Adoption and Impacts of Zero-Tillage in the Rice-Wheat Zone of Irrigated Haryana, India

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Research Paper[2]

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COMPREHENSIVE Assessment of water management in agriculture

Rice Wheat

CIMMYT MR
INTERNATIONAL MAIZE AND WHEAT IMPROVEMENT CENTER

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CIMMYT® (www.cimmyt.org) is an internationally funded, not-for-profit organization that conducts research and training related to maize and wheat throughout the developing world. Drawing on strong science and effective partnerships, CIMMYT works to create, share, and use knowledge and technology to increase food security, improve the productivity and profitability of farming systems, and sustain natural resources. Financial support for CIMMYT's work comes from many sources, including the members of the Consultative Group on International Agricultural Research (CGIAR) (www.cgiar.org), national governments, foundations, development banks, and other public and private agencies.

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Abstract: This study documents the adoption and impacts of zero-tillage (ZT) wheat in the rice-wheat systems of India's Haryana State primarily drawing on a detailed empirical survey of 400 rice-wheat farmers. Our random stratified sample revealed 34.5% to be ZT wheat adopters and a quarter of the wheat area in the surveyed communities to be under ZT. The study suggests the potential for further diffusion but also flags the issue of disadoption (10%). ZT adopters, non-adopters, and disadopters differ significantly in terms of their resource bases, with adopters typically showing the most favorable values. ZT drastically reduces tractor operations in farmers' ZT wheat fields from an average of 8 passes to a single pass, implying a saving of 6 tractor hours and 36 liters of diesel per hectare. At 4.4 tons per hectare, ZT achieved the highest wheat yields in the survey year, a significant 4.0% yield increase over conventional tillage. The higher yield and lower water use resulted in significantly higher water productivity indicators for ZT wheat. ZT did not have any significant spillover effect on the subsequent rice crop. The combination of a significant "yield effect" and "cost-saving effect" makes ZT adoption worthwhile and is the driving force behind its rapid spread and widespread acceptance, providing a much needed boost to economic returns to wheat cultivation. Based on these findings, the study provides a number of recommendations for research and development in Haryana's rice-wheat systems.

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Table of contents

List of tables

Page No.

List of figures

List of acronyms

CIMMYT	International Maize and Wheat Improvement Center, Mexico (www.cimmyt.org)
CT	conventional tillage
ICAR	Indian Council for Agricultural Research (www.icar.org.in)
IGP	Indo-Gangetic Plains
INR	Indian rupees
NA	not applicable
NS	not significant
p.a.	per annum (per year)
RCT	resource-conserving technology
RT	reduced tillage
RWC	Rice-Wheat Consortium for the Indo-Gangetic Plains (www.rwc.cgiar.org)
s.d.	standard deviation (std. dev.)
t	tons (1,000 kg)
ZT	zero-tillage
ZTD	zero-tillage drill

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Executive summary

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 productivity. The present study documents the adoption and impacts of zero-tillage (ZT) wheat in the rice-wheat systems of India's Haryana State drawing on detailed empirical surveys.

Diffusion of zero-tillage (chapter 3)

Our random stratified sample of 400 rice-wheat farmers revealed 34.5% to be ZT wheat adopters and a quarter of the wheat area in the surveyed communities to be under ZT. The present study thus empirically confirms the significant levels of adoption of ZT wheat in Haryana's rice-wheat systems, underscoring the appeal of the technology among farmers. Adoption is, however, far from uniform, with significant variation in penetration and use over districts and villages. The variations over districts seem to be associated with prevailing cropping systems, with disadoption more common in both rice-wheat and sugarcane-based cropping systems. Although ZT promotion has emphasized rice-wheat districts, ZT adoption is also spreading rapidly in cotton-wheat districts. Village-wise adoption rates show a considerable gradient from zero to saturation, the latter suggesting that ZT has considerable merit and wide applicability once the technology has proven itself within a community. Village-level data also showed that the average disadoption rate of 10% is typically piecemeal and only occasionally widespread.

Chapter 3 shows that ZT diffusion in many ways follows the customary diffusion pattern of technological innovations. After nearly a decade of adaptive research, demonstration and slow initial diffusion, diffusion started to pick up rapidly from the year 2000 onwards. The technology seems primarily to spread from farmer to farmer. To meet increasing demand, supply of ZT drills by manufacturers has progressively increased, both in terms of increased production capacity and capacity use. Within Haryana State, both ZT adoption and ZT manufacturing capacity are geographically concentrated in the north.

The data suggest 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. However, the present study also flags the issue of disadoption (10%), both prolonged and temporary. Our findings suggest that there is no clear single overarching constraint, but a combination of factors at play, including technology performance, technology access, and seasonal constraints. This merits further scrutiny in order to better understand the rationale for disadoption. Three-quarters of those who have used ZT have done so continuously. Surveyed ZT adopters apply ZT to approximately half their total wheat area. Those reliant on tractor services were observed to devote a larger area share to ZT than tractor owners. Ownership of a ZT drill was reported by 15% of the households. The majority of ZT adopters (60%) therefore relied on contracted ZT drill services at the time of the survey.

Understanding adoption of zero-tillage (chapter 4)

The farmers in the ZT adopter, non-adopter and disadopter categories differ significantly in terms of their resource base. For the various indicators compiled, adopters typically show the most favorable values and the non-adopters the least favorable, with disadopters taking an intermediate position. This has two important implications. First, it highlights that ZT adoption is strongly associated with the wealth of the farm household, likely reflecting its risk-bearing capacity and ability to innovate. Second, it shows that ZT disadopters combine characteristics of both adopters and non-adopters. The favorable characteristics may facilitate the initial adoption of ZT, whereas the unfavorable characteristics undermine its continued use.

Bivariate analysis highlighted that penetration of ZT (adoption + disadoption) was positively associated with size of operational holding and possession of farm and household assets. Adoption of ZT was positively associated with membership of the Jat Sikh caste, use of canal and tubewell irrigation, and reliance on permanent labor, and negatively associated with reliance on family labor. Disadoption of ZT was positively associated with sugarcane cultivation, youth of the household head, membership of the Jat caste, and various proximity indicators, the latter likely reflecting the combined effect of exposure to ZT and diversification incentives.

Farming was the main income source across households, contributing 84% of overall household income. The share of farming in income was significantly higher for adopters compared to non-adopters and disadopters. This agricultural specialization reflects their larger land holdings and more commercial orientation. Adopters also have taken the rice-wheat specialization furthest. The combination of these factors likely enhances the incentives for adopters to innovate and cut production costs in rice-wheat systems.

