing).
7. Land rent (prevailing seasonal rent).
8. Interest on capital invested (9% of all costs).

As performance indicators are included:

- Net revenue = (gross revenue) – (total production cost)
- Percentage of plots with positive net revenue
- Benefit:cost (ratio) = (gross revenue) / (total production cost)
- Production cost = (total production cost) / (grain yield)

Further details are given in the respective country case studies (Erenstein et al. 2007a; Farooq et al. 2007).

Diffusion of Zero Tillage

In India, rapid and widespread adoption of ZT started in Haryana (Laxmi et al. 2007; Malik et al. 2005c). The emphasis on ZT development originated from diagnostic studies that highlighted the importance of time conflicts between rice harvesting and wheat planting in the area (Fujisaka et al. 1994; Harrington et al. 1993). ZT was thereby perceived to be a viable option to alleviate the problem of late planting of wheat after rice, the combined result of late maturing rice and long turnaround time. By reducing soil movement, ZT also serves as an effective control measure of *Phalaris minor,* a major weed, which reduced wheat yields in the IGP and which showed emerging resistance to isoproturon herbicide after repeated and widespread use in the mid-1990s (Malik et al. 2002b; Yadav and Malik 2005). The ability to control herbicide-resistant phalaris thereby became a major initial driver for adoption of ZT in northwest India, which in combination with new herbicides eventually managed to control the phalaris problem. Experts estimated the zero/reduced tillage (ZT/RT) area in Haryana to be 350,000 hectares in 2003-04 (Laxmi et al. 2007; RWC 2004).

In Pakistan, promotion and adoption of ZT started in Punjab (Aslam et al. 1993; Iqbal et al. 2002; Khan et al. 2002; Sheikh et al. 1993). The emphasis on ZT development again originated from diagnostic studies that highlighted the importance of time conflicts between rice harvesting and wheat planting in the area (Amir and Aslam 1992; Byerlee et al. 1984; Sharif et al. 1992). Favorable experimental findings led to a ZT pilot production program in the 1990s to expand the use of this technology in the rice-wheat zone of Punjab (Aslam et al. 1993). ZT was subsequently picked up by farmers with an estimated 0.2 mha planted with ZT drill during 2001-02 (Mann and Meisner 2003) while, according to unpublished data from the On-Farm Water Management, an estimated 0.3 mha had been planted in 2003-04 (RWC 2004).

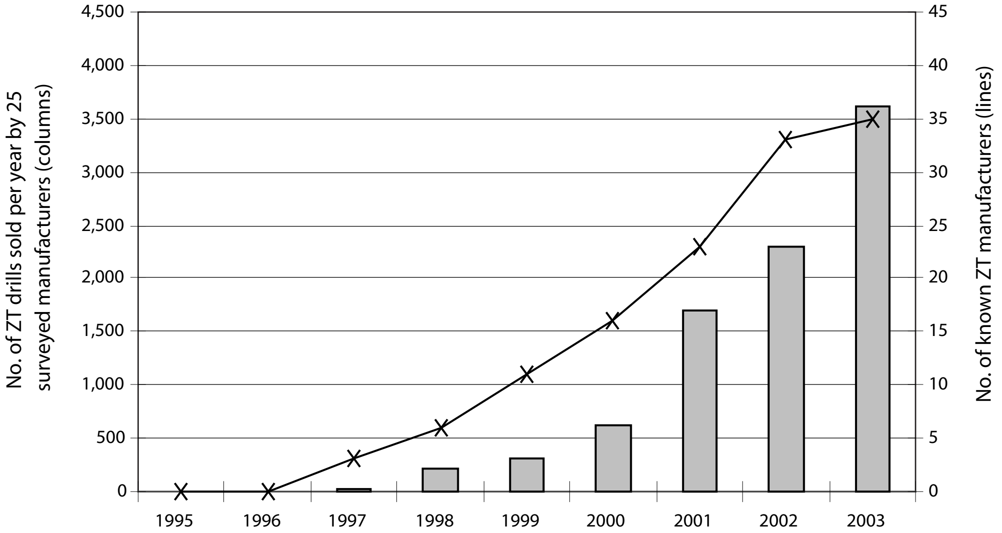
Supply of Zero-Tillage Drills

In both India and Pakistan, promotion and adoption of ZT emphasized the use of a tractor-drawn ZT seed drill. This drill typically opens a number (6-11) of narrow slits with inverted-T tines for placement of seed (and sometimes fertilizer) at a depth of 7.5-10 cm into the soil. This specialized agricultural machinery was originally not available in South Asia. A key component in the technology diffusion was creating the local manufacturing capacity to supply adequate and affordable ZT drills. In both study areas, ZT manufacturing capacity is geographically concentrated in the rice-wheat belt (northwest of Haryana and northeast of Punjab). In Pakistan, this corresponds to the traditional farm-machinery-making centers for cultivators and threshers like Daska town in the Sialkot district, Punjab. In India, the first commercial ZT drills also originated from the traditional machinery-manufacturing centers like Ludhiana and Amritsar in Indian Punjab. It was only later that manufacturers in Haryana joined this business.

The two country studies compiled ZT drill sales figures in Haryana and Punjab and the comparison is revealing. The two States show a largely similar increase in the number of manufacturers over time, both in absolute and relative terms (figure 3 - lines). However, aggregate sales figures for surveyed drill manufacturers for Punjab are a fraction of those for Haryana (figure 3 - columns). By the end of 2003, a cumulative total of 8,800 ZT drill machines had been sold by the 25 surveyed manufacturers in Haryana, against 2,000 ZT by 31 manufacturers in Punjab. Whereas annual ZT drill sales figures for surveyed manufacturers in Haryana were still on the increase, the sales figures in Punjab were relatively flat with peak sales in 2002, similar to the ZT adoption peak. Manufactured ZT drills are also exported to other States/provinces in the respective countries. Conversely, in Haryana ZT, drills are also brought in from neighboring Indian Punjab, which also witnessed a significant growth in ZT manufacturing capacity and output. For instance, by the end of 2003, a cumulative total of 6,900 ZT drill machines had been sold by an additional 25 surveyed manufacturers in the Indian Punjab. The wider manufacturing base and significant growth in sales imply healthy competition between manufacturers in India, with favorable implications for price and quality and generally lighter drills. The average sale price of a ZTD in 2003 amounted to $325[3] in India as against $559 in Pakistan. The Indian government support for ZT has also led to a subsidy on the purchase of ZT drills in some States like Haryana (e.g., 23%, Ekboir 2002), which further lowered the acquisition price.

FIGURE 3.
Number of ZT drills sold per year by surveyed manufacturers (columns) and number of ZT drill manufacturers (lines): (a) Haryana; (b) Punjab, 1994-2003.

(a)



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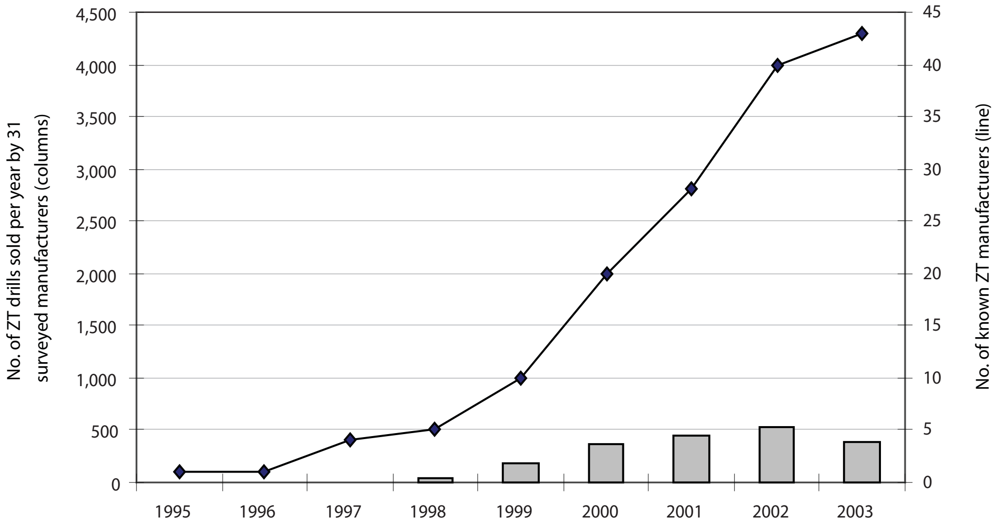
[3] In this report, $=US$. Exchange rates (averages for July 2003 to June 2004) are $1=Indian Rs 45.41 [*Source:* Handbook of Statistics on Indian Economy, Reserve Bank of India, 2005]; $1=Pakistan Rs 57.59 [*Source:* Handbook of Statistics on Pakistan Economy, State Bank of Pakistan, 2005].

(b)



Adoption of Zero Tillage

Our random stratified sample of rice-wheat farmers revealed 34.5 percent and 19.4 percent to be ZT adopters in Haryana and Punjab, respectively, in rabi 2003-04 (table 2). ZT adopters are defined here as farmers who have used the ZT drill for wheat in untilled fields during rabi 2003-04. The corresponding aggregate ZT wheat areas in the sample was 26 percent and 18 percent, respectively, of the aggregate wheat area in rabi 2003-04 (figure 4). The studies thus empirically confirm the significant levels of adoption of ZT wheat in the rice-wheat systems of the northwest IGP, underscoring the appeal of the technology among farmers.

The surveyed farmers were questioned when they first used ZT and their use of ZT since then. The plotted responses (figure 5) distinguish between ZT adoption (i.e., those who actually used ZT in the corresponding year, dash) and ZT penetration (i.e., those who

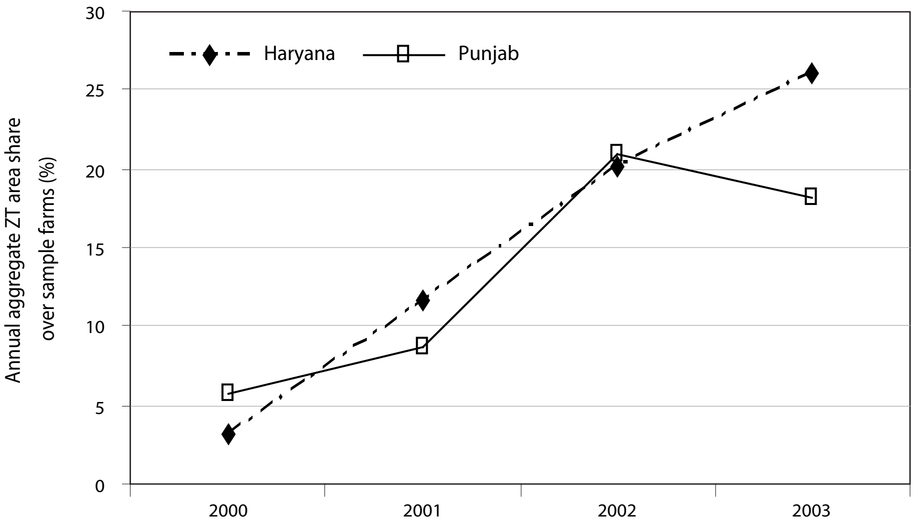
TABLE 2.
Breakdown of sample by ZT adoption category for wheat season 2003-04.

ZT Adoption category	Haryana (n=400)	Punjab (n=458)
Adopter (%)	34.5	19.4
Non-adopter (%)	55.5	66.6
Dis-adopter (%)	10	14
	100	100

Chi-squared test-.00.

Note: Adopter used ZT in at least one of the farm’s wheat fields in 2003-04. Both non-adopters and dis-adopters did not use ZT for wheat in 2003-04, but dis-adopters did use ZT for wheat in a prior season.

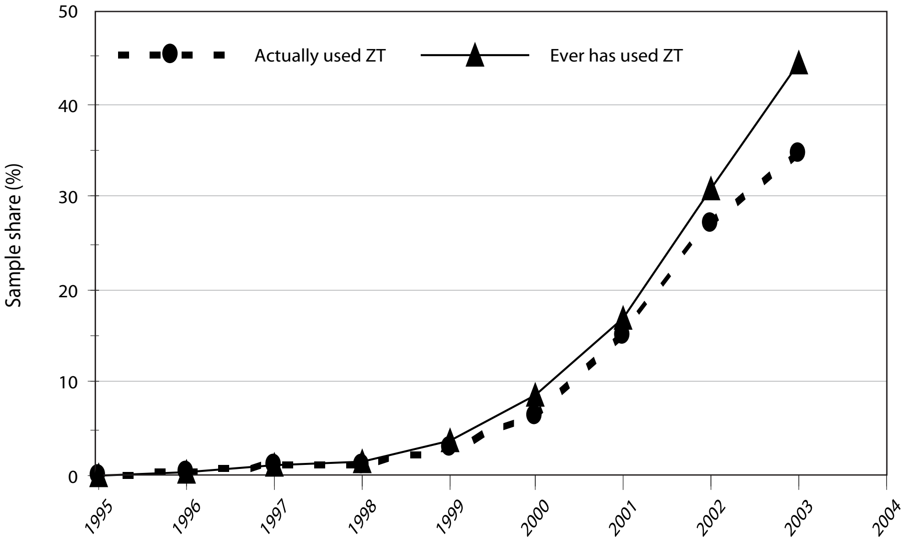
FIGURE 4.
Aggregate ZT area share for surveyed farms over time in Haryana and Punjab.



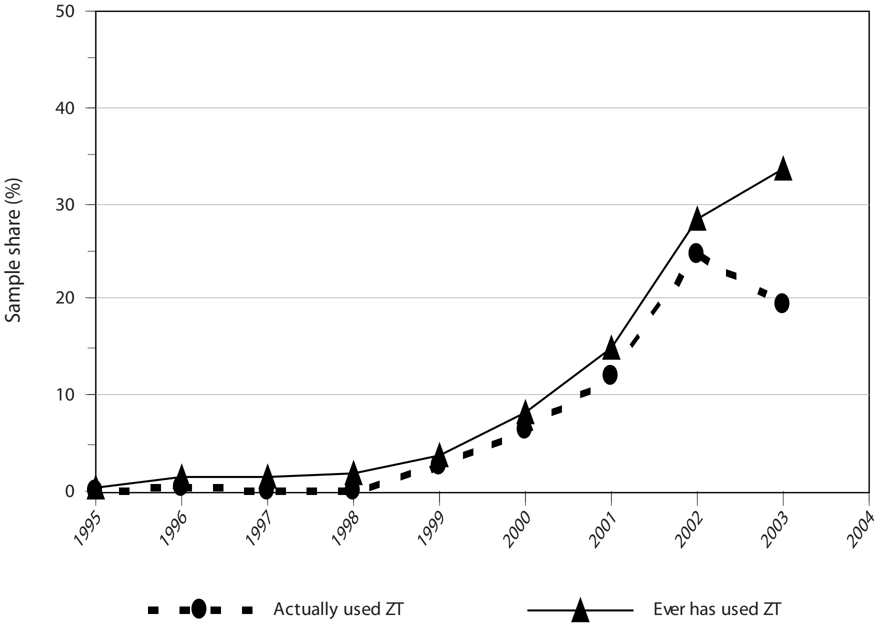
had used ZT by that year, adopters and dis-adopters combined, line). In the case of Haryana, the ZTD diffusion in many ways follows the traditional diffusion pattern of technological innovations. After nearly a decade of adaptive research, demonstration and slow initial diffusion, diffusion started to pick up rapidly from 2000 onwards. The data suggest that ZT adoption levels for wheat may end up somewhat higher than the observed one-third of the surveyed rice-wheat farmers at the time of the survey (figure 5a). In the case of Punjab, up to 2002-03, ZT diffusion in many ways seemed to follow the traditional diffusion pattern of technological innovations similar to that of Haryana. Diffusion started to pick up rapidly from 2000, but adoption rates seem to have abruptly peaked in 2002-03 (at 24%, figure 5b). A separate study in Punjab also reports a considerable increase in the adoption of ZT between 2000 and 2003, although without showing signs of peaking (Ahmad et al. 2007).

FIGURE 5.
Diffusion of ZT based on first year of use: (a) Haryana; (b) Punjab.

(a)



(b)



Our random stratified sample of rice-wheat farmers also revealed 10 percent and 14 percent to be ZT dis-adopters in Haryana and Punjab, respectively (table 2). Dis-adopters are defined here as farmers who had used ZT in preceding seasons, but did not do so in the 2003-04 rabi season for whatever reason. It is noteworthy that the dis-adoption rates are lower in Haryana, both in absolute terms (share of surveyed households) and in relative terms (share of households that have tried ZT). Most dis-adoption is of recent nature in both sites, and was particularly pronounced in the 2003-04 season (figure 5).[4] The village-level data for the subsequent rabi season (2004-05) in the Punjab study area suggested further dis-adoption (Farooq et al. 2007). The subsequent years will thus inform us whether ZT adoption levels for wheat in Punjab may end up significantly lower or higher than at the time of the survey.

Dis-adoption is both permanent and temporary, whereas 74 percent and 54 percent of those who have used ZT in Haryana and Punjab, respectively, have done so continuously. Temporary dis-adoption could be associated with the untimely availability of the ZT drill or unfavorable seasonal conditions for ZT in the survey year 2003-04. For instance, untimely rain prior to rice harvesting may cause combiners to cause ruts in the fields that need to be evened out through tillage. Alternatively, untimely rain can cause a flush of weeds that a farmer prefers to control through reduced tillage. However, in the survey year, rainfall during the critical months of October and November suggests a relatively normal aggregate rainfall for Punjab, albeit somewhat late, whereas Haryana was relatively dry.[5] Prolonged or even permanent dis-adoption could be associated with a farmer structurally losing access to a functional ZT drill or being disillusioned with ZT for whatever reason. For

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[4] In Figure 5, dis-adoption is shown as the difference between the dashed and continuous lines.

[5] For the Pakistan study area, October-November rainfall in nearby Lahore was 16 mm in 2003 (0 mm in October and 16 mm in November) as against a 30-year average of 16.6 mm (12.4 mm in October and 4.2 mm in November; Lahore meteorological station, unpublished data). For the India study area, October-November rainfall in Kurukshetra was only 1 mm in 2003 (0 mm in October and 1 mm in November) as against a 1989-2005 average of 21 mm (18 mm in October and 3 mm in November; Office of the Deputy Director, Agriculture, Kurukshetra, unpublished data).

instance, particularly dis-adopters and the Punjab study reported the lack of yield enhancement with ZT as an issue (see subsequent chapters). It is also noteworthy that in both study areas dis-adopters had typically used ZT for one single year, suggesting an unsuccessful first experience and/or limited perseverance.

The slower diffusion and higher dis-adoption in Punjab are likely associated with the ongoing institutional ZT controversy there. ZT diffusion in Punjab has been hampered by institutional rivalry whereby "some government agencies … have differences of opinion on the usefulness and the benefits of zero-tillage technology" (Iqbal et al. 2002:677). This is also illustrated by Sheikh et al. (2003:90), who find a significantly negative association between the number of extension visits and ZT adoption, leading them to conclude that "[t]his suggests that extension workers are not recommending the technology." Provincial agricultural extension is indeed not supportive of ZT wheat and this message is carried through in their extension campaigns and by their field staff. One of their fears is that ZT, by not plowing, may enhance over-wintering of the stem borer in the rice stubble which may undermine the productivity and competitiveness of basmati rice, a major export crop. However, there is no scientific evidence of such risk (Inayatullah et al. 1989; Srivastava et al. 2005). Filling the institutional vacuum, OFWM has played an important role in promoting this technology. This has created institutional rivalry between OFWM and agricultural extension with unfortunate implications for the farmers and the technology alike in Punjab, particularly in view of conflicting information. In contrast, the initial reluctance of many stakeholders vis-à-vis ZT in India was transformed into a significant support for ZT at all levels.

Better understanding the rationale for dis-adoption merits further scrutiny. Our findings suggest that there is no clear single overarching constraint, but that a combination of factors is at play, including technology performance, technology access, seasonal constraints and, particularly in the case of Punjab, the institutional ZT controversy.

In line with ZT drill sales and ZT use, ZT drill ownership is significantly less widespread in Punjab than in Haryana, being reported by 7 percent and 15 percent of the surveyed households, respectively. As expected, drill ownership was significantly higher for adopters, less common for dis-adopters and virtually absent for non-adopters in each site (table 4). The majority of ZT adopters therefore relied on contracted ZT drill services at the time of the survey in both sites (74% and 60% of ZT adopters, respectively). This is in line with the common tillage practices in these areas where many farmers do not own a tractor but rely on tillage contract services to get their fields prepared. Contracted ZT drill services have thereby made the technology accessible to smallholders without a tractor, whereas tractor owners can put off the investment decision. At the same time, the prevailing reliance on contractual services may constrain timely availability of the ZT drill and thereby (partially) forfeit the timely establishment of the wheat crop. Also, not all ZT drills are available for contract services: about a third of the operational ZT drills in Punjab were reportedly only used on the owners' farm during the last 3 years. Another study of ZT drill owners in Punjab found that only 40 percent were providing the drills on a rental basis (Khan et al. 2002:63). Anecdotal evidence suggests that large land- and tractor-owning farmers in Punjab are often reluctant to contract out their machinery – an issue also reported for the 2000-01 season (Iqbal et al. 2002:677). The varying access to ZT drills adds to the site-specificity of findings. For instance, yet another study in Punjab revealed that the reasons for ZT users not purchasing a ZT drill included having easy access to drills on rent or free of cost from relatives/friends, drills still in an experimental phase and high drill costs (Tahir and Younas 2004). Yet, the same study also reported that 40 percent of ZT users claimed that the number of available drills was insufficient.

Partial adoption of ZT on a share of the wheat area of the adopting farm seems to be the prevalent practice. In Punjab, this share averaged 74 percent in the survey year, as against 53 percent in Haryana. The adoption intensity could reflect differential access to a ZT drill: one might expect ZT drill owners to have higher adoption intensities than those reliant on ZT-service providers. However, in neither study area is there a significant difference in ZT area share between these two categories of ZT drill access in the survey year. This suggests that ZT access categories did not constrain the extent of ZT adoption in the survey year, provided they had access to a ZT drill in the first place. The adoption intensity could also vary between tractor owners and those reliant on tractor-service providers. One might expect tractor owners to have lower incentives for ZT use in view of the relative lower tillage costs on the farm (e.g., sunk cost of tractor and machinery, ensured and timely access, etc.) and ZT potentially negatively affecting their future income as providers of tractor services. In Punjab, there was no significant difference in terms of ZT area share between tractor owners and those reliant on tractor-service providers, but in Haryana there was a marked contrast. Here non-tractor owners had significantly higher ZT adoption intensities (>66% wheat area) than tractor owners (approximately 50% of wheat area, table 3). In Punjab, the ZT area share was also relatively constant over time, but in Haryana the ZT share decreased (table 3). This is primarily associated with early adopters devoting a larger area share to ZT than late adopters in Haryana, as ZT adopters typically maintain or increase their ZT area share over time (figure 6). Early adopters having a higher adoption intensity is somewhat contrary to expectations, but it can be explained by the relative contribution of tractor owners and non-tractor owners over time. In Haryana, the absolute number of both tractor owners and non-tractor owners adopting ZT increased over time, but the number of tractor owners (with their lower ZT adoption intensities) increased at a faster rate (table 3). Consequently, the relative share of non-tractor owners (with their higher ZT-adoption intensities) amongst ZT adopters in Haryana decreased from about half in 1999-2000 to a third in 2000-02 and less than a third in 2002-04 (table 3). A separate study in the Punjab area revealed that half the ZT users did not allocate the whole of their wheat area to ZT because they were still experimenting with the technology (Tahir and Younas 2004). Other reasons for partial area adoption in that study included the availability of enough time for CT (11% of cases), land not suitable for ZT (10%), nonavailability of ZT drill at sowing time (8%) and lack of proper knowledge (6%), and a range of perceived negative carryover effects in relation to ZT use (e.g., in terms of yield, soil compaction and tillage for subsequent rice).

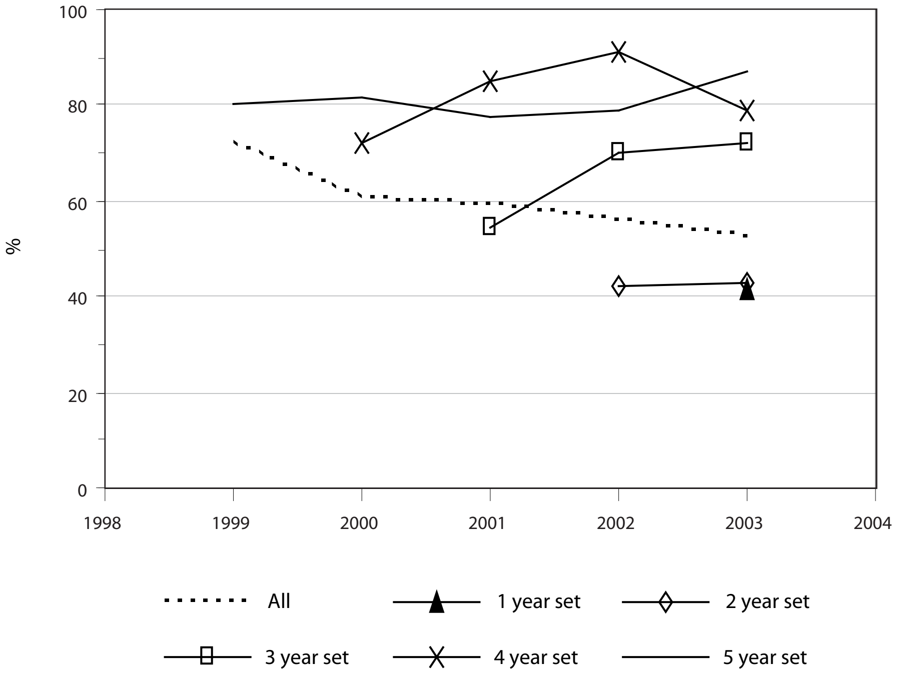
TABLE 3.
Evolution of wheat area share planted with ZT drill per farm by site.

	Haryana			Punjab		
	Tractor owner	Non-tractor owner	Overall	Tractor owner	Non-tractor owner	Overall
2003-04	48 (99)	66 (39)	53% (s.d.=37, n=138, p=0.01)	73 (50)	77 (30)	74% (s.d.=35, n=80, NS)
2002-03	49 (81)	80 (27)	56% (s.d.=37, n=108, p=0.00)	68 (64)	70 (38)	69% (s.d.=32, n=101, NS)
2001-02	53 (40)	74 (20)	60% (s.d.=37, n=60, p=0.02)	64 (27)	66 (15)	65% (s.d.=33, n=42, NS)
2000-01	47 (15)	91 (7)	61% (s.d.=38, n=22, p=0.01)	77 (16)	67 (3)	6% (s.d.=26, 7n=19, NS)
1999-00	64 (5)	80 (6)	73% (s.d.=31, n=11, NS)	78 (5)	56 (1)	74% (s.d.=31, n=6, NS)

Note: Figures in parentheses are number of nonzero cases (n). s.d. = standard deviation. P = significance of t-test (comparison within site). Nonzero values only: i.e., only includes farmers who used ZT in the respective year in part of their wheat area.

FIGURE 6.
ZT share of total wheat area per ZT farm over time for different subsets of ZT adopters: (a) Haryana; (b) Punjab.