Extension factors rated highest in constraining ZT adoption, followed by financial factors, with technical factors playing only a minor role. Knowledge blockages, resource constraints, and ZT drill cost and availability all contributed to non-adoption. This suggests that there is potential to further enhance the access to this technology and thereby its penetration. The lack of a significant yield difference and the perceived high cost of the ZT drill contributed to disadoption.

Binomial logit models reiterate that ZT adoption is closely associated with ZT promotion, remoteness, farm size, assets and rice-wheat specialization. Canal irrigation enhanced the likelihood of trying out the technology and (sandy) loam soils reduced it, but neither significantly affected the likelihood of its continued use.

Technical impact of zero-tillage technology (chapter 5)

ZT drastically reduces tractor operations in farmers' ZT wheat fields from an average of 8 passes to a single pass, implying a saving of 6 tractor hours and 36 liters of diesel per hectare. At 4.4 t/ha, ZT achieved the highest wheat yields in the survey year, a significant 4.0% yield increase over conventional tillage. Recall data, where farmers were asked about harvests in the three preceding years, show similar yields for ZT and conventional tillage, but overall significantly higher yields than in the survey year. This highlights that ZT was less susceptible to yield loss. The ZT-induced time savings in land preparation did not translate into a markedly timelier establishment. ZT was not observed to have any significant effect on seed rate (109 kg/ha of seed), chemical fertilizer use (246 kg/ha of fertilizer; nutrient ratio 187:58:1), or weed management (1.0 weedings).

The adoption and water use surveys confirm that ZT saved irrigation time for wheat, but did not significantly reduce the number of irrigations (3.4 per season). Total tubewell water volume applied to ZT was 2,200 m^3 compared to 2,500 m^3 for conventional tillage, a statistically significant water saving of 13.4%, which was primarily achieved in the first irrigation. The higher yield and lower water use result in significantly higher water productivity indicators for ZT wheat. Overall water productivity was estimated to average 2.5 kg of wheat per m^3 of irrigation water and 1.5 kg per gross m^3. The survey results also flag the dangerous prevalence of one single wheat variety, with PBW 343 being reported in 89% of the wheat plots.

ZT did not have any significant spillover effect in terms of affecting the management, yield, or water productivity of the subsequent rice crop. Most significant differences between surveyed rice plots reflect differences between adopters and nonadopters. Differences between adopters' rice plots after ZT wheat and after conventional wheat were typically not significant. Measured rice crop management indicators included tillage operations (5.3 per season), seed rate (11 kg/ha of seed), chemical fertilizer use (204 kg/ha of fertilizer; nutrients ratio 156:44:4), weed management (1.7 weedings), pesticide use (89% of plots), and irrigation (34 irrigations per season). The mean farmer-estimated rice yield was 4.7 t/ha. Water productivity was estimated to average 0.34 kg rice per irrigation m^3 and 0.23 kg of rice per gross m^3. Water productivity indicators for rice are markedly lower than those for wheat, largely a reflection of significantly higher water inputs in rice cultivation in order to maintain standing water in the paddies, for relatively similar yields. Rice cultivation practices also differ from wheat in terms of the intensity of land preparation (fewer tractor passes but including wet cultivation), fertilization practices (less inorganic fertilizer use and more organic fertilizer), pesticide use (near universal), and harvesting practices (less reliance on combine harvesting). Three groups of rice varieties were reported in the surveyed plots: superfine rice varieties (46.5% of plots), evolved basmati (30.2%) and traditional basmati (23.2%). These varietal groups had a marked effect on rice management practices, yield and water productivity.

Therefore, in the case of Haryana, ZT only had significant positive effects on yield and water productivity for the wheat crop. The study confirms that the generally favorable impacts of ZT reported in trials, in terms of enhancing wheat yield and saving water, are also achieved in farmers' fields. However, there were no significant effects on yield and water productivity for the subsequent rice crop.

Financial impact of zero-tillage technology (chapter 6)

On an average per hectare basis, wheat production entails a gross revenue of INR 29,700, total costs of INR 28,100 and a meager net revenue of INR 1,600. This gives an average return of 6% to production costs, with 68% of wheat plots generating a positive net revenue. The average net revenue-based water productivities therefore amount to only INR 1.5 per irrigation m^3 and INR 0.8 per gross m^3. ZT plots show significantly lower total costs and significantly higher gross and net revenue. Compared to the conventional plots of adopters, ZT showed a conclusive advantage of INR 3,100 per hectare in the survey year, composed of a 'yield effect' of INR 1,200 and a 'cost saving effect' of INR 1,900. The ZT-induced cost saving is substantial, and represents a saving of 7.0% on total costs, or 15.3% 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's competitiveness in rice-wheat systems. It also highlights the relative significance of the ZT-induced income enhancement, which boosts returns well above the breakeven point. Indeed, 92% of ZT plots had a positive net revenue. ZT plots thereby achieve a significantly higher return on production costs (17%) and significantly higher estimates for net revenue-based water productivities (INR 3.6 per irrigation m^3 and INR 1.9 per gross m^3). The combination of significant yield and cost saving effects make adoption worthwhile and is the main driver behind the rapid spread and widespread acceptance of ZT in Haryana.

On an average per hectare basis, rice production entails a gross revenue of INR 38,600, total costs of INR 34,400 and a net revenue of INR 4,200. This gives an average return of 13% to production costs, with 67% of rice plots generating a positive net revenue. The net revenue-based water productivities amount to INR 0.38 per irrigation m^3 and INR 0.25 per gross m^3. ZT wheat does not significantly affect gross revenue, production cost, net revenue or financial water productivity of the subsequent rice crop. The type of rice variety has a significantly more pronounced effect on performance indicators than the preceding wheat crop. Compared to superfine rice and traditional basmati, evolved basmati typically achieve the most favorable performance indicators.

The relative performance at the aggregate rice-wheat system level primarily mirrors the effects of ZT on wheat performance, although the differences tend to be more subdued and the higher wheat gross revenue with ZT is dampened by the non-significant variation in rice gross revenue. The significant ZT-induced cost saving is maintained, whereas for the other indicators ZT and conventional plots of adopters typically tend to outperform the plots of non-adopters and disadopters, but do not differ significantly from each other. Therefore, we can conclude that financial effects of ZT are limited to the wheat crop, with no significant positive or negative carry-over effects for the rice-wheat system.

Based on these findings the study goes on to explore the farm- and regional-level impacts (Chapter 7) and provides a number of conclusions and recommendations for research and development in India's rice-wheat systems (Chapter 8).