(a)



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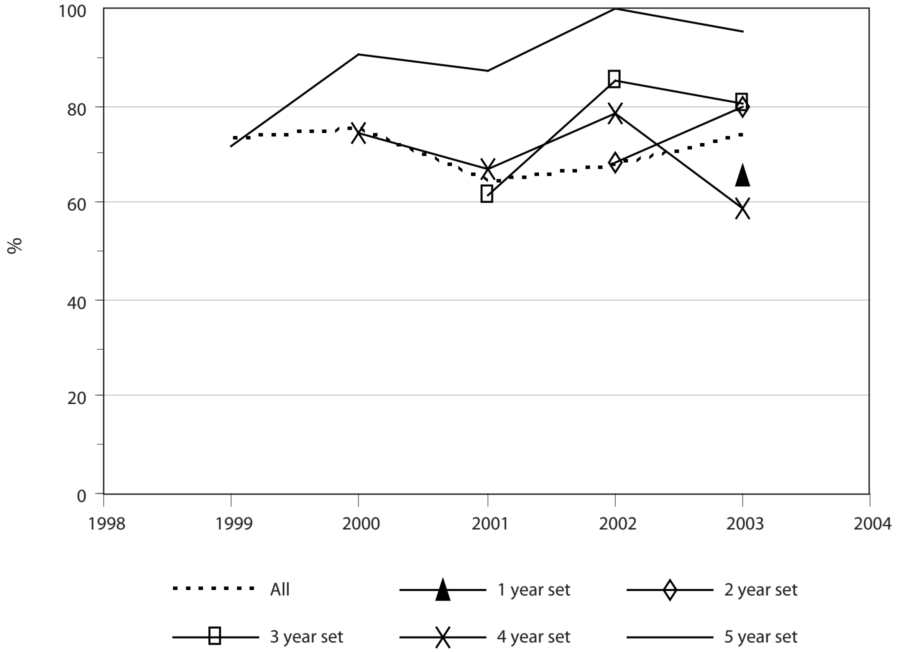
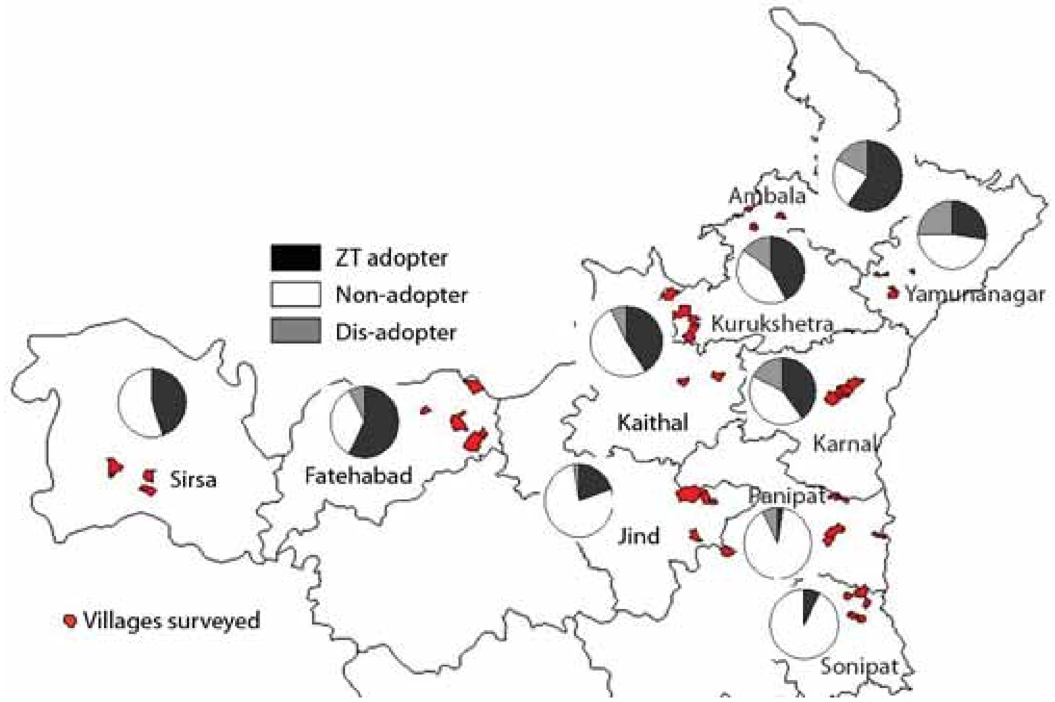


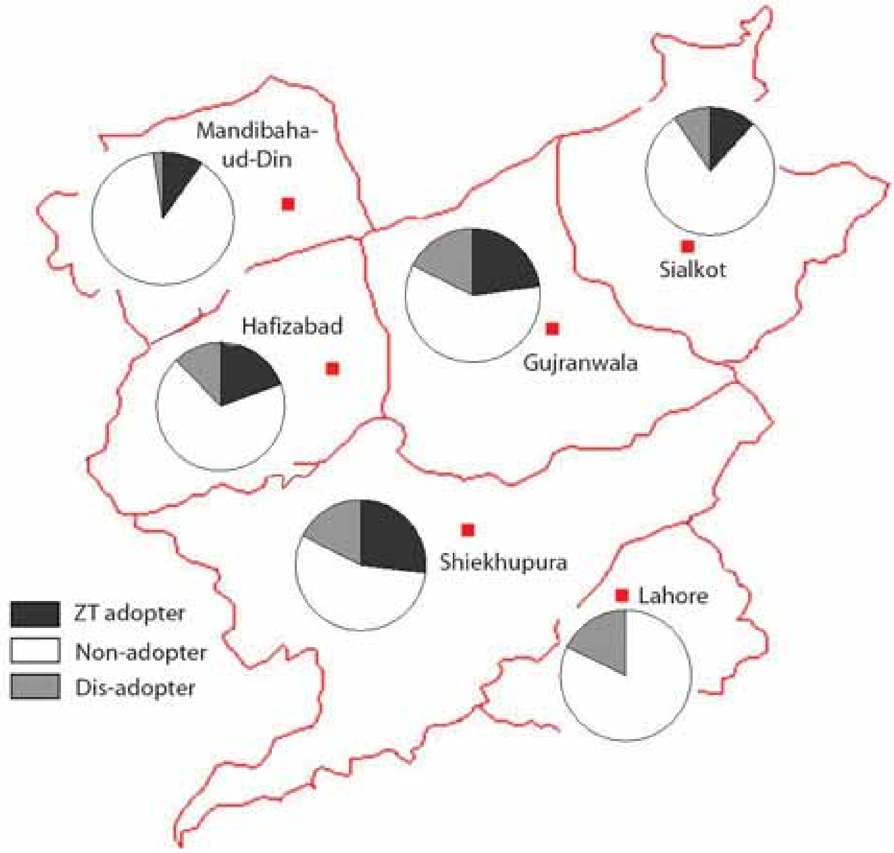
Note: Nonzero values only, subsets refer to farmers grouped by the number of consecutive years of using ZT prior to 2004. For 1, 2, 3, 4 and 5-year set, respective number of farms: n=62, 30, 31, 9 and 6 in Haryana and n=25, 32, 12, 7 and 4 in Punjab.

FIGURE 7.
ZT adoption rates by survey locations: (a) Haryana; (b) Punjab.

(a)



(b)



ZT adoption is also far from uniform, with significant variations in terms of penetration and use over districts and villages in both study sites (figure 7). In Haryana, the variations over districts seem to be associated with prevailing cropping systems, with dis-adoption more prevalent in both rice-wheat and sugarcane-based cropping systems. Although ZT promotion has emphasized rice-wheat districts in Haryana, ZT adoption is also spreading rapidly in districts where cotton-wheat predominates. Cotton-wheat systems tend to have the same problem of late wheat planting. However, in Punjab, ZT is even more controversial in cotton-wheat systems because of feared carryover of bollworms on unincorporated cotton residues. In Punjab, ZT penetration (adoption + dis-adoption) is geographically concentrated in the rice-wheat heartland: the contiguous Sheikhupura, Gujranwala and Hafizabad districts. In these districts, 32-45 percent of surveyed farmers have tested the ZT drill, with 20-27 percent current adopters. The soils in these districts are relatively heavy, suggesting that the need for the ZT drill is relatively felt more in these areas. In the remaining three Punjab districts, ZT penetration was modest with 11-21 percent of surveyed farmers having tested the ZT drill. In both Haryana and Punjab, the district-level data show that a) an increased penetration of ZT is associated not only with increased adoption levels but also with increased dis-adoption levels; and b) ZT adopters typically outnumber dis-adopters. The assumed intensity of ZT promotion at the district level did not show a clear linkage to increased adoption rates, an issue likely associated with the technology primarily spreading from farmer to farmer in both study sites and the institutional rivalry in Punjab.

In both Haryana and Punjab, village-wise adoption rates show a considerable gradient from none to saturation. The village-level data thereby allow for some important inferences. First, it illustrates that ZT penetration to individual villages was widespread but not comprehensive at the time of the survey in both Haryana and Punjab. Second, the gradient in village-wise adoption rates suggests that intrinsically there is nothing wrong with the technology itself, but that access and application of the technology may be an issue. Indeed, the fact that some villages are saturated and others show no dis-adoption suggests that ZT has considerable merit and wide applicability once the technology has proven itself within a community. Third, village-wise dis-adoption varies over the two study sites. In Haryana, the village-level data show that the average dis-adoption of 10 percent is typically piecemeal and only occasionally widespread and likely associated with crop diversification in favor of sugarcane and vegetables. In Punjab, dis-adoption seems to be concentrated in about half the villages where ZT had penetrated. Access to ZT drills varies over villages and is likely to have contributed to the observed adoption patterns.

Understanding Adoption of Zero Tillage

The previous chapter confirmed the significant adoption of ZT in Haryana and Punjab. However, it also highlighted that adoption is far from universal and that a significant share of households had become dis-adopters. This chapter synthesizes the differences at the household level that may help explain the decision to become adopters or dis-adopters.

Factors Affecting the Adoption

The ZT adopters, non-adopters and dis-adopters categories differ significantly in terms of their resource base in both study areas. For the various indicators compiled, adopters typically have the most favorable values and the non-adopters the least favorable, with dis-adopters taking an intermediate position. This has two important implications. First, it highlights that ZT adoption in the initial diffusion stage is strongly associated with

TABLE 4.

Selected indicators by adoption category in Haryana and Punjab study sites.

	Haryana			Punjab		
	Adopters (n=138)	Non-adopters (n=222)	Dis-adopters (n=40)	Adopters (n=89)	Non-adopters (n=305)	Dis-adopters (n=64)
Asset indicators						
No. of farm asset categories per household (hh)[a]	4.9 b	4.4 a	4.5 ab	3.7 y	3.0 x	3.6 y
Tractor owner (% of hh)	72 b	53a	63ab	58 y	37 x	61 y
ZT drill owner (% of hh)	40 c	1 a	10 b	26 c	1 a	14 b
No. of household asset categories per hh[b]	6.6 b	5.6 a	6.5 b	4.8 y	3.5 x	4.3 y
No. of car/vehicles per hh	0.32b	0.12a	0.22ab	0.33 y	0.07 x	0.16 x
Total operational holding (ha)	9.07 b	5.07 a	7.41 b	16.29 z	6.28 x	10.69 y
Farms having both canal and tube well irrigation, kharif (%)	44 b	29 a	33 ab	71 y	59 x	75 y
Farms having primarily light soil type (%)	64	71	58	37 x	51 y	50 y
Farms with well-drained land (%)	96	97	100	46 x	59 y	58 y
Relative contribution of labor sources to overall farm labor use (% share)						
- Family	40 a	51 b	50 b	48 x	72 z	55 y
- Permanent hired	19 c	8 a	13 b	26 y	10 x	23 y
- Casual hired	41	41	37	26 y	19 x	22 x
Distance to district headquarters (km)	22.9 b	20.0 ab	16.7 a	26.6 x	27.8 x	31.4 y
Distance to Agricultural Research Station or KVK (km)	22.5 b	19.5 b	15.2 a	60.5 x	70.6 y	58.7 x
Age of household head (yr)	42.8 b	42.7 b	38.2 a	41.5	44.8	43.7
Education index household head	1.6	1.5	1.5	1.6 x	1.2 y	1.5 x
Household belongs to Jat/Jat Sikh cast (%)	59 b	44 a	70 b	40 x	50 y	33 x
Income share from farm (%)	89 b	81 a	83 a	85 y	77 x	84y
Farm income share from rice (%)	46.2 b	41.9 a	40.4 a	53.9 y	49.6 x	54.1 y
Farm income share of wheat (%)	42.7 b	41.8 b	39.1 a	32.2	32.1	31.8

Note: Data followed by different letters differ significantly (a,b,c in Haryana, x,y,z in Punjab) – Duncan (.10), within row comparison per site.

[a] Farm assets categories include tractor, disc/rotavator, tube well, combine harvester, motorized thresher, insecticide hand pump, bullocks and milk animals. [b] Household asset categories include sewing machine, television, refrigerator, tape recorder, telephone, radio, bicycle, motorcycle/scooter and car/motor vehicle; hh=household/s.

the wealth of the farm household, likely reflecting their risk-bearing capacity and ability to innovate. Second, it highlights that ZT dis-adopters combine characteristics of both adopters and non-adopters. The favorable characteristics may thereby facilitate the initial adoption of ZT, whereas the unfavorable characteristics undermine its continued use.

Bivariate analysis of the various adoption-survey indicators highlighted contrasts and similarities between ZT adopters, dis-adopters and non-adopters in each site. Table 4 lists some of the factors that differed significantly, which included:

- *Farm and household assets*: In both Haryana and Punjab, penetration of ZT (adoption + dis-adoption) was positively associated with the possession of farming assets (particularly a tractor and farm equipment) and household assets (particularly a car/vehicle and household appliances).
- *Land characteristics:* In both Haryana and Punjab, adoption of ZT is positively associated with the size of operational holding, with dis-adopters having intermediate farm sizes. Adoption of ZT was also positively associated with the conjunctive use of canal and tube-well irrigation in both sites. Soils in Haryana tend to be lighter and better-drained than in Punjab (farms with only [sandy] loam soils 67% and 46%, respectively; farms with well-drained land 97% and 57%, respectively). In Punjab, heavy soils and drainage problems are associated with continued ZT use. These soils would be more difficult to plow and so ZT would have more potential in reducing turnaround time. In Haryana, there was no significant association between soil type or drainage and ZT adoption. In Punjab, ZT adoption was also positively associated with farms having fallow land in the rabi season. In part, this is associated with the strong association of ZT with farm size; but it also reflects the potential of ZT to increase the area cultivated as compared to CT.
- *Sources of farm labor*: In both Haryana and Punjab, adoption of ZT was positively associated with reliance on permanent labor and negatively associated with reliance on family labor. In Punjab, adoption of ZT was also positively associated with reliance on casual labor.
- *Selected farm and farmer characteristics*: Distance is associated with adoption and dis-adoption in each site, but no clear pattern emerges across the two sites. In Haryana, various proximity indicators were associated with dis-adoption, the latter likely reflecting the combined effect of exposure to ZT and diversification incentives. In Haryana, dis-adoption of ZT was also positively associated with the youth of household head and the Jat caste, whereas adoption of ZT was positively associated with the Jat Sikh caste. In Punjab, non-adoption was associated with a low literacy ratio. Family size, organizational membership and credit access indicators provided no clear association with adoption classes.

In both Haryana and Punjab, farming was the main income source across households, contributing 80 percent or more of overall household income. In Haryana, the share of farming was significantly higher for adopters compared to non-adopters and dis-adopters (table 4). In Punjab, the share of farming was significantly higher for adopters and dis-adopters compared to non-adopters. This highlights a positive association of ZT adoption and penetration, respectively, with the farm households' reliance on agriculture for income. This agricultural specialization reflects their larger landholding and more commercial orientation.

In Haryana, rice and wheat contributed about equal shares to household income (43% and 42%, respectively). In Punjab, the relative income share favors rice over wheat (51% and 32%, respectively), associated with the more widespread cultivation of high-value basmati rice. In our Haryana sample, adopters have taken the rice-wheat specialization furthest. In Punjab, adopters and dis-adopters had a significantly higher relative contribution of rice to farm income compared to non-adopters, and the wheat share was similar. On average, rice and wheat crops occupied threefourths of the total operational holding in Punjab, while slightly more than 15 percent of the farm size was allocated for fodder crops during both seasons. The combination of these factors likely enhances the incentives for adopters in Haryana and adopters and dis-adopters in Punjab to innovate and cut production costs in rice-wheat systems. In Haryana, dis-adoption of ZT was positively associated with sugarcane cultivation, which is often grown in a 2-year rotation with wheat. This reduced their reliance on rice-wheat systems whereas the prevailing tine-type ZT drills will not work without prior tillage in former sugarcane fields owing to the persistent rootstocks. To use ZT in such fields, heavier double-disc drills are needed that can cut through the rootstocks, and these only started becoming available in 2002-03.

ZT Adoption Constraints

Each household was requested to rate a number of technical, extension and financial factors in terms of the degree they constrained the adoption of the ZT technology. The list of factors to be rated was largely similar for both study sites and all households irrespective of adoption category. Overall, the individual constraints were generally rated as less severe in Punjab than in Haryana. Therefore, instead of the absolute values, the relative values within each site are more revealing. The results of the ranking analysis are presented in table 5 and discussed subsequently.

Technical Factors

Compared to extension and financial factors, technical factors as a group rated relatively high in terms of constraining ZT adoption in Punjab, whereas they played a relatively lesser role in Haryana (table 5). The most pressing and revealing technical constraint is the yield of ZT relative to CT in both study areas. The single most serious constraint for dis-adopters was the reduced/low yield with ZT in Punjab (constraint index of 0.5, implying it is a moderate constraint) and the lack of a significant difference in yield in Haryana (constraint index of 0.5), contributing to their dis-adoption of the technology. The yield constraint also scored relatively high for non-adopters in Punjab, thereby adding to their reluctance to try the technology.

The nonavailability of high-quality ZT drills was primarily raised by non-adopters in each site. In Haryana, non-adopters also highlighted the lack of local manufacturing and/or repair facilities for ZT drills. In Punjab, the nonavailability of the ZT drill on a rental basis was solely reported by some of the non-adopters. This suggests that there is still scope for further diffusion of the technology in both sites, and that these ZT-drill-related constraints were not related to ZT dis-adoption.

In Punjab, soil hardening was particularly reported by non-adopters and dis-adopters, but not really by adopters, suggesting this may either be a perceived issue or something related to the differences in soil types reported earlier. In Punjab, the weed problem at the time of planting was particularly mentioned by dis-adopters, possibly contributing to the dis-adoption decision, perceiving tillage as a more economical means for controlling the problem. The extension services in Punjab have discredited ZT for the perceived danger in pest carryover in the rice stubble (particularly rice stem borer). Interestingly, the risk of increased insect and disease problems was rated insignificant by the farmers across adoption categories in both sites.

Extension Factors

Compared to technical and financial factors, extension factors as a group rated relatively high in terms of constraining ZT adoption in Haryana, whereas they played a relatively lesser role in Punjab (table 5). This finding is contradictory to our expectations in view of the ZT controversy in Punjab and the public support for ZT in Haryana. In part, these findings may reflect the overall more lax scoring of constraints in Punjab and/or divergences in interpretation. Still, the “lack of technical assistance from extension workers” highlighted a significant and consistent difference

TABLE 5.

Constraint index for zero tillage adoption by adopter categories (0: no constraint; 1: very serious constraint).

	Haryana			Punjab		
Factor groups/factors	Adopters (n=138)	Non-adopters (n=222)	Dis-adopters (n=39)	Adopters (n=89)	Non-adopters (n=305)	Dis-adopters (n=64)
Technical factors						
- Nonavailability of high-quality ZT drills	0.03 a	0.44 b	0.09 a	0.02 x	0.11 y	0.04 x
- Lack of local manufacturing/ repair facility for ZT drills	0.04 a	0.40 b	0.05 a	0.01	0.02	0.01
- Standing stubbles/crop residues at the time of planting	0.14	0.18	0.18	0.12	0.07	0.07
- Dense population of weeds at the time of planting	0.07	0.09	0.13	0.04 x	0.04 x	0.10 y
- Lack of appropriate soil moisture at the time of planting	0.05	0.09	0.05	0.02	0.03	0.05
- Risk of increased problem with insect pests and diseases	0.02	0.02	0.03	0.00	0.01	0.01
- Hardening of upper soil	0.02	0.02	0.03	0.02 x	0.10 y	0.14 y
- Reduced yield [1]	-	-	-	0.12 x	0.35 y	0.50 z
- ZT not available on rented basis [1,2]	-	-	-	0.00 x	0.09 y	-
- Early harvesting of rice [2]	0.04 a	0.10 b	-	0.01	0.02	-
- No significant difference in yield [3]	-	-	0.50	-	-	0.09
- Increased weed problem following adoption of ZT [3]	-	-	0.15	-	-	0.08
- No significant cost savings [3]	-	-	0.08	-	-	0.07
- Increased irrigation water requirement [3]	-	-	0.03	-	-	0.05
Extension factors						
- Lack of technical assistance from extension worker	0.37 a	0.61 b	0.35 a	0.04 x	0.10 y	0.02 x
- Nonavailability of extension literature on ZT methods	0.38 a	0.59 b	0.34 a	0.02	0.05	0.02
- Lack of coverage of ZT method by mass media	0.34 a	0.57 b	0.38 a	0.03	0.04	0.02
Financial factors						
- High cost of ZT drill	0.18 a	0.50 c	0.31 b	0.02 x	0.09 y	0.03 x
- Lacks resources for farmers to purchase ZT drill	0.11 a	0.36 b	0.16 a	0.02	0.05	0.04
- No credit available for purchasing ZT drill	0.09 a	0.29 b	0.13 a	0.02	0.02	0.01
- No credit available for purchasing other inputs	0.07 a	0.22 b	0.10 a	0.00	0.02	0.00

Note: Data followed by different letters differ significantly – Duncan (.10), within row comparison per site. [1] Only asked for Punjab; [2] Only asked adopters and non-adopters; [3] Only asked dis-adopters.

between adoption categories in both sites. The same pattern emerges for the two other constraints in Haryana ("nonavailability of extension literature on ZT methods" and "lack of coverage of ZT method by mass media"). These extension constraints were consistently rated highest by non-adopters, suggesting that they lacked adequate access to ZT knowledge. This suggests there is still significant scope for further enhancing ZT adoption by alleviating knowledge blockages, possibly through farmer to farmer extension which so far is the prevailing source of ZT information. Adopters and dis-adopters gave similar ratings for these extension constraints, suggesting that the knowledge of ZT technology was not an underlying reason for dis-adopting its use.

Financial Factors

The most serious financial constraint was the perceived high cost of the ZT drill in both sites (table 5), particularly being reported by non-adopters. However, dis-adopters in Haryana also rated this constraint significantly higher than adopters, suggesting this is one factor that also contributed to their dis-adoption of ZT. Again in Haryana, non-adopters' ratings for the remaining three financial indicators (in relation to resources and credit) were consistently highest, but there was no significant difference between adopters and dis-adopters. This reiterates that the non-adopters in Haryana are more resource-constrained, and that this may have contributed to their reluctance to adopt ZT so far.

A separate study suggests that ZT diffusion in the Punjab study area is constrained by the lack of financial resources, lack or untimely availability of ZT drills and lack of familiarity among the smallholders (Jehangir et al. 2007).

Logit Analysis

A multivariate analysis with a logit regression model allows us to include various indicators in a single adoption model to analyze their combined effect on the likelihood of ZT adoption. For each site we present two different binomial logit models (table 6). The first model reflects the penetration of ZT, using as dependent variable whether the household ever used ZT. The second model reflects the current use of ZT, using as dependent variable whether the household used ZT in the survey year (2003-04). The contrasts between the two models highlight some of the factors particularly associated with dis-adoption.

In Haryana, the binomial logit models reiterate that ZT adoption is closely associated with ZT promotion, remoteness, farm size, assets and rice-wheat specialization. Canal irrigation enhanced, and predominantly light soils reduced, the likelihood of trying out the technology, but did not significantly affect the likelihood of its continued use.

In Punjab, the binomial logit models reiterate that ZT adoption is again closely associated with farm size and rice-wheat specialization. ZT promotion, having more physical assets and not belonging to the prevailing caste, played an important role in trying out ZT, but less so in continuing with its use. Conversely, predominantly light soils reduced the likelihood of continued ZT use. The negative role of light soils in both models likely reflects that these soils would be easier to plow and so the potential time saving of ZT is less important since turnaround time would already be fast (Hobbs pers. comm. 2007, Ithaca).

Characteristics of farm households therefore contribute significantly to the explanation of the observed adoption and dis-adoption patterns, given that the explanatory power of the adoption models could be enhanced by including other variables at the household, community or regional level. For instance, our models do not adequately capture some features of the ZT innovation process, such as local ZT champions and the functioning (or absence) of ZT service providers. In the end though, adoption and dis-adoption can be expected to reflect the underlying performance of the technology in the farmers' fields, an issue we explore in the next chapter.

TABLE 6.
Factors affecting ZT use in Haryana and Punjab (four binomial logit models, normalized on nonuse of technology).

	Haryana		Punjab	
Independent variable	Model 1: ZT use ever	Model 2: ZT use 2003-04	Model 1: ZT use ever	Model 2: ZT use 2003-04
Constant	-4.00 (0.92)***	-5.31 (0.97)***	-2.77 (0.74)***	-2.17 (0.84)**
Distance to district headquarters (km)	0.036 (0.012) ***	0.035 (0.012) ***	-0.0039 (0.0083)	-0.016 (0.010)
ZT promotion in district (dummy)	1.64 (0.34)***	0.97 (0.33)***	0.63 (0.34)*	0.46 (0.39)
Farm size (ha)	0.065 (0.022) ***	0.046 (0.019)**	0.040 (0.015) ***	0.041 (0.014) ***
Primarily light soils (dummy)	-0.42 (0.24)*	-0.17 (0.24)	-0.37 (0.22)	-0.65 (0.27)**
Share operational area with canal irrigation	0.64 (0.27)**	0.36 (0.27)	0.35 (0.23)	0.086 (0.273)
Asset index	1.55(0.71)**	1.64 (0.74)**	1.53 (0.72)**	0.92 (0.81)
Any formal credit source (dummy)	-0.22 (0.27)	-0.28 (0.27)	0.40 (0.26)	0.0067 (0.3096)
Age of household head	-0.0058 (0.010)	0.0064 (0.011)	-0.011 (0.008)	-0.015 (0.010)
Education index for household head	-0.024(0.13)	0.033 (0.13)	0.16 (0.12)	0.16 (0.14)
Family size	-0.017 (0.024)	-0.0072 (0.0251)	0.015 (0.020)	0.0052 (0.021)
Household belongs to main caste (dummy)	0.32 (0.24)	0.0013 (0.2487)	-0.48 (0.24)*	-0.29 (0.29)
Number of organizational memberships	0.22 (0.22)	0.084 (0.213)	0.051 (0.296)	0.18 (0.30)
Rice-wheat specialization index	1.16 (0.54)**	2.38 (0.60)***	1.21 (0.46)***	0.93 (0.55)*
Model parameters				
Cases predicted correctly	67%	71%	73%	82%
Log-likelihood	-234	-225	-248	-224
Chi-squared	82	66	85	58
Degrees of freedom	13	13	13	13
Significance level	.000	.000	.000	.000
Valid cases	400	400	457	457

Note: Standard errors are in parenthesis. *** significant at 1%; ** significant at 5%; * significant at 10%.

Technical Impacts of ZT Technology

On-station and on-farm trials with ZT wheat in the rice-wheat systems of the IGP have shown primarily positive impacts on wheat-crop management, particularly through reduced input needs combined with potential yield increases (Hobbs and Gupta 2003b; Laxmi et al. 2007; Malik et al. 2002a; Malik et al. 2005a). At the same time, no major carryover effects on the subsequent rice are reported (Inayatullah et al. 1989; Srivastava et al. 2005). This chapter presents the technical impacts of ZT technology in farmers' fields, by synthesizing survey results of how the farmers' use of ZT has reportedly affected crop management and productivity of the rice-wheat system. In doing so, we will primarily contrast the ZT fields and CT fields on adopter farms in the two study sites. The detailed country studies also present the information for the CT fields of non-adopters and dis-adopters (Erenstein et al. 2007a; Farooq et al. 2007). The previous chapter has highlighted significant differences at the household level that helped explain the dis-adoption decision, but these were also found to significantly influence crop management practices, yields and water productivity (Erenstein et al. 2007a; Farooq et al. 2007). Adopters and dis-adopters may have adapted their "conventional" crop management practices after having used ZT. However, contrasting our "conventional" data with earlier diagnostic studies (Byerlee et al. 1984; Harrington et al. 1993) suggests that this is not the case. Furthermore, in the absence of a real baseline, we cannot unambiguously establish causality. Partial ZT adoption prevails and thereby enables us to limit ourselves to adopter farms, but this may also introduce a new bias. Partial adopters have purposively chosen to apply ZT to one field and CT to another in the survey year. Typically, such choice is influenced by a number of considerations and field characteristics. For instance, a partial adopter may be using ZT on relatively less-productive soils and CT on better ones because ZT is still under evaluation in the early adoption phase and/or CT performs poorly there. Although we cannot test or control for all such considerations, the available data at least show no significant difference in terms of soil type between ZT and CT plots on adopter farms. We therefore prefer to err on the safe side and assume that the comparison between the ZT plots and CT plots of adopters is the least-biased assessment of ZT's impact. The first section of this chapter synthesizes the effects on the wheat crop. The second section synthesizes the carryover effects on the rice crop. The third section sums up.

Wheat Crop

The CT wheat establishment practice in both Haryana and Punjab involves intensive tractor tillage and broadcasting of wheat. ZT drastically reduces tractor operations in farmers' ZT wheat fields from an average of eight passes to a single pass, implying a per ha saving of 6 and 7 tractor hours and 36 and 35 liters of diesel in Haryana and Punjab, respectively (table 7).