1 Introduction[3]

In South Asia, rice-wheat cropping systems cover 13.5 million hectares 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, and 85% of the is system concentrated the Indo-Gangetic Plains (IGP), encompassing Northern India, Pakistan, Nepal and Bangladesh (Timsina and Connor 2001). In the face of environmental degradation and increasing competition for water from the industrial and domestic 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 the stagnation of 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 tubewells, placing tremendous pressure on groundwater supplies (Abrol 1999; Ahmad et al. 2007; Qureshi et al. 2003). The negative environmental effects of` irrigation are increasing as overexploitation of groundwater and poor water management lead to falling 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, tubewell irrigation has raised production costs in terms 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 for the Indo-Gangetic Plains (RWC, www.rwc.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 to control pests and diseases (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). 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 (Anwar et al. 2002; Hobbs and Gupta 2003a; Khan et al. 2002; Malik et al. 2002a; Malik et al. 2005a).

To date, the RCT that has been most successful in the IGP is zero-till planting of wheat after rice (Laxmi et al. 2007). Zero–tillage (ZT) practices in rice-wheat systems vary from surface seeding to planting with seed drills drawn by four-wheel tractor (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 entails 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 practices for wheat involve multiple passes of the tractor to complete plowing, harrowing, planking, and seeding operations. Use of ZT significantly reduces energy costs, mainly by reducing tractor costs associated with conventional tillage methods, but also as water savings reduce the time that tubewells must be operated. Use of ZT also allows the wheat crop

3 This section draws on Morris (2003).

to be planted sooner than would be possible using conventional tillage methods, significantly reducing 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: heat stress at the end of the wheat cycle reduces wheat yield potential by 1-1.5% 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 conventional tillage (Gupta et al. 2002; Hobbs and Gupta 2003b). ZT uses residual soil moisture more effectively. Irrigation can be stopped once the field is covered, and with ZT irrigation water spreads more quickly across the surface. ZT can improve soil structure and facilitates crop residue buildup, 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 of initiating this study, these benefits had yet to be conclusively documented in farmers' fields where farmers had adopted ZT independently, although some recent studies have now become 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 are showing promise (Connor et al. 2003; Jat et al. 2006). For this reason, the current study focuses on ZT wheat which was known to have spread into farmers' fields.

The extent to which ZT has diffused across the IGP is not known precisely. Field observations suggest, and knowledgeable experts estimate, that the area under ZT is significant and 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 therefore 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 estimates of impact is problematic and misses eventual adaptations by farmers in terms of fine tuning and modifying the technology to their circumstances.

To promote more rapid 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 their 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). Only by understanding these factors will researchers, extension specialists, machinery manufacturers, and policy makers 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 zero-tillage as a resource-conserving technology in farmers' rice-wheat fields in the Indo-Gangetic Plains. The specific objectives of the present study are to:

1. Document the diffusion of zero-tillage in the rice-wheat belt of Haryana, India.
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 to accelerate adoption and diffusion of ZT.

The present study is complemented by a similar study that was conducted in Punjab, Pakistan (Farooq et al. 2007). The sites for the parallel studies were chosen to represent the intensively cropped rice-wheat systems characteristic of the western irrigated Indo-Gangetic Plains. A separate report synthesizes the findings of the two detailed country studies (Erenstein et al. 2007a).

The present report is organized into eight chapters. In the second chapter we introduce the study area and review the methodology. In the third chapter we document the diffusion of the technology. In the fourth chapter we analyze the factors affecting ZT adoption. In the fifth chapter we analyze and evaluate the technical plot-level impact of the technology and in the sixth chapter the financial plot-level impacts. In the seventh chapter we analyze the farm and regional impacts. The eighth chapter concludes.

2 Study area and research methodology

2.1 Study area

The study focuses on the irrigated rice-wheat zone in Haryana State, India, located in the northwest of India and part of the Trans-Gangetic Plains, the northwestern part of the IGP (Figure 1). The average annual precipitation ranges from 300 mm yr^{-1} (Sirsa district) to 1100 mm yr^{-1} (Yamunanagar district) (Central Ground Water Board 2007). The semi-arid climate is continental monsoonal, with some 80% of the total precipitation during the monsoon season from June to September. Wheat is grown in the cold and dry weather during November to March (*rabi* season), whereas rice is grown during the warm, humid or semi-humid monsoon season from June to October (*kharif* season) (Timsina and Connor 2001). With annual potential evapotranspiration of at least 1,400 mm (Harrington et al. 1993), the rice and wheat crops are dependent on irrigation, which uses both surface and groundwater. The study area is served by a well-developed canal irrigation system, although groundwater now provides the major share of total farm water supply, (Harrington et al. 1993) compensating for the generally inadequate volume, frequency, and timing of canal water in the IGP (Ahmad et al. 2007). The soils in the study area 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).

The rice-wheat system in the study area is highly mechanized, input-intensive, and commercial, and farm holdings are relatively large, particularly when compared to the Eastern IGP (Erenstein et al. 2007b; Gupta et al. 2003). Another distinguishing feature of the study area within the IGP is the popularity of Basmati rice (Timsina and Connor 2001), an aromatic, fine-quality rice which takes longer to mature. Wheat has traditionally been, and continues to be, the mainstay of food security in the northwestern IGP, and the introduction and widespread cultivation of rice only occurred in recent decades (Erenstein et al. 2007d). The introduction of rice put increasing pressure on farmers ability to plant wheat in good time, without incurring yield losses. Delays in planting the wheat crop are mainly due to late harvesting of the previous crop and/or a long turnaround time. Late harvest of the previous rice crop can be linked to both late rice establishment and the duration of the rice crop, particularly basmati. Long turnaround time often reflects intensive tillage operations, soil moisture problems (either too wet or too dry), unavailability of traction power for plowing, and the urgent need to store the rice crop before preparing land for wheat cultivation. Farmers perceive a need for intensive tillage due to the difference in soil management practices for rice and wheat: the former is grown under anaerobic conditions and the latter under aerobic conditions (Laxmi et al. 2007).

2.2 Data sources

The present study interprets zero-tillage (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 farmer adoption of ZT began only in the late 1990s. The state of Haryana was purposively chosen for this study as the state in India where ZT promotion was initiated and adoption has been most significant (Laxmi et al. 2007; Malik et al. 2005c). The study draws from three primary data sources: a survey of ZT drill manufacturers, a formal adoption survey of rice-wheat farmers and a water use survey of rice-wheat farmers.

Survey of zero-tillage drill manufacturers

The present study focuses on ZT using a 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 supply side analysis. For this purpose a survey of ZT drill manufacturers was implemented in December 2003 (Parwez et al. 2004).