Earlier diagnostic studies reported an average of six tillage operations in Punjab (ranging from 2 to 10; Byerlee et al. 1984) and eight tillage operations in Haryana (4-8 on lighter soils and 8-12 on heavier soils; Harrington et al. 1993), followed by another tractor cultivation after broadcasting. Our study highlights that the current CT practices do not deviate much from the earlier studies. It was only in Haryana that mechanized sowing had gained ground, being now reported in 32 percent of CT fields, whereas broadcasting still prevailed in Punjab. The total number of tillage operations in CT wheat plots (including any cultivation to cover broadcast seed) also did not vary between the two study areas (8.2 in Haryana and 8.1 in Punjab), soil types or adopter categories. Therefore, contrary to expectations, the diffusion of ZT has, so far, not resulted in any reduction in "conventional" tillage intensity.

The ZT-induced time savings in land preparation did not translate into a timelier

TABLE 7.
Selected wheat management indicators for ZT and conventional plots on adopter farms in Haryana and Punjab study sites.

	Haryana		Punjab	
	ZT (n=138)	Conventional (n=99)	ZT (n=87)	Conventional (n=67)
Total no. of tillage operations (no./season)	1.00a	8.02b	1.00x	7.99y
Duration of tillage operations (tractor hours/ha)	2.22 a	8.19 b	2.39x	9.32y
Diesel consumption for tillage operations (l/ha)	12.1 a	48.0 b	7.2x	42.0y
Planting date	Nov.10	Nov.12	Nov.27	Nov.24
Seed rate (kg/ha)	109	110	119	119
Total nutrients (kg NPK/ha)	256	247	174	179
Number of weed controls (no. of applications/season)	0.98	0.97	0.76	0.84
Number of irrigations (no./season)	3.23	3.27	3.25	3.33
Duration of irrigations (hours/ha)	33.8	36.6	23.4	26.6
Estimated irrigation water use (m^3/ha)	1,830	1,970	2,480	2,760
Crop duration (days)	148	147	153	155
Manual harvesting (% reporting)	28	32	33x	52y
Burning of crop residues (% reporting)	12	12	59	51

Note: Data followed by different letters differ significantly – T-test (.10), within row comparison per site.

establishment, with insignificant differences in planting dates between ZT and CT in both Haryana and Punjab (table 7). This is contrary to expectations, but a similar finding was reported in another study (Tahir and Younas 2004). Ownership of a tractor did significantly advance the wheat-sowing date in both sites, albeit with only 2 days. It was only in Punjab that the ownership of a ZT drill significantly advanced the sowing date for ZT plots by 8 days, suggesting that reliance on ZT service providers delays wheat establishment. The type of preceding rice crop proved rather influential in Haryana, where the average wheat planting date varied significantly depending on the farms' rice specialization: for superfine rice it was 9 November; for evolved basmati 13 November; and for traditional basmati, 15 November (p=0.00, n=474).

The use of the ZT drill is potentially seed-saving compared to broadcasting, without any yield loss. It is also potentially fertilizer-saving, particularly using the ZT seed-cum-fertilizer drill which places the basal fertilizer in the planted row at the time of planting. Yet, ZT was not observed to have any significant effect on seed rate or chemical fertilizer use in either site. Similarly, no effect on weed and pest management was apparent (table 7).

In Haryana, ZT achieved the highest wheat yields in the survey year (4.4 metric tons per hectare [mt/ha]), a significant 4.0 percent yield increase over CT (4.2 mt/ha, table 8). However, in Punjab, ZT did not have a significant effect on the mean farmer-estimated wheat yield of 3.3 mt/ha. A positive yield effect of ZT is often associated with more timely wheat establishment in view of the terminal heat stress for late planted wheat in South Asia (Hobbs and Gupta 2003a; Laxmi et al. 2007). Both sites indeed highlight a significant and similar negative correlation between wheat yield and sowing date in surveyed

TABLE 8.
Selected wheat productivity indicators for ZT and conventional plots on adopter farms in Haryana and Punjab study sites.

	Haryana		Punjab	
	ZT (n=138)	Conventional (n=99)	ZT (n=87)	Conventional (n=67)
Grain yield (tons/ha)	4.38b	4.21a	3.24	3.36
Irrigation water productivity				
- ton/irrigation	1.43	1.35	1.07	1.07
- kg/irrigation m^3	3.11b	2.65a	1.67	1.47
Gross water productivity (kg/m^3 (rain + irrigation))	1.76b	1.59a	1.02	0.97

Note: Data followed by different letters differ significantly – t-test (.10), within row comparison per site.

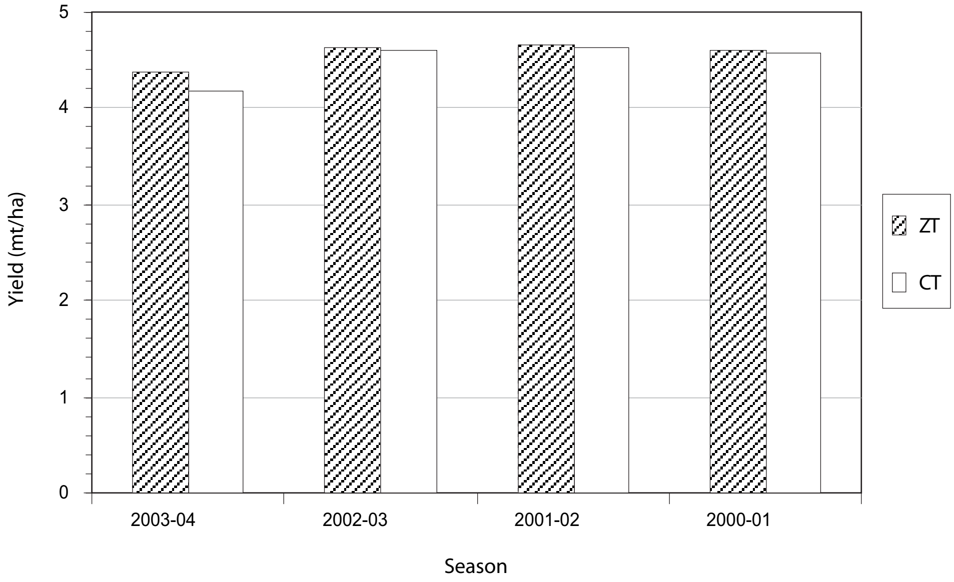
plots (Julian day number, correlation coefficient: -0.15, prob. 0.00). Wheat plots established before November 16 yielded significantly more (200 kg/ha) compared to plots established thereafter in both sites. However, as mentioned above, although ZT reduces turnaround time, there was no significant difference in terms of time of wheat establishment between ZT and CT plots in the survey year. This suggests that farmers have generally been reluctant to significantly advance their wheat planting date despite apparently increased opportunities to do so with ZT. In Punjab, wheat grown on (sandy) loam or well-drained soils also yielded significantly more (200 kg/ha) compared to heavier or poorly drained soils in the survey year, but no significant interaction with ZT was apparent. A separate study in Punjab also reports a mixed wheat yield effect of ZT, with 54 percent of farmers reporting a yield increase, 30 percent a decrease and 16 percent no change (Ahmad et al. 2007).

To put the survey year in perspective, wheat yields under ZT and CT on surveyed farms were also compiled for previous seasons. The recall data for the three preceding years do not show significant differences in ZT and CT yields in both sites (figure 8). In Haryana, average wheat yields in the preceding years were significantly higher than in the survey year. This suggests that ZT plots in Haryana were less susceptible to yield loss in the survey year, contributing to the observed yield advantage over CT, possibly through better soil-moisture conservation. The survey year indeed was relatively dry and had above-average maximum temperatures in both March and April (more than 10 ºC over a 30-year average; Central Soil Salinity Research Institute, Karnal, unpublished data), which adversely affected wheat yields. The general lack of a yield increase largely reflects the fact that the ZT-induced time savings in land preparation did not translate into timelier establishment. The overall late wheat establishment in Punjab likely contributed to the lack of a yield-effect, as the relative performance of ZT tends to be better in timely sown wheat (Malik et al. 2002a). The lack of a significant yield effect has undermined widespread ZT acceptance and is a major factor explaining dis-adoption in Punjab. Without a yield benefit, the immediate payoff to ZT is reduced to its cost-saving potential, primarily for land preparation and establishment.

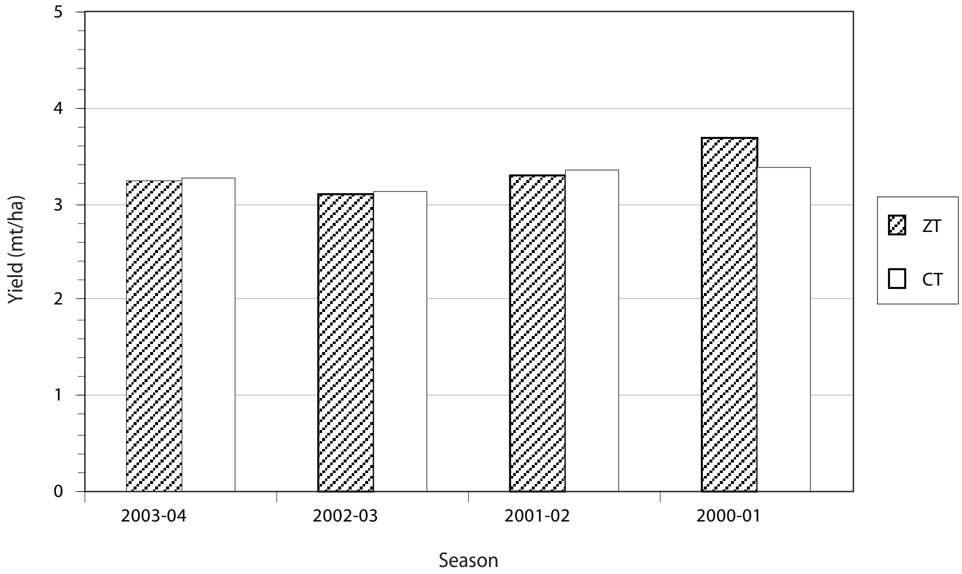
The water use indicators from the adoption survey for ZT and CT wheat were generally not significantly different in both sites. ZT did reduce the duration of the first tube-well irrigation in both sites, which is associated with irrigation water flowing faster over untilled fields. Consequently, generally less irrigation water is applied to ZT during the first irrigation. This is generally beneficial as, in tilled fields, often too much water is applied to parts of the field resulting in

FIGURE 8.
Reported wheat yields (mt/ha) under ZT and CT for current and previous seasons; adoption survey, farmer recall: (a) Haryana; (b) Punjab.

(a)



(b)



Note: Nonzero values only. For 2003-04, 2002-03, 2001-02 and 2000-01 seasons, respective number of ZT - CT farms: n = 138-361, 108-359, 60-375 and 22-296 in Haryana and n = 87-451, 66-162, 37-94 and 18-38 in Punjab.

waterlogging and yellowing of wheat plants. However, in neither site did ZT have any significant effect on the total number of irrigations (3.4/season), duration of subsequent and total irrigations and the estimated irrigation volume (table 7). The higher yield in combination with the limited water savings still results in significantly higher water productivity indicators for ZT wheat compared to CT wheat in Haryana (table 8). The relatively similar yields in the survey year, combined with the relatively modest irrigation savings by ZT, imply that water productivity indicators are generally not significantly different from CT in Punjab (table 8).

The results therefore provide some support to the postulated water saving nature of ZT. Still one should realize that the results presented here relate to survey findings, which are subject to farmer recall and where we cannot control for all underlying sources of variation. These confounding effects may mask some of the ZT technology effects, if any. A separate water use survey conducted within the context of the Haryana study indeed showed more significant water savings attributable to ZT than those observed in the adoption survey (Erenstein et al. 2007a).This survey confirmed that ZT for wheat saves irrigation time (6.4 hours/ha/season), saves irrigation water (340 m^3/ha/season) and enhances wheat yield (260 kg/ha), but ZT again did not significantly reduce the number of irrigations. According to the same survey, total tube-well water volume applied to ZT amounted to 2,200 m^3 compared to 2,500 m^3 for CT, a statistically significant water saving of 13.4 percent which was primarily achieved in the first irrigation. This implied significantly higher water productivity indicators for ZT wheat (1.5 kg/gross m^3) compared to CT wheat (1.3 kg/gross m^3, p.:0.00) in Haryana.

The discussion so far focused on the specific contrast between ZT and CT in the two study sites. The available data however also highlight some similarities and contrasts between the two sites. On average, across all surveyed plots, Haryana and Punjab reported relatively similar wheat management practices, for instance in terms of CT practices, weedings (1.0 weeding and 0.9 weedings, respectively, typically a herbicide application) and seed rate (109 and 117 kg/ha of seed, respectively). Wheat establishment is timelier in Haryana (12 November on average) than in Punjab (26 November). However, chemical fertilizer use is significantly higher in Haryana (246 kg/ha of fertilizer-nutrients, 187:58:1 against 179 kg/ha of fertilizer-nutrients, 115:61:1). Manual harvesting was less common in Haryana (43% of plots, remainder combined) than in Punjab (52% of plots, remainder combined and reaped). Compared to Punjab, wheat straw removal in Haryana was more widespread (reported as 74% against 98% plots, respectively) and burning of wheat residues was less common (45% against 11%, respectively). The survey results also flag the risky prevalence of one single wheat variety in each area, with PBW 343 being reported in 89 percent of the wheat plots in Haryana and Inqalab-91 being reported in 69 percent of plots in Punjab. The prevalence of a single variety over large areas is worrying in view of the underlying risk from any resistance breakdown. This has become even more pressing in view of their susceptibility to, and advent of, the virulent new stem rust for wheat (UG99, Mackenzie 2007; Raloff 2005).

Mean farmer-estimated wheat yields (all surveyed plots) in Haryana (4.2 mt/ha) are substantially higher than in Punjab (3.3 mt/ha), a differential that is likely associated with the later wheat establishment and lower fertilizer use in Punjab and agro-ecological differences. Across all surveyed plots, water productivity was estimated to average 2.5 kg of wheat per irrigation m^3 and 1.5 kg of wheat per gross m^3 in Haryana, whereas the same indicators for Punjab were 1.5 kg and 1.0 kg of wheat, respectively. The lower water productivity in Punjab is the combined result of lower wheat yields and larger water input.

Rice Crop

The prevailing practice in both Haryana and Punjab is to transplant rice in puddled fields and keep the fields ponded. ZT wheat did not have any significant spillover effect in terms of affecting crop management, yield and water productivity of subsequent rice crop in both Haryana and Punjab. Most significant differences between surveyed rice plots reflect structural differences between adopters and non-adopters (Erenstein et al. 2007a; Farooq et al. 2007). Actual differences between rice plots after ZT wheat and rice plots after CT wheat for adopters were typically not significant (table 9; table 10). One exception was the above-average pesticide use in rice after ZT wheat plots in Punjab (applied to 92% of ZT plots compared to 83% of CT plots).

Surveyed rice crop management indicators for Haryana and Punjab (all surveyed plots) included:

- Tillage operations (average of 5.3 and 9.1/ season in Haryana and Punjab, respectively).
- Seed rate (11 and 8.8 kg/ha of seed, respectively).
- Chemical fertilizer use (204 kg/ha of fertilizer-nutrients, 156:44:4 and 132 kg/ha, 98:34:0, respectively).
- Weed management (1.7 and 0.9 weedings, respectively).
- Pesticide use (89% and 83% of plots, respectively).
- Irrigation (34 and 35 irrigations/season, respectively).
- Harvesting practices (62% and 21% manual, respectively).

Various rice-management practices thus differ substantially between Haryana and Punjab. As in the case of wheat, Haryana has a substantially higher chemical fertilizer use. Tillage for rice is markedly more intensive for Punjab, whereas Haryana tends to do more weedings. In both sites, chemical weed control is the dominant method, but in Haryana this is often supplemented by a manual weed control.

In Haryana, three groups of high-quality rice varieties were reported in the surveyed rice plots: superfine rice varieties (46.5% of plots), evolved basmati (30.2%) and traditional basmati (23.2%). Superfine rice is of shorter duration (117 days after transplanting vs. 123 days for both varieties of basmati) and is transplanted earlier, thereby vacating the field 3 weeks earlier than traditional basmati. These varietal groups had a marked effect on rice-management practices (e.g., nutrient, water, harvest; Erenstein et al. 2007a). Superfine rice is also higher yielding (5.9 mt/ha) than evolved basmati (4.5 mt/ha) or traditional basmati (2.6 mt/ha) and has the highest physical water productivity (0.5 kg/ irrigation m^3 and 0.3 kg/gross m^3). In Punjab, super basmati is the prevailing rice variety reported in 88 percent of plots and has a similar yield as the other basmati varieties being reported for the remaining plots. Super basmati is late maturing (130 days after transplanting vs. 123 days for other varieties) and is transplanted late, thereby vacating the field nearly 2 weeks later than the other varieties, and thus highly conflicting with optimum wheat sowing. ZT potentially reduces the turnaround time between rice and wheat. One might thus expect a positive association between rice varieties that vacate the field late and the use of ZT wheat. However, no significant association was found, except for traditional basmati being less commonly cultivated by dis-adopters in Haryana (which may thus have reduced the need to continue with ZT).

Harvesting rice mechanically with a combine harvester is markedly more common in Punjab (79% of plots) than in Haryana (38%) in the survey year. This is associated with the rice varieties being grown. In Haryana, superfine rice is predominantly combine harvested (82% of plots), whereas the basmati varieties were universally hand-harvested for a number of reasons, including the tendency of its long grains to break, being more prone to lodging (reducing the effectiveness of mechanical harvesting), smaller field sizes and more intensive residue use (Erenstein et al. 2007d). In Punjab, super basmati is typically combine harvested (81%) whereas this is less common for the other basmati varieties (55%). The popularity of combine harvesting of rice in Punjab is also associated with the larger farm size, limited turnaround time between rice and wheat and the

TABLE 9.
Selected rice management indicators for ZT and conventional plots on adopter farms in Haryana and Punjab study sites.

	Haryana		Punjab	
	Rice after ZT wheat	Rice after conventional wheat	Rice after ZT wheat	Rice after conventional wheat
	(n=76	(n=107)	(n=60)	(n=71)
Total no. of tillage operations (no./season)	5.25	5.20	9.00	9.04
Duration of tillage operations (tractor hours/ha)	7.61	7.63	16.2	15.5
Diesel consumption for tillage operations (l/ha)	46.1	46.4	66.3	66.7
Transplanting date	June 24	June 21	July 7	July 6
Seed rate (kg/ha)	11.0	10.9	8.70	8.86
Total nutrients (kg NPK/ha)	193	209	137	137
Number of weed controls (no. of applications/season)	1.78	1.67	0.97	0.87
Pesticide/fungicide use (% reporting)	96	94	92	83
Number of irrigations (no./ season)	31.8	33.2	33.8	34.3
Duration of irrigations (hours/ha)	275 [a]	311 [b]	163	142
Estimated irrigation water use (m^3/ha)	14,500	16,100	17,000	15,100
Crop duration (days)	121	121	127	128
Manual harvesting (% reporting)	53	55	8	17
Burning of crop residues (% reporting)	39	46	73	65

Note: Data followed by different letters differ significantly – t-test (.10), within row comparison per site.

TABLE 10.
Selected paddy productivity indicators for ZT and conventional plots on adopter farms in Haryana and Punjab study sites.

	Haryana		Punjab	
	Rice after ZT wheat (n=76)	Rice after conventional wheat (n=107)	Rice after ZT wheat (n=60)	Rice after conventional wheat (n=71)
Grain yield (tons/ha)	4.68	4.97	3.62	3.59
Irrigation water productivity				
- kg/irrigation	161	157	121	113
- kg/m^3	0.40	0.40	0.28	0.32
Gross water productivity (kg/m^3)	0.26	0.27	0.23	0.24

Note: Differences within site not statistically significant – t-test (.10).

fact that mean rice harvesting date is 3 weeks later than in Haryana. The latter is the combined effect of later rice transplanting (12 days: 6 July vs. 24 June in Punjab and Haryana, respectively) and longer duration of the rice crop (9 days: 129 vs. 120 days in Punjab and Haryana, respectively). Combine harvesting has implications for ZT. The loose residues left by the combiner hamper the operation of the prevailing ZT drills and are typically removed or burned. Untimely rain prior to rice harvesting may also cause combiners to cause ruts in the fields that need to be evened out through tillage. Compared to Punjab, in Haryana the removal of rice straw from the field was less common (reported in 84% against 58% plots, respectively) and rice straw burning was relatively similar (56% against 47%, respectively).

The differential management practices, varieties and overall agro-ecology contribute to the mean farmer-estimated paddy yields (all surveyed plots) in Haryana (4.7 mt/ha) again being substantially higher than in Punjab (3.5 mt/ha). Water productivity was estimated to average 0.34 kg of paddy per irrigation m^3 and 0.23 kg of paddy per gross m^3 for all surveyed rice plots in Haryana whereas the same indicators for Punjab were 0.28 kg and 0.22 kg of paddy, respectively. The lower water productivity in Punjab is primarily a reflection of the lower paddy yields, as estimated water input was relatively similar (table 9).

Water productivity indicators for rice is markedly lower than that for wheat, largely a reflection of significantly higher water inputs in paddy cultivation so as to maintain standing water in the paddies during the hot monsoonal season with relatively similar yields. Rice cultivation practices also differ from wheat in terms of:

- Intensity of land preparation (in Haryana less tractor passes but including wet cultivation; in Punjab one more tractor pass and wet cultivation).
- Fertilization practices (less inorganic fertilizer use and more farmyard manure).
- Pesticide use (near-universal).
- Harvesting practices (less reliance on combine harvesting in Haryana; wider reliance on combine harvesting in Punjab).

In Sum

The underlying studies cannot unambiguously confirm that the generally favorable implications of ZT in terms of enhancing wheat yield and saving water reported in trials are also achieved in farmers' fields. It was only in Haryana that ZT had significant positive effects on yield and water productivity for the wheat crop in the survey year. Both studies concur in that there were no significant effects on yield and water productivity for the subsequent rice crop. Both studies also confirmed the drastic reduction in tractor time and diesel use in wheat land preparation and establishment, which imply substantial cost savings.

Financial Impacts of ZT Technology

The financial implications of a new technology are a major determinant of technological change. The on-station and on-farm trials with ZT wheat in the rice-wheat systems of the IGP do not always include a financial analysis (Laxmi et al. 2007; Malik et al. 2002a; Malik et al. 2005a). But in those where such an analysis was included, results are generally very favorable for ZT due to the combined "yield-enhancement effect" and "cost-saving effect" (e.g., Laxmi et al. 2007; Malik et al. 2005a). Most financial analyses are based on partial budgets, and typically limited to the wheat crop.

The previous chapter reviewed the technical impact of ZT in terms of crop management and productivity for both the wheat crop and the subsequent rice crop. The present chapter puts a monetary value on the observed changes and thereby allows us to aggregate the observed technical impacts and assess the financial impact of ZT at the individual crop and plot levels. The first section of this chapter reviews the ZT effects on the wheat-crop budget. The second section reviews the carryover effects on the rice-crop budget. The third section aggregates the wheat- and rice-crop budget effects to derive the crop-system effects at the plot level.

Wheat Profitability

On an average hectare basis (across all surveyed plots), wheat production implies a gross revenue of $654 and 581, total costs of $619 and 473 and a net revenue of $36 and 108 in Haryana and Punjab, respectively (Erenstein et al. 2007a; Farooq et al. 2007). This implies an average return of 6 percent and 23 percent to production costs, with 68 percent and 81 percent of wheat plots having positive net revenues in Haryana and Punjab, respectively. Although yields and gross revenue are higher in Haryana, this is annulled by the higher production costs resulting in more meager returns to wheat production. The higher production costs in Haryana ($146 difference) are primarily a reflection of the higher land rent ($126 difference). Due to the relatively low net returns in Haryana the average net-revenue-based water productivities thereby amount to only $0.033 per irrigation m^3 and $0.017 per gross m^3, whereas the corresponding values for Punjab are $0.069 and 0.044, respectively.

ZT plots in Haryana show significantly lower total costs and significantly higher gross and net revenues. Compared to the CT plots of adopters, ZT shows a conclusive net advantage of $69 per ha in the survey year, composed of a "yield effect" of $26 and a "cost saving effect" of $43 (table 11). The ZT-induced cost saving is substantial, and represents a saving of 7.0 percent on total costs, or 15.3 percent on operational costs (excluding land). The relatively minor net revenues derived from wheat cultivation underscore the need for continued yield enhancement and cost savings to maintain wheat competitiveness in rice-wheat systems. It also highlights the relative significance of the ZT-induced income enhancement, which boosts returns well above breakeven. Indeed, 92 percent of ZT plots had positive net revenues. ZT plots thereby achieved a significantly higher return on production costs (17%) and significantly higher estimates for net-revenue-based water productivities ($0.08/ irrigation m^3 and $0.042/ gross m^3 - table 12). The combination of a significant "yield effect" and "cost saving effect" makes ZT adoption worthwhile and is the main driver behind the rapid spread and widespread acceptance of ZT in Haryana.

The difference between ZT and CT plots in Punjab is less pronounced and therefore less conclusive. Gross revenue does not significantly differ between wheat plots, but compared to non-adopters and dis-adopters, adopters achieved significantly lower total costs and higher net revenues in both their ZT and CT plots. Compared to the CT plots of adopters, ZT does imply a significant cost-saving effect of $45 per ha, but this was partially annulled by a nonsignificant negative yield effect of $20,

TABLE 11.
Crop budget ($/ha) for ZT and conventional wheat on adopter farms in Haryana and Punjab study sites.

	Haryana		Punjab	
	ZT (n=138)	Conventional (n=98)	ZT (n=87)	Conventional (n=67)
A. Gross revenue	671 ^{b}	645 ^{a}	578	598
- Grain	607 ^{b}	581 ^{a}	507	525
- Straw	64	64	71	73
B. Total cost	576 ^{a}	619 ^{b}	428 ^{x}	473 ^{y}
B1. Land preparation	0 ^{a}	51 ^{b}	0 ^{x}	49 ^{y}
B2. Crop establishment	41 ^{b}	28 ^{a}	44 ^{y}	24 ^{x}
Subtotal B1+B2	41 ^{a}	79 ^{b}	44 ^{x}	72 ^{y}
B3. Fertilizer cost	67	64	72	74
B4. Plant protection cost	37	36	10	11
B5. Irrigation cost	14	15	20	21
B6. Harvesting expenditures	62	65	64 ^{x}	73 ^{y}
B7. Land rent	308	308	182	182
B8. Interest on capital invested	48 ^{a}	51 ^{b}	35 ^{x}	39 ^{y}
C. Net revenue (A – B)	95 ^{b}	26 ^{a}	151	125
% plots with positive NR	92	67	85	84
Benefit:cost (ratio) (A/B)	1.17 ^{b}	1.05 ^{a}	1.37 ^{y}	1.27 ^{x}
Production cost ($/kg)	0.13 ^{a}	0.15 ^{b}	0.14	0.15

Note: Data followed by different letters differ significantly – T-test (.10), within row comparison per site. Some (sub)totals do not exactly add up due to rounding.

resulting in a nonsignificant advantage of $25 for ZT in terms of net revenue (table 11). The ZT-induced cost saving is again substantial, and represents a saving of 9.5 percent on total costs, or 16.4 percent on operational costs (excluding land). ZT plots thereby achieved a significantly higher return on production costs (a respectable 37%) and significantly higher net-revenue-based water productivities ($0.097/irrigation m^{3} and $0.06/gross m^{3} - table 12). The ZT “costs-saving effect” seems robust enough to make adoption worthwhile and is the driver behind the prior spread of ZT amongst adopters in Punjab. However, learning costs eat into the costs-saving effect and may undermine the apparent returns to adoption for prospective adopters, particularly in view of the lack of a positive yield effect.

Rice Profitability

On an average hectare basis (across all surveyed plots), rice production implies a gross revenue of $849 and 804, total costs of $757 and 563 and a net revenue of $92 and 241 in Haryana and Punjab, respectively (Erenstein et al. 2007a; Farooq et al. 2007). This implies an average return of 13 percent and 46 percent to production costs, with 67 percent and 91 percent of rice plots having positive net revenue in Haryana and Punjab, respectively. Although paddy yields and gross revenue were again higher in Haryana, this was annulled by the higher production costs resulting in lower returns to paddy production. The higher production costs in Haryana ($194 difference) are again primarily a reflection of the higher land rent ($126 difference). The net-revenue-based water

TABLE 12.
Financial (net revenue) water productivity indicators for ZT and conventional wheat on adopter farms in Haryana and Punjab study sites.