A list of 50 ZT drill manufacturers in Haryana and Punjab was compiled for this study drawing on expert knowledge and word of mouth. Manufacturers in Punjab were included as the rice-wheat belt in the two states is contiguous and significant interstate movement of the ZT drills was expected. The identified ZT manufacturers were interviewed personally using a one page structured questionnaire (Annex 3). It covered manufacturer contact details and ZT drill sales history.

The list of 50 manufacturers proved not to be exhaustive; a further 29 were subsequently identified in the two states. These additional manufacturers were interviewed by phone to collect contact details and data on start of ZT manufacturing and 2003 ZT drill sales.

Adoption survey of rice-wheat farmers in Haryana

The main primary data source for this study was a formal adoption survey of rice-wheat growers from the rice-wheat zone of Haryana State, India. The survey used a stratified sampling frame. Within the state, the 10 districts where rice-wheat systems predominate were purposively chosen. In six of these districts (Ambala, Yamunanagar, Kurukshetra, Kaithal, Karnal, Panipat), ZT has been widely promoted. In the remaining four districts (Jind, Fatehabad, Sirsa, Sonipat), promotion of ZT has been less extensive. Within each district one or two blocks (the sub-sub-district administrative level, below the *Tehsil* or sub-district) where rice-wheat systems predominate were chosen purposively. Within these a total of 5 villages per district were randomly chosen. Within each selected village, 8 farm households were chosen randomly. This gave a total of 50 villages and 400 farm households. The spatial spread of the surveyed villages is depicted in figure 1, highlighting the concentration of the surveyed districts in the northern half of the state.

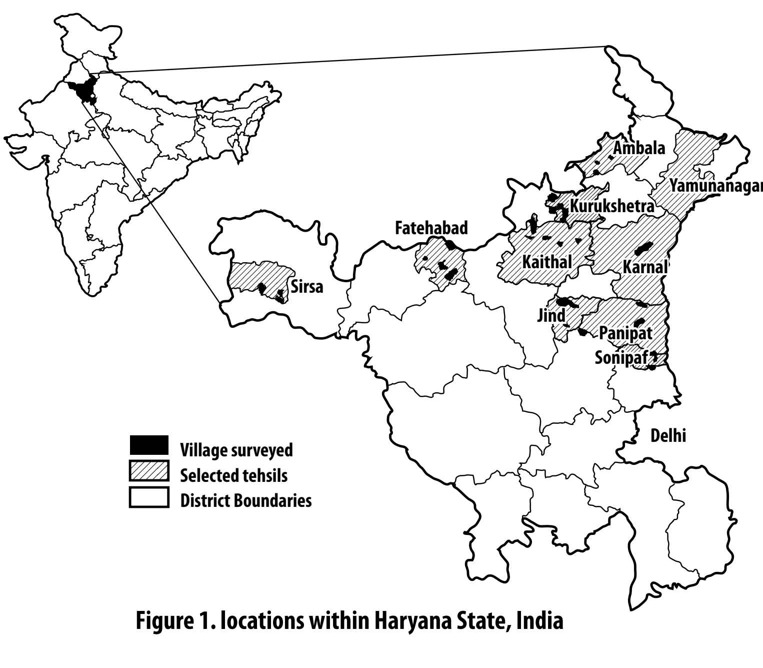

Figure 1. locations within Haryana State, India

Each selected household was visited twice during 2004 to collect detailed information using a structured questionnaire. The questionnaire (Annex 4) covered various indicators at the farm and plot levels. The farm-level indicators cover a range of farmer and household characteristics and experience with and perceptions of ZT. The field-level indicators cover plot-level details on crop management for both rice (Kharif 2003) and wheat (Rabi 2003-04). Where farmers had used both ZT and conventional tillage for their wheat crop, both plots were surveyed giving a total of 499 wheat plots from 400 farm households. Similarly, depending on the preceding wheat crop, 468 rice plots were surveyed. To put the rabi 2003-04 season into context, the study also traced the adoption history of each farmer.

Water use survey of rice-wheat farmers in Haryana

A small water use survey of rice-wheat farmers was conducted to supplement the adoption survey data with more detailed water use data. The water use survey focused on farmers in the Pabnawa distributary in the Kurukshetra and Kaithal districts of Haryana. This area was chosen purposively in view of previous water-monitoring activities and a high known degree of resource-conserving technology use. The survey used a one-page questionnaire (Annex 3) to compile irrigation and yield data for an RCT plot and a conventional tillage plot on selected farms. Farms were selected purposively for having both types of plots. During rabi 2003-04 a total of 43 farms were surveyed and data were collected for 51 conventional wheat plots, 47 zero-tillage wheat plots, and 12 bed-planted wheat plots. During kharif 2004 a total of 19 farms were surveyed and data were collected for 25 conventionally transplanted rice plots, 23 un-puddled transplanted rice plots and 12 direct-seeded rice plots.

2.3 Analytical methods

Data handling

For the subsequent analysis and reporting, farm households were classified based on their use of ZT in wheat. The farmers that used ZT for wheat during rabi (winter/dry season) 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 disadopters. Amongst the 400 households in the adoption survey, 138 were classified as adopters, 222 as non-adopters and 40 as disadopters (Table 1).

We hypothesize that there are a number of differences between the three adoption categories, and that these may help explain the observed adoption decision. The groups were sufficiently large to allow for statistical comparisons between adoption categories at the farm level. For the farm-level analysis (primarily chapters 3 and 4), tables therefore typically include the averages for each category as well as the overall sample, indicating statistically significant differences between adoption categories where relevant.

Adopters do not necessarily apply ZT to all their wheat fields. For ZT adopters, information was typically collected for two wheat plots, the ZT plot and the non-ZT plot, giving a total of 499 wheat plots from 400 farm households. We can thus distinguish between 4 categories of wheat plots: ZT wheat plots of adopters (138 plots) and 3 types of conventional wheat plots, distinguishing between adopters (99), non-adopters (222) and disadopters (40) (Table 2). We hypothesize that there are differences between the three types of conventional plots: firstly as adopters, non-adopters and disadopters may have inherently different crop management practices irrespective of the use of ZT, for instance in view of inherently different asset bases, and secondly as adopters and disadopters may have changed their 'conventional' crop management practices having used ZT. For instance, although not using ZT in the strict sense, they may have opted for reduced tillage practices in their non-ZT fields. The groups were sufficiently large to allow for statistical comparisons between wheat plot types. For the wheat plot-level analysis (primarily chapters 5 and 6), tables therefore typically include the averages for each category as well as the overall sample, indicating statistically significant differences between plot types where relevant.