	Haryana		Punjab	
	ZT (n=138)	Conventional (n=98)	ZT (n=87)	Conventional (n=67)
- \$/irrigation	31 ^{b}	8 ^{a}	59	51
- \$ cents/irrigation m^3	8.0 ^{b}	2.3 ^{a}	9.7 ^{y}	7.3 ^{x}
- \$ cents/gross m^3 (rain + irrigation)	4.2 ^{b}	1.3 ^{a}	6.0 ^{y}	4.8 ^{x}

Data followed by different letters differ significantly – t-test (.10), within row comparison per site.

productivities amounted to \$0.008 and 0.025 per irrigation m^3 and \$0.005 and 0.02 per gross m^3 in Haryana and Punjab, respectively. The large differences in water productivities in the two sites are primarily a reflection of the difference in net revenue, as estimated water input was relatively similar. Compared to wheat, financial water productivity is lower for paddy, the higher net revenues for rice being more than annulled by the higher water inputs.

Prior ZT wheat does not significantly affect gross revenue, production cost, net revenue or financial water productivity of the subsequent rice crop in either Haryana or Punjab (table 13; table 14). In Haryana, the type of rice variety had a significantly more pronounced effect on the

TABLE 13.
Crop budget (\$/ha) for paddy crop after ZT and conventional wheat on adopter farms in Haryana and Punjab study sites.

	Haryana		Punjab	
	Rice after ZT wheat (n=76)	Rice after conventional wheat (n=107)	Rice after ZT wheat (n=60)	Rice after conventional wheat (n=71)
A. Gross revenue	817	852	829	826
- Grain	806	840	785	780
- Straw	10	12	44	46
B. Total cost	720	743	564	551
B1. Land preparation	48	48	66	67
B2. Crop establishment	26	25	21^x	23 ^{y}
Subtotal B1+B2	74	74	87	89
B3. Fertilizer cost	56	59	54	55
B4. Plant protection cost	67	63	24	23
B5. Irrigation cost	111^a	132^b	125	111
B6. Harvesting expenditures	44	46	45	46
B7. Land rent	308	308	182	182
B8. Interest on capital invested	59	61	47	46
C. Net revenue [A-B]	96	110	265	275
Plots with positive NR (%)	68	76	95	94
Benefit:cost (ratio) [A/B]	1.15	1.16	1.51	1.54
Production cost (\$/kg)	0.18	0.17	0.16	0.16

Note: Data followed by different letters differ significantly – t-test (.10), within row comparison per site. Some (sub)totals do not exactly add up due to rounding.

TABLE 14.
Financial (net revenue) water productivity indicators for paddy crop after ZT and conventional wheat on adopter farms in Haryana and Punjab study sites.

	Haryana		Punjab	
	Rice after ZT wheat (n=76)	Rice after conventional wheat (n=107)	Rice after ZT wheat (n=60)	Rice after conventional wheat| (n=71)
$/irrigation	3	4	11	10
$ cents/irrigation m^3	0.9	1.1	2.8	3.3
$ cents/gross m^3 (rain + irrigation)	0.6	0.7	2.2	2.4

Note: Differences within site not statistically significant – t-test (.10).

performance indicators than the preceding wheat crop. Compared to superfine rice and traditional basmati, evolved basmati typically achieved the most favorable performance indicators in Haryana.

Rice-Wheat System Profitability

The relative performance at the aggregate rice-wheat system level primarily mirrors the ZT effects on wheat performance, although the effects tend to be more subdued. In the case of Haryana, the higher wheat gross revenue with ZT was annulled by the nonsignificant variation in paddy gross revenue. In both Haryana and Punjab, the significant ZT-induced cost saving was maintained (table 15). For the other indicators, ZT and CT plots of adopters typically tend to outperform non-adopters and dis-adopters, but did not differ significantly from each other on adopter farms in both sites. This also applies to the financial water productivity indicators at the system level (table 16). We can therefore conclude that financial ZT effects are

TABLE 15.
System-level profitability indicators ($/ha/year) by ZT and conventional (CT) wheat use on adopter farms in Haryana and Punjab study sites (paddy + wheat – aggregation before averaging).

	Haryana		Punjab	
	ZT wheat + CT rice (n=76)	CT wheat + CT rice (n=86)	ZT wheat + CT rice (n=59)	CT wheat + CT rice (n=57)
Gross revenue	1,486	1,499	1,406	1,436
- rice crop	817	859	826	829
- wheat crop	670 ^{b}	640 ^{a}	580	607
Total costs:	1,297 ^{a}	1,358 ^{b}	986 ^{x}	1,032 ^{y}
- rice crop	720	740	562	558
- wheat crop	577 ^{a}	618 ^{b}	423 ^{x}	474 ^{y}
Net revenue	189	141	420	403
- rice crop	96	119	264	270
- wheat crop	93 ^{b}	22 ^{a}	157	133
Benefit:cost (ratio)	1.15	1.11	1.44	1.40

Note: Data followed by different letters differ significantly – Duncan (.10), within row comparison per site.

limited to the wheat crop, with no significant positive or negative carryover effects for the rice-wheat system as a whole. For significant improvements at the system level we would need to alter the way rice is grown to dry direct-seeded rice and start retaining crop residues as mulch. As long as the rice crop remains puddled, the ZT gains for wheat remain purely seasonal with no cumulative gains in terms of enhanced soil productivity and water productivity at the cropping-system level.

TABLE 16.
System-level financial (net revenue) water productivity indicators by ZT and conventional (CT) wheat use on adopter farms in Haryana and Punjab study sites (paddy + wheat – aggregation before averaging).

	Haryana		Punjab	
	ZT wheat + CT rice (n=76)	CT wheat + CT rice (n=86)	ZT wheat + CT rice (n=59)	CT wheat + CT rice (n=57)
$/irrigation	5.9	4.4	12.6	11.4
$ cents/irrigation m^3	1.7	1.2	2.9	3.3
$ cents/gross m^3 (rain + irrigation)	1.0	0.8	2.3	2.4

Note: Differences within site not statistically significant – t-test (.10).

Farm and Regional Impacts of ZT

The impact of the ZT technology so far was assessed in technical and financial terms at the plot level. Some of the higher system-level implications are discussed in this section. At the first level we assess the farm-level implications of ZT for the adopting farms. At the second level we assess the regional implications of ZT including social and environmental considerations.

Farm-Level Impacts of ZT

In both Haryana and Punjab, adopters and dis-adopters were near-unanimous that they spent less time cultivating wheat after adoption of ZT. The time thus saved was primarily used for other agricultural activities, and to a lesser extent for more leisure time and other nonagricultural activities. Adopters and dis-adopters generally agreed that the adoption of ZT did not reduce the time for cultivating rice. In both Haryana and Punjab, adopters and dis-adopters differed significantly in terms of whether ZT had increased the family's income, with the majority of adopters and only a minority of dis-adopters reporting an increase. It was only in Punjab that the adoption of ZT reportedly increased the family's food consumption, with nearly half the adopters reporting an increase. As there was no significant yield increase linked to the adoption of ZT in Punjab, this may reflect the ZT-induced cost savings and correspondingly higher disposable income being used to enhance family food consumption.

In terms of changes in farming activities, adopters and dis-adopters in both sites reported primarily productivity effects of ZT proper, with most farmers reporting time and cost savings. In the case of Haryana, it is interesting to note that the reporting of the various ZT-related benefits was markedly less pronounced for dis-adopters, which suggests that they typically had less successful experiences with ZT, leading to their dis-adoption with the technology. In the case of Punjab, adopters and dis-adopters largely concurred in terms of the ZT-related benefits. This reiterates that in Punjab, ZT dis-adoption reflected a complex of factors. For some dis-adopters, the yield considerations reported earlier were paramount and thereby nullified time and cost-saving considerations. Other dis-adopters may have had such favorable perceptions, but unable to act upon them in view of problematic access to the ZT drill in the survey year.

This study provides some support to the postulated water-saving nature of ZT wheat at the field scale. The water use survey, particularly in Haryana, showed that ZT for wheat saves irrigation time (6.4 hours/ha/season), saves irrigation water (340 m^3/ha/season) and enhances wheat yield (260 kg/ha). The absence of any reported significant change in farm activities or area cultivated in both sites suggests that these water savings generally did not lead to an immediate alternative use of the water saved on the farm. Instead, the reduced water applications at the field scale seem to have primarily saved irrigation time and irrigation cost and reduced groundwater extraction for the ZT wheat crop compared to the CT wheat crop. A different study in the Punjab rice-wheat area reported that the water savings from resource-conserving technologies actually increased water demand and groundwater depletion through expansion in cropped area on medium- and large-scale farms (Ahmad et al. 2007). In Haryana, any significant area expansion was unlikely, as rabi fallow is uncommon (only 1.8% of households reported some rabi fallow, with an average 99% of the operational area being cultivated during the rabi season). In Punjab, rabi fallow is more common (18% of households reported some rabi fallow, averaging 0.35 ha/household) and was found to be positively associated with ZT adoption. Part of the incentive to adopt ZT in Punjab may have thus been the potential of ZT to increase the area cultivated in rabi – although we cannot unambiguously make this assertion based on the available data. In any case, the eventual increase in area due to ZT may still be limited by the overall limited fallow area even in Punjab (with an average 97% of the operational area already being cultivated during the rabi season).

In both Haryana and Punjab, adopters typically have a more favorable resource base and tended to variously outperform non-adopters and dis-adopters, irrespective of their use of ZT. The carryover effects on the rice crop were typically insignificant, although their inclusion tended to dampen the significance of the observed effects at the system level. The present section therefore limits itself to scaling up of the observed significant effects between the adopters' ZT plots and CT plots for the wheat crop.

With an average ZT wheat area of 5.0 and 8.3 ha per household in Haryana and Punjab, respectively, ZT adopters save an average of 180 and 288 liters of diesel, 30 and 57 tractor hours and $210 and 374 per season at the farm level, respectively. In Haryana, ZT adopters also gain 0.9 mt of wheat grain per season at the farm level. This implies an increase of $132 in gross return that, combined with the cost saving, results in an increase of $342 in net revenue in Haryana.

Most ZT-adopting households have postponed the investment decision to buy a ZT drill with the majority of adopters (60% and 74% in Haryana and Punjab, respectively) being service-provider dependent in the survey year. Rental markets make the ZT drill divisible and therefore accessible irrespective of farm size, but do imply increased dependence on timely and effective service delivery. The lack or untimely availability of drills and the high drill cost, particularly in Punjab, have been raised as issues limiting ZT diffusion (Jehangir et al. 2007; Tahir and Younas 2004). To put the investment in a ZT drill in perspective, we have estimated the ZT drill investment recovery indicator – the number of wheat seasons needed to recap the investment. The cost saving alone implies the average ZT adopter would recover the ZT drill purchase within 1.9 and 1.5 wheat seasons in Haryana and Punjab, respectively. In the case where ZT adopters extended ZT to their whole wheat area (i.e., an additional wheat area of 4.0 and 5.8 ha/household, respectively), they could recover a ZTD investment within 1.0 and 0.9 wheat seasons. Adding the yield gain, the ZTD investment recovery in Haryana would be in 1.2 wheat seasons on current ZT area alone and 0.6 seasons in case ZT is extended to the whole wheat area. Providing ZT drill rental services would further shorten the time needed to recap the investment. This suggests that the ZT drill investment cost is not prohibitive for an average ZT adopter already owning a tractor.

ZT adopters have the largest farms and wheat areas and therefore potentially benefit most on an aggregate-household basis from a cost-saving technology such as ZT (table 4). In both Haryana and Punjab, the average dis-adopter household could conceivably recover a ZT drill investment within 1.7 wheat seasons based on cost savings alone. The average non-adopter household could conceivably recover a ZT drill investment within 1.9 and 3.1 wheat seasons, respectively. Tractor ownership was also least common amongst non-adopters (table 4). This highlights that the investment in a ZT drill is typically less attractive for the dis-adopters and particularly for non-adopters compared to adopters, unless they would be able to benefit from providing significant ZT drill rental services.

The diesel and tractor time savings are major contributors to the ZT-induced cost savings and apply to tractor-owning and tractor-hiring households alike. Indeed, the tractor time saving is beneficial to tractor-owning households through both extended tractor lifetime and alternative use, tractors being variously used and in much demand. The alternative tractor uses are particularly important for the income security of tractor-service providers, as an eventual increase in income from ZT services is likely to be offset by a more than proportional decrease in traditional tillage services.

In both sites, ZT wheat had limited effects on the subsequent rice crop in the same field. ZT wheat also seems to have had few discernible effects on other farm activities of the household, including other crops, livestock and nonfarm activities. Livestock are dependent on the wheat and rice residues, but ZT wheat has so far had limited implications for crop-residue management. This reflects the prevailing harvesting, residue-collection and residue-burning practices for the preceding rice crop with generally still limited consideration for the retention of crop residues as mulch – a necessary component of conservation agriculture. ZT-induced labor savings were relatively minor in view of the prevailing mechanization levels and crop management practices.

With rice still being cultivated in the traditional way in the subsequent season, ZT-induced enhancement of land quality is relatively short-lived. Farm-level impact of ZT thereby primarily reflects immediate effects on the wheat crop budget through cost savings and, in the case of Haryana, additional yield effects. The ZT-induced yield enhancement in the survey year in Haryana seemed, at least in part, attributable to the less favorable weather for wheat growth, ZT being relatively less adversely affected than CT wheat despite similar planting dates. The reduced yield variability has important implications for overall farm risk management and enhanced income stability.

Regional Impacts of ZT

According to expert estimates, 0.35 and 0.3 mha of wheat were planted by ZT drill during 2003-04 in Haryana and Punjab (RWC 2004), respectively. Extrapolating our plot-level findings to this area, ZT implied a saving of 12.6 and 10.4 million liters of diesel, 2.1 and 2.1 million tractor hours and $14.6 and 13.5 million in production costs per season, respectively. In Haryana, ZT also implied a gain of 60,000 mt grain per wheat season. In financial terms, Haryana had a net income increase of $23.9 million per season, comprising the aforementioned “cost saving effect” of $14.6 million and a “yield effect” of $9.2 million. If we assume that ZT can be extended to a third of the total rice-wheat area in India and Pakistan (10.4 and 2.2 mha, respectively), these aggregate benefits would be conceivably increased with a factor of 9.8 in India and 2.4 in Pakistan, respectively. However, particularly the Punjab study flags the significant ZT dis-adoption, which thereby questions the extent to which these larger regional savings will be actually realized.