To assess eventual carryover effects on the subsequent rice crop, we have compiled detailed crop management information for rice distinguishing between rice grown after ZT wheat and rice grown after conventional wheat. Where the farmer had both types of plot data were compiled for each, giving a total of 468 rice plots from 400 farm households. The rice plot data refer to the kharif 2003 season, and hence are influenced by the adoption status of ZT wheat in the preceding rabi 2002-03 season. Our adoption class category relates to the adoption decision in rabi 2003-04, hence we can find rice plots grown after ZT wheat for both current adopters and disadopters (Table 3). We can thus potentially distinguish 5 categories of plots. However, all plots with data for rice sown after zero-till wheat were

Table 2. Sample breakdown for wheat plot-level data by adoption category (rabi 2003-04).

	Adopters	Non-adopters	Disadopters	Overall
Number of plots with zero-tillage wheat data	138	-	-	138
Number of plots with conventional wheat data	99	222	40	361
Total number of plots with wheat data	237	222	40	499

Table 3. Sample breakdown for rice plot-level data by adoption category (kharif 2003).

	Adopters	Non-adopters	Disadopters	Overall
Number of plots with data for rice sown after zero-tillage wheat	76	-	31	107
Number of plots with data for rice sown after conventional wheat	107	221	33	361
Total number of plots with rice data	183	221	64	468

Table 1. Sample distribution across administrative boundaries and adoption categories.

District	Tehsil (sub-district)	Villages	Sample farmers by adoption category (number)			Sample size
			Adopters	Non-adopters	Disadopters	
Ambala	Ambala	5	24	9	7	40
Fatehabad *	Tohana	5	23	14	3	40
Jind *	Safidon	5	8	31	1	40
Kaithal	Kaithal	5	17	20	3	40
Karnal	Karnal	5	16	17	7	40
Kurukshetra	Pehowa	5	17	17	6	40
Panipat	Panipat	5	1	36	3	40
Sirsa *	Rania	5	18	22	0	40
Sonipat *	Sonipat	5	3	37	0	40
Yamunanagar	Jagadhari	5	11	19	10	40
Total (number) 10	10	50	138	222	40	400

* Districts where ZT promotion has been less intensive

kept together in one group, in view of their relatively limited number and to facilitate presentation of results. Consequently, we retain 4 categories of rice plots: rice plots sown after ZT wheat (grouping current adopters and disadopters alike, 107 plots), and 3 types of rice plots sown after conventional wheat, distinguishing between adopters (107), non-adopters (221) and disadopters (33) (Table 3). We again hypothesize that there are differences between the four types of rice plots. The groups were sufficiently large to allow for statistical comparisons between rice plot types. For the rice plot-level analysis (primarily chapters 5 and 6), tables therefore typically include the averages for each category as well as the overall sample, indicating statistically significant differences amongst plot types where relevant.

In the system level analysis (primarily discussed in chapter 6) we aggregate the implications of ZT for system productivity—i.e. the combined effect on the wheat and subsequent rice crops. In aggregating two possible methods may be used. The first aggregates *after* averaging by plot type, i.e. it simply adds the previously reported averages for wheat and rice by plot type. The second aggregates *before* averaging, i.e. aggregation is done for each individual plot and subsequently averaged by plot type. The advantage of the first method is that it corresponds with the previous section and maintains the maximum number of observations (499 wheat plots and 468 rice plots). The advantage of the second method is that it more adequately captures carry-over effects and allows us to test the statistical significance of differences. However, the second method loses a number of observations due to incomplete matching.[4] Of the 499 wheat plots, only 416 are retained in the second scenario, 83 plots being dropped for lack of corresponding rice plot data. This particularly reduces the number of ZT plots (by 62 plots out of the original 138 plots), reflecting the recent nature of the technology's adoption. Despite these differences, the two methods present a largely similar picture. The second allows for stronger inferences and is the one presented.

Data analysis

The significance of all bivariate contrasts between adopter categories and plot types was calculated using the appropriate statistical tests (e.g. t-test, ANOVA with post-hoc 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 cover a range of relatively fixed and exogenous characteristics of farm households that are 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 non-discriminating. For consistency reasons, we retained the same explanatory variables as in the Punjab, Pakistan study (Farooq et al. 2007).

The water productivity analysis follows the water productivity framework developed by Molden and others (Molden 1997; Molden et al. 1998; Seckler 1996), which is increasingly being applied by researchers (Ahmad et al. 2004; Cabangon et al. 2002; Jehangir et al. 2007). The main inflow components for the study area and considered in this study are irrigation, from canals and tubewells, and rainfall. Water productivity was estimated on the basis of the yields and profits achieved per unit of gross inflow (irrigation + rain) and of irrigation inflow.

The water inflow indicators for the farmer adoption survey draw on from plot-level farmer recall data on the number and duration of irrigations by source (canal and tubewell). These were converted into water volumes using average irrigation volumetric rates as recorded by the water survey conducted as part of this study (52.5 m^3/hour for tubewell water and 69.4 m^3/hour for canal water). For gross inflow we use the total seasonal rainfall recorded in the study area: 93 mm in rabi 2003-04 (November-April) and 509 mm in kharif 2003 (June-October) (State Office of the Deputy Director of Agriculture, Kurukshetra, unpublished data).

The financial analysis is done per individual household using the reported agricultural input and output levels and local farm prices as prevailing at the time of the survey. Prices are reported market prices, including eventual taxes and subsidies. These market rates are assumed to be a reliable reflection of opportunity costs, irrespective of the ownership of resources (e.g. in the case of land and tractors) and facilitate comparison. Missing values have been substituted with the corresponding average for the locality. The values in Indian rupees were converted to

[4] E.g. for a particular farmer there may be an observation for a plot with ZT wheat but no corresponding observation for rice after ZT wheat. Or alternatively, as in the case with rice after ZT wheat plots for disadopters, there is no matching ZT wheat plot.

US dollars, using an average conversion rate for July 2003 to June 2004 of USD 1 = INR 45.41 (RBI 2007).

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:

- land preparation (all tillage plus eventual post-sowing pass to cover seed);
- crop establishment (cost of seeding operation, including seed, labor and machinery);
- fertilizer (both chemical fertilizer and farmyard manure);
- plant protection (herbicides, manual weeding, pesticides, and fungicides);
- irrigation (flat area-based rate for canal irrigation and variable time-based rate for tubewell irrigation);
- harvest (labor and machinery for harvesting and threshing);
- land rent (prevailing seasonal rent); and
- interest on capital invested (9% of all costs).

The following measures are included as performance indicators:

- net revenue = (gross revenue) – (total production cost);
- percentage of plots with positive net revenue;
- benefit/cost ratio = (gross revenue) / (total production cost); and
- production cost = (total production cost) / (grain yield).