Water is a major concern for the sustainability of intensive cropping systems in both Haryana and Punjab and for the Indian and Pakistan economy as a whole (e.g., Briscoe and Malik 2006). Perhaps somewhat disappointingly, the adoption surveys could not unambiguously verify that ZT generated significant water savings. In part, this is likely due to measurement errors in view of our survey estimates. Nonetheless, the farmer responses imply there is some water saving, but maybe less significant than often alluded. Only the water use survey in Haryana verified that ZT generated significant water savings in wheat fields.

The present study concurs with other studies that resource conserving technologies (RCTs) like ZT can be successful in improving field-scale irrigation efficiency through irrigation savings (Ahmad et al. 2007; Gupta et al. 2002; Humphreys et al. 2005; Jehangir et al. 2007). However, as highlighted by Ahmad et al. (2007:1), “whether or not improved irrigation efficiency translates to ‘real’ water savings depends on the hydrologic interactions between the field and farm, the irrigation system and the entire river basin. In fact, the water saving impacts of RCTs beyond the field level are not well understood and documented.” For instance, some of the irrigation water “saved” would be simply recycled, percolating into the groundwater table from where it would later be reused by farmers through pumping (Ahmad et al. 2007). This calls for more systematic assessments of water balance components at farm to system scales (Ahmad et al. 2007; Jehangir et al. 2007).

In any event, the irrigation water savings with ZT in wheat are still modest. To put the water savings for ZT wheat further in perspective it is useful to recall that irrigation input for rice is a multiple of that of wheat (a factor of 8.4 in Haryana and 5.9 in Punjab, based on our average survey data). In part, this reflects higher potential evapotranspiration of rice (640 mm) as compared to wheat (330 mm; Ullah et al. 2001). In the case of wheat, the actual evapotranspiration is generally lower than the potential requirement (Ahmad et al. 2002; Jehangir et al. 2007). However, in the case of rice irrigation, water applied is significantly higher than crop water requirement (Ahmad et al. 2007). This highlights that there is significantly more scope for reducing irrigation water input for rice than for wheat without yield loss. Significant irrigation water savings can indeed be achieved with resource conserving technologies in rice (some 30-40%), although these are typically derived from the recycled water component and do not reduce actual evapotranspiration (Ahmad et al. 2007; Humphreys et al. 2005). Therefore, in terms of regional water savings, enhancing water productivity of the rice component of the rice-wheat system will be imperative.

Water rights and institutional arrangements further confound the picture. Despite a gradual increase in water scarcity at the subbasin or basin scales, improving water productivity and achieving real water savings remain secondary concerns for most rice-wheat farmers (Ahmad et al. 2007). The current attraction of ZT in wheat indeed primarily relates to the cost savings and not the water savings as such. This is likely to remain as long as farmers are not charged according to their actual water use and do not pay the real (economic) cost of water. But this implies making politically unpopular adjustments to (ground)water rights and the subsidy and taxation schemes that currently undermine the sustainability of rice-wheat systems.

The study does flag some equity concerns as ZT uptake and the corresponding benefits are positively associated with farm size in each study area. Although, in principle, accessible to smallholders through service providers, various constraints have limited its uptake amongst smallholders. In the present context, the tractor and cost-saving nature of ZT wheat have relatively limited implications for labor use. Consequently, whereas ZT, by necessity, has bypassed landless, it also seems to have had limited negative impact on the landless through labor displacement. Monitoring and better understanding the equity implications of extending ZT and RCTs to the rice component of the rice-wheat system are imperative.

The ZT-induced fuel savings imply a significant positive environmental externality by reducing CO_2 emissions, a significant contributor to global warming. The widespread burning of rice residues at land preparation time for the subsequent wheat crop in the rice-wheat tract is generating a significant negative externality in terms of significant air pollution. Conservation agriculture implies retaining some crop residues as mulch (i.e., soil cover) but, to date, ZT in the study areas has not had a significant effect on the practice of residue burning. The prevailing ZT drills (with tines) can sow a crop in standing ("anchored") rice stubbles but tend to rake loose residues. This is particularly an issue in combine harvested fields with irregularly spread loose straw, leading farmers to adhere to the residue-burning practice. Further adaptations to crop-residue-management practices and/or the drill could alleviate the perceived need to burn loose residues.

From the point of view of conservation agriculture there is a need to maintain some crop residue cover on the soil surface and to move beyond ZT being applied to the wheat crop only. The environmental and soil implications of ZT wheat for the rice-wheat system as a whole remain short-lived (i.e., seasonal) as long as the subsequent rice crop remains intensively tilled and puddled. ZT can be a stepping stone to conservation agriculture – but this implies changes to the way rice is grown, managing crop residues so as to maintain some soil cover and enhancing crop rotation.

The rice-wheat belt is of extreme strategic importance for national food security in both India and Pakistan. Options to enhance national wheat production through increasing area are severely limited, thereby making the enhancement of wheat competitiveness in this belt imperative. The Haryana study highlights the relatively minor net revenues derived from wheat cultivation which underscores the need for continued yield enhancement and cost savings to maintain wheat competitiveness. It also highlights the relative significance of the ZT-induced income enhancement, which boosts returns well above breakeven. However, there is no room for complacency. Extending the ZT area will enhance the competitiveness of wheat, but this needs to be complemented by varietal renewal (e.g., more diverse and stem-rust resistant wheat varieties; non-puddled rice varieties), other resource-conserving technologies (e.g., for rice; laser leveling) and diversification of rice-wheat systems. Furthermore, the advent of the virulent new stem rust for wheat (UG99, Mackenzie 2007; Raloff 2005) and global warming (Ortiz et al. 2006) could have far-reaching consequences across the IGP. In Punjab, late establishment of wheat remains a structural problem in these systems and ZT has the potential to alleviate this. The Punjab study did find significant cost savings, but did not find any significant ZT-induced yield effect, largely a reflection of the lack of a ZT-induced planting date effect. More emphasis should be placed on highlighting the enhanced timeliness aspect of ZT, which would further boost the returns to adopting ZT and alleviate yield concerns. In the end, the sheer size of the rice-wheat system implies even small gains add up to a significant regional impact.

Conclusions and Recommendations

Conclusions

The two country studies confirmed widespread adoption of ZT wheat in the rice-wheat systems of Haryana (34.5% of surveyed households) and Punjab (19%). The combination of a significant "yield effect" and "cost-saving effect" makes adoption worthwhile and is the main driver behind the rapid spread and widespread acceptance of ZT in Haryana. In Punjab, adoption is driven by the significant ZT-induced cost savings for wheat cultivation. Thus, the prime driver for ZT adoption is monetary gain in both sites, not water savings or natural resources conservation. Water savings are only a potential added benefit.

ZT adoption for wheat accelerated from insignificant levels from 2000 onwards in both sites. Geographic penetration of ZT is far from uniform suggesting the potential for further diffusion, particularly in Haryana. Diffusion seems to have stagnated in the Punjab study area, and further follow-up studies are needed to confirm this. The study also revealed significant dis-adoption in the survey year: 14 percent in Punjab and 10 percent in Haryana. Better understanding the rationale for dis-adoption merits further scrutiny. Our findings suggest that there is no clear single overarching constraint but that a combination of factors is at play, including technology performance, technology access, seasonal constraints and, particularly in the case of Punjab, the institutional ZT controversy. In terms of technology performance, the relative ZT yield was particularly influential: dis-adopters reporting low ZT yields as a major contributor to farmer disillusionment in Punjab and the lack of a significant yield effect in Haryana. In neither site did the ZT-induced time savings in land preparation translate into timelier establishment, contributing to the general lack of a yield increase. Knowledge blockages, resource constraints and ZT drill cost and availability all contributed to non-adoption. This suggests that there is potential to further enhance access to this technology and thereby its penetration.

The study highlights that in both Haryana and Punjab ZT has been primarily adopted by the larger and more productive farmers. The structural differences between the adopters and non-adopters / dis-adopters in terms of resource base, crop management and performance thereby easily confound the assessment of ZT impact across adoption categories. This calls for comparison of the ZT plots and CT plots on adopter farms. Whether this introduces new biases merits further scrutiny.

ZT-induced effects primarily apply to the establishment and production costs of the wheat crop. Both the Haryana and Punjab study confirmed significant ZT-induced resource-saving effects in farmers' fields in terms of diesel and tractor time for wheat cultivation. Water savings are however less pronounced than expected from on-farm trial data. It was only in Haryana that there were significant ZT-induced water savings in addition to significant yield enhancement. The higher yield and water savings in Haryana resulted in significantly higher water productivity indicators for ZT wheat. In both sites, there were limited implications for the overall wheat crop management, the subsequent rice crop and the rice-wheat system as a whole. The ZT-induced yield enhancement and cost savings provided the much needed boost to the returns to, and competitiveness of, wheat cultivation in Haryana. In Punjab, ZT has so far been primarily a cost-saving technology.

Recommendations

There is scope for widely recommending ZT and making it the prevalent practice for wheat cultivation in rice-wheat systems in the IGP. Cost and resource savings alone are robust and significant enough to merit widespread use, more so in view of the recent structural price hikes in energy prices. Enhanced yields are an added benefit, particularly in Haryana.

There is scope for more emphatically stressing timeliness of wheat establishment. Late establishment is a major contributor to low wheat productivity in Punjab. ZT has the potential to significantly alleviate untimeliness, but in practice this did not materialize – thereby foregoing a potential benefit. In Haryana, the average planting date shows that a significant share of wheat plots is still established late, which constrains wheat productivity. Here too the potential of ZT to significantly alleviate untimeliness only partially materialized and can be better utilized – both in terms of early establishment after non-basmati rice and timely establishment after basmati rice.

There is a need to enhance the accessibility of smallholders to ZT drill service providers. The majority of ZT adopters so far are large farmers who have relied on contracted ZT drill services (60% in Haryana and 74% in Punjab). Such services have much merit, but only when they are timely, reliable and widely accessible. Many of the potential benefits from ZT are easily thwarted by a late or uncertain arrival of the ZT drill or its improper use – calling for well-trained operators and properly maintained ZT drills. Resource constraints, ZT drill cost and limited tractor ownership naturally limit the potential for self-owned ZT drills for smallholders.

There is a need to enhance the accessibility of smallholders to ZT knowledge. Penetration of ZT is still uneven both geographically and within communities. Alleviating knowledge blockages can further an equitable access to this promising technology. There is an important role here for agricultural extension, particularly in Pakistan. In Punjab, ZT must be duly projected as one option in the wheat-planting campaign run through the mass media (the radio, TV and printed material) by the Department of Agricultural Extension. There is also particular scope for more field days, farmer exchanges, farmer to farmer extension and a more participatory and farmer-field school approach.

There is also a need for additional water saving technologies – particularly to reduce water consumption of the rice component in rice-wheat systems. ZT wheat was found to be water saving in Haryana, but this still seems largely insufficient to address the impending water crisis. Other technological options are needed and laser leveling is promising in this regard (Humphreys et al. 2005; Jat et al. 2006). Research efforts to grow rice with less water need to be strengthened. For instance, more research is needed on aerobic direct-seeded rice in terms of suitable varieties and management of water, weeds, residues and nutrients.

To realize ZT's potential as a stepping stone to conservation agriculture there is a need to change the way rice is grown, managing crop residues so as to maintain some soil cover and to enhance crop rotation. This calls for changes in the prevailing ZT equipment design to enable sowing with residue retention. Some such “second-generation ZT drills” have recently been developed in the IGP and these merit further testing and adaptation with concerned stakeholders. It also calls for research on how much residue is needed, particularly in view of the prevailing alternative use of crop residues as basal animal feed (Erenstein et al. 2007c).

Technological intervention needs to be complemented with policy reform to create an enabling environment for sustainable agriculture that includes crop rotation and promotes economic resource use. This could easily prove more significant, particularly for water savings, but implies addressing some of the more thorny policy issues such as the subsidy and taxation schemes (e.g., flat water charges, underpriced/ free irrigation water, incentive structure geared towards rice and wheat) that currently undermine the sustainability of rice-wheat systems.

There is scope for combining qualitative and quantitative approaches in impact assessment. The two country studies primarily relied on a household survey which allowed us to quantify and test for significance of observed differences. However, the studies would have benefited from complementary informal surveys to shed more light on understanding, for instance, the reasons for dis-adoption and partial adoption. The two approaches are complementary and can enrich the interpretation and validity of findings. In this respect, a livelihood system and value chain perspective will be useful and should enhance the relevance and equity of research and development (R&D) interventions.

Finally, a more objective and synergetic approach to ZT is needed in Punjab. The State Extension Department has long been opposed to ZT because of possible stem-borer issues but these appear to be unfounded. Compared to Haryana, the advent of ZT in Punjab has been severely hampered by the polarization of the R&D field in terms of ZT advocates and ZT opponents, with farmers facing conflicting information and lack of institutional support. The ZT controversy and institutional rivalry have proven counterproductive, wasted scarce resources and stalled ZT diffusion. It is advisable that both camps come to a neutral and modest middle ground. ZT is neither a silver bullet nor a Pandora's box. It is just a valuable technological option that merits promotion as it saves resources and time and reduces costs with no yield penalty.

The study also identifies some areas for further empirical research, including:

- More rigorous documentation of the water savings of resource-conserving technologies like ZT.
- A better understanding of the ZT dis-adoption process – particularly in terms of disentangling the underlying causes. This study generated some insight but could not resolve a number of imponderables. For instance, the site-specific circumstances dis-adopters faced in terms of their access to drill, the quality of the drill, timeliness, quality of soil, the skill of the operator, etc. Participatory approaches could provide useful complementary information.
- A better understanding of partial ZT adoption – particularly in terms of the rationale and underlying field selection criteria and the eventual biases this may imply in terms of technology performance.
- A better understanding of the adoption and impacts of ZT in the eastern Gangetic Plains. The present study focused on the northwest IGP where ZT diffusion started (Laxmi et al. 2007). However, the northwest IGP is better endowed and has more intensive rice-wheat systems than the eastern plains (Erenstein et al. 2007c; Erenstein et al. 2007b). This calls for a closer scrutiny of the adoption, impacts and implications of ZT now that the uptake of ZT in the eastern plains has started to pick up.
- The possible refinement and extrapolation of recommendation domains for technologies like ZT. For instance, anecdotal evidence coming from Pakistan suggests ZT by soil type interactions. Also the implications and potential use of ZT in wheat-cotton systems with low cotton-residue-retention levels and the extrapolation to other systems like the maize-wheat and the rain-fed systems.
- More intensive, participatory and timely monitoring of the performance and impact of new technologies like ZT in farmers' fields.

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