3 Diffusion of zero-tillage

In India rapid and widespread adoption of zero-tillage (ZT) started in Haryana State (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 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 on Phalaris minor, a major weed that reduces wheat yields in the IGP and showed emerging resistance to isoproturon herbicide after recurrent and widespread use in the mid-1990s (Malik et al. 2002b; Yadav and Malik 2005). The potential to control herbicide resistant phalaris thus became a major initial driver of adoption of ZT in northwest India. ZT, in combination with new herbicides, eventually managed to control the phalaris problem. Experts estimated the zero/reduced-tillage (ZT/RT) area in the state to be 350,000 hectares in 2003-04 (Laxmi et al. 2007). The present chapter analyses the extent of diffusion drawing on both supply- and demand-side indicators, drawn from the manufacturer survey and the farmer survey respectively.

This chapter is divided into seven sections. The first summarizes the findings of the zero-tillage drill (ZTD) manufacturers' survey. The second section deals with the actual adoption rates across sample districts. The third section attempts to trace the adoption history of adopters and disadopters of the ZT drill. The fourth section addresses the intensity of adoption. The fifth section addresses ZTD ownership. In the sixth section, we discuss the ZT information sources.

3.1 Supply of zero-tillage drills[5]

Promotion and adoption of ZT in Haryana emphasized the use of a tractor-drawn ZT seed drill. This drill typically opens a number (6-11) of narrow furrows using inverted-T tines for placement of seed (and sometimes fertilizer) into the soil at a depth of 7.5-10 cm. This specialized agricultural machinery was not originally available in India. In 1989, CIMMYT's regional wheat agronomist introduced inverted-T openers to Indian researchers. These inverted-T openers were originally developed in New Zealand by Aitcheson Industries. In 1991, a first prototype of the Indian ZT seed drill was developed at G. B. Pant University of Agriculture and Technology, Pantnagar. In 1992-93, a collaborative program for further development and commercialization of ZT was initiated with small-scale industries in Indian Punjab, the home of traditional farm machinery manufacturing centers for cultivators and threshers. After considerable investment of resources and several design changes, the first ZT seed drill was made available for field-testing within 12 months. The RWC for the Indo-Gangetic Plains joined hands with the national agricultural research system and provided support to pursue farmer participatory research and further adapt the ZT technology to rice-wheat systems. To overcome bureaucratic hurdles, RWC acquired several ZT drills and donated them to CCS Haryana Agricultural University (Hisar) for experimenting in farmers' fields. In 1997, after further refinement based on the feedback received from scientists and farmers, private manufacturers supplied over 150 improved ZT drill machines to State Agricultural Universities and Indian Council for Agricultural Research (ICAR) institutions located at Haryana, Punjab, Uttar Pradesh and Bihar. The initial manufacturers spent a lot of time in the fields with farmers and scientists to better understand the problems in machine operation, leading to rapid improvement of subsequent models (Laxmi et al. 2007). The first commercial ZT drills originated from the traditional farm machinery manufacturing centers like Ludhiana and Amritsar in Indian Punjab. Only later did manufacturers in Haryana join this business.

By 2004, 92 ZTD manufacturers were known to operate in the Indian IGP. The manufacturing capacity is spatially concentrated, with 79 manufacturers

[5] Findings from the ZT manufacturer survey were earlier reported in Parwez et al. 2004. The present section draws from that study and the same data set.

located in the northwest (35 in Haryana and 44 in Punjab). Data on the first year in which ZTDs were sold by each manufacturer allow us to plot the ZTD manufacturing capacity in Haryana and Punjab over time (Figure 2, lines). The number of ZTD manufacturers increased slowly in the 1990s with a total of 8 manufacturers in 1998. In the subsequent years, there has been a steady growth in the ZTD manufacturing capacity for the two states combined. Most of the ZTD manufacturing capacity was long based in Haryana, but growth in the number of manufacturers there started to stagnate in 2003 whereas it continued to grow in Punjab.

The sales history of the 50 surveyed manufacturers in Haryana and Punjab (25 each) provides evidence of the significant growth of annual zero-till drill sales per manufacturer (Table 4). Sales averaged 84 p.a. per active manufacturer, increasing from 33-45 p.a. in 1998-2000 to 138 in 2003. No significant difference in average sales was recorded between manufacturers based in Haryana and Punjab. However, sales per manufacturer vary widely from 1 to 1200 drills p.a., with a high coefficient of variation. Therefore, median sale numbers proove more informative; these show a similar increase of 10-15 drills p.a. in 1999-2000 to 57 in 2003.

The significant growth of zero-till drills in use was thus met by both increasing numbers of manufacturers and increasing average sales per manufacturer. Figure 2 (columns) depicts the aggregate sales history of the 50 surveyed manufacturers in Haryana and Punjab. From a combined total of 151 ZTDs sold in 1997, sales increased to a total of 6,875 ZTDs in 2003, with Haryana registering more than half the reported sales in each year since 1998. By the end of 2003, a cumulative total of 15,700 ZTD machines had been sold by the 50 surveyed manufacturers in the two states.

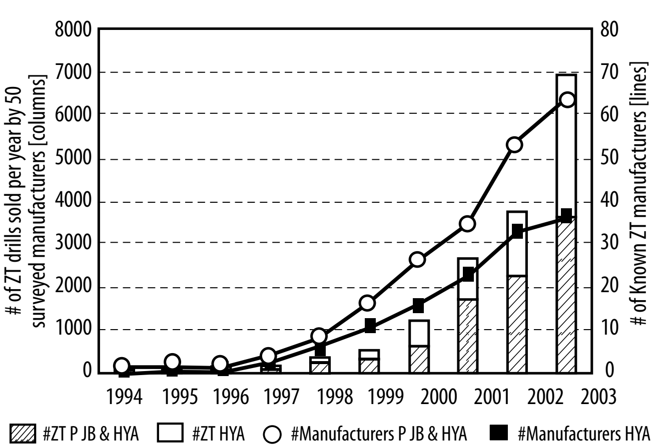

Figure 2. Number of ZT drill manufacturers [lines] and number of ZT drills sold per year by surveyed manufacturers [columns] in Haryana (HYA) and Punjab (PJB), India, 1994-2003.

The average sale price of a ZTD in India in 2003 was USD 325. The Haryana State Government supported ZT in the form of a subsidy (23% of the total in 2001), which has enhanced farmers' access to the machine (Ekboir 2002). The subsidy on the machines became operational in 2000 and may have contributed to the rapid increase in ZTD sales in the following years. The sales history of the 50 surveyed manufacturers shows that 69% of the ZTDs purchased from Haryana manufacturers during 2001-03 benefited from the subsidy, whereas this figure was only 31% for those purchased in Punjab (Table 5).

Telephone interviews of the 29 additional manufacturers in Haryana and Punjab not originally surveyed revealed that the majority had already been making rabi drills and shifted to ZTDs by changing the shovel-type tines to ZT tines (inverted T tines or chisel tines). Some local artisans were also found to convert old rabi drills into ZTDs by replacing the tines. In 2003, these additional manufacturers each produced from 1 to 250 ZTDs. Assuming a conservative average of 30 drills each, this would add another 870 ZTDs in 2003.

If we assume all machines to be operational, and unreported sales to cancel out machines exported to other states, then the reported 565,000 hectares of ZT/RT in the two states in 2003-04 (Laxmi et al. 2007) implies an average of 34 hectares planted per ZTD. This compares reasonably with the results of a survey of 153 ZTD-owning farmers in Haryana, which showed that on an average each ZT machine had planted 42 hectares of wheat in 2001-02 (Punia et al. 2002).

Table 4. Zero-tillage drill sales of 50 surveyed manufacturers in Haryana and Punjab, 1998-2003.

Year	Mean	Standard deviation	Minimum	Maximum	Median	n
1998	40.9	50.9	1	150	30	9
1999	32.9	50.1	1	200	11.5	16
2000	45.5	86.4	4	420	13.5	26
2001	77.3	135.5	2	600	30	35
2002	88.3	138.3	5	650	38	43
2003	137.5	231.0	1	1200	57	50
1998-2003	84.4	156.9	1	1200	34	186

Table 5. Aggregate Zero-tillage drill sales and subsidy coverage for 50 surveyed manufacturers in Haryana and Punjab, 2001-2003.

	Haryana		Punjab	
Year	Drills sold	% with subsidy	Drills sold	% with subsidy
2001	1,703	66	1,003	28
2002	2,308	77	1,487	29
2003	3,604	63	3,271	33
2001-03	7,615	69	5,761	31

3.2 Zero-tillage adoption rates

Our random stratified sample of 400 rice-wheat farmers revealed 34.5% to be ZT adopters in 2003-04 (Table 6). ZT adopters are defined here as farmers who used the ZT drill for wheat in untilled fields during rabi 2003-04. The aggregate ZT wheat area planted by the sampled farmers was 26% of the aggregate total wheat area in rabi 2003-04. The divergence between the adoption intensities in terms of households (34.5%) and wheat area (26%) reflects that the surveyed ZT adopters apply ZT to only part of their total wheat area (see section 3.4).

Earlier expert estimates for Haryana State as a whole estimated the ZT/RT area at 350,000 hectares in 2003-04, which corresponds to 38% of the estimated rice-wheat rotation area of 910,000 hectares (Laxmi et al. 2007) and 15% of the state's wheat area of 2.3 m ha (MoA, 2005). Our adoption estimates for the rice-wheat belt thereby fall within a similar range as other expert estimates. However, we should recall that our stratified sampling frame focuses on the rice-wheat heartland and typically comprises the districts where ZT dissemination started and diffusion took off. We may therefore expect our estimates of ZT adoption to be higher than levels in the rice-wheat system as a whole. This suggests that the earlier estimates may actually be rather high. Nonetheless, the present study does empirically confirm the significant levels of adoption of ZT wheat in Haryana's rice-wheat systems, underscoring the appeal of the technology among farmers.

Our random stratified sample of rice-wheat farmers also revealed 10% to be ZT dis-adopters in 2003-04 (Table 6). Disadopters are defined here as farmers who have used ZT in preceding seasons, but did not do so in the 2003-04 rabi season for whatever reason. In cases of temporary disadoption, these disadopters may again adopt ZT in subsequent seasons, an issue we will explore in the next section when discussing adoption history. Nonetheless, a 10% level of disadoption is relatively high and an issue that merits further scrutiny.

Table 6. Breakdown of sample by ZT adoption category (rabi 2003-04).

ZT Adoption category	Share of sample (%) (n=400)
Adopter	34.5 (138)
Non-adopter	55.5 (222)
Disadopter	10.0 (40)
Total	100

Note: Figures in parentheses are number of cases (n).

The present study and adoption figures refer to the use of the ZTD in untilled fields only. The ZTD may also be used in reduced tilled or conventionally tilled fields, but such partial adoption is not included here as ZT. An additional 1.75% (n=7) of surveyed farmers used the ZTD in tilled fields, representing 1.4% of non-adopters (n=3) and 10% of disadopters (n=4).

The survey averages mask significant differences in adoption rates among the districts surveyed (Table 7). Adoption rates vary from a low of 2.5% in Panipat to 60% in Ambala. Yamunanagar district apart, the districts surveyed can be categorized into three broad clusters:[6]

- Limited penetration of ZT (Sonipat, Panipat and Jind): Less than a quarter of households have ever used ZT;
- Intermediate levels of ZT adoption (Kurukshetra, Karnal, Kaithal, Sirsa): 40-45% of households are using ZT; and
- Widespread adoption of ZT (Ambala, Fatehabad): Some three-fifths of households are using ZT.

These clusters tend to be spatially grouped (Figure 3). The districts with limited penetration are the southernmost districts surveyed, comprising the southern part of the rice-wheat belt in the state. The districts with intermediate levels tend to fall in the northeast of the state while districts with widespread adoption are located on the Punjab border.

Table 7. Distribution of ZT adoption categories (% farmers, row-wise) across sample districts.

	Adoption Categories			
Districts	Adopters (n=138)	Non-adopters (n=222)	Disadopters (n=40)	Overall (n=400)
Ambala	60	22.5	17.5	100 (n=40)
Fatehabad *	57.5	35	7.5	100 (n=40)
Kurukshetra	42.5	42.5	15	100 (n=40)
Karnal	40	42.5	17.5	100 (n=40)
Yamunanagar	27.5	47.5	25	100 (n=40)
Kaithal	42.5	50	7.5	100 (n=40)
Sirsa *	45	55	0	100 (n=40)
Jind *	20	77.5	2.5	100 (n=40)
Panipat	2.5	90	7.5	100 (n=40)
Sonipat *	7.5	92.5	0	100 (n=40)
Total	34.5	55.5	10	100

* Districts where ZT promotion has been less intensive

[6] Adoption and disadoption combined reflect the penetration of ZT, whereas non-adoption provides a single indicator that highlights non-penetration of the technology. For this purpose we have ordered the districts in the table in terms of the extent of non-adoption.

The odd district is Yamunanagar. It shows similar non-penetration rates as the intermediate cluster, but the households that have used ZT are split between adopters and disadopters. The district indeed shows the highest disadoption rates amongst the districts surveyed. This district is located in the far northeast of the state and has a significant area of sugarcane-based cropping systems.

The association between prevailing cropping systems and ZT promotion has contributed to the observed spatial diffusion of ZT. To further illustrate this we present the prevailing cropping system in the surveyed districts in table 8. The table confirms that rice-wheat systems predominate across all surveyed districts, typically being the first and occasionally the second cropping system in terms of area.[7] However, there is significant variation in the extent of dominance. In six of the ten surveyed districts rice-wheat system area is a multiple of the next biggest crop system area. These districts are regarded as the rice-wheat belt proper and it is typically here where ZT promotion has been most intensive. In three of the remaining districts (Sirsa, Fatehabad and Jind), the drier northwestern districts surveyed, cotton-wheat systems are prevalent. Cotton-wheat systems tend to have the same problem of late wheat planting. However, crop residue management under ZT is an issue for cotton-wheat systems because of feared carry-over of bollworms on un-incorporated cotton residues. The ZT technology has been less intensively promoted in these districts. In the last district (Yamunanagar), rice-wheat systems are on a par with sugarcane-based systems, and there is also a relatively significant maize-wheat area, but ZT technology has nonetheless been intensively promoted here. The prevailing cropping pattern in Yamunanagar likely contributed to its relatively high disadoption level. Indeed, the prevailing tyne-type ZTDs work well in rice-wheat systems but will not work without prior tillage in former sugarcane fields owing to the persistent root-stocks. 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.

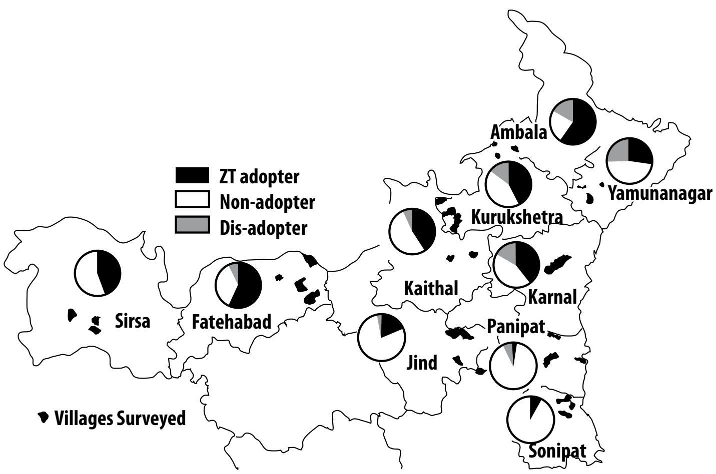

Figure 3. ZT adoption rates by survey location within Haryana State, India.

The contrast between the core rice-wheat districts (Ambala, Kaithal, Karnal, and Kurukshetra) and the cotton-wheat districts is also noteworthy. Significant adoption in the core rice-wheat districts was to be expected, but these districts also show significant disadoption. Cotton-wheat districts combine a range of respectable adoption levels with relatively insignificant disadoption. Two possible factors may have contributed to this. First, the nature of the

Table 8. Prevailing cropping systems in surveyed districts in terms of area (000 ha) and rank (in parentheses).

	Rice-wheat	Sugarcane/ ratoon-wheat	Cotton-wheat	Maize-wheat	Sorghum-wheat	Pearl millet-wheat	Pearl millet-mustard	Pearl millet- gram
Ambala	65 (1)	12 (2)		7.5 (3)				
Fatehabad *	52 (2)		108 (1)				11 (3)	
Jind *	81 (1)		60 (2)			39 (3)		
Kaithal	150 (1)	5.4 (3)				5.7 (2)		
Karnal	161 (1)	10 (2)						
Kurukshetra	97 (1)	14 (2)						
Panipat	69 (1)	5 (2)						
Sirsa *	32 (2)		215 (1)					4 (3)
Sonipat *	62 (1)	11 (3)			15 (2)			
Yamunanagar	20 (2)	21 (1)		3.3 (3)				

* Districts where ZT promotion has been less intensive.
Source: adapted from Yadav and Subba Rao 2001.

[7] The table also reiterates the prevalence of wheat, with all but two of the main cropping systems being wheat based.

original adoption decision: in the core rice-wheat systems some farmers may have been induced into a supply-led decision to try ZT in response to its widespread promotion. In the cotton-wheat systems the decision to try ZT is more likely demand-led. Second, the relatively more recent nature of adoption in the cotton-wheat systems reduces the scope for disadoption. Clarifying the relative role of the cropping system and other factors in disadoption is an issue that merits follow-up.

There is also significant variation in ZT adoption and disadoption by village. In part this can be attributed to the recent nature of its diffusion and its embodiment in a lumpy technology (i.e. a non-divisible piece of machinery). Indeed, village-wise adoption rates amongst our sample farmers vary from 100% to 0%, and disadoption rates from 50% to 0%. Table 9 therefore provides some village-level adoption indicators. The first classifies the village according to the predominant adoption category. This illustrates that in 19 villages (38%) adopters already predominate whereas in the remaining 31 villages non-adoption is still prevalent. The second indicator classifies the villages by each adoption category. The non-adopter column is perhaps easiest to interpret. This illustrates that there are 8 villages (16%) where there had been no penetration of ZT yet (i.e. 100% non-adoption) and 5 villages (10%) where all sampled farmers had used ZT (i.e. 0% non-adoption and thus all adoption and/or disadoption). The latter 5 villages, where all sampled farmers had used ZT, include 3 villages where all sampled farmers used ZT in the survey year. In addition to the former 8 villages where there had been no penetration of ZT, there are 3 villages where limited ZT use had been abandoned. As a result, there were only 11 villages (8+3, 22%) with no ZT adoption in the survey year. Aside from the 8 villages with no penetration of ZT, we can further categorize the 42 villages where ZT had penetrated into 22 villages with no disadoption amongst sampled farms, 14 villages with some disadoption and 6 villages where disadopters outnumber adopters (not shown in table 9). Two important conclusions can be drawn from the village-level data. First, ZT penetration into individual villages had reached a long way but was still not complete at the time of the survey. Indeed, village-wise adoption rates show a considerable gradient from zero to saturation. The latter suggests that ZT has considerable merit and wide applicability once the technology has proven itself within a community. Second, disadoption is typically piecemeal and only occasionally widespread, and likely associated with crop diversification in favor of sugarcane and vegetables.

3.3 Zero-tillage adoption history

The surveyed farmers were asked about when they first used ZT and their use of ZT since. The plotted responses (Figure 4) distinguish between adoption (i.e. those that actually used ZT in the corresponding year, dashed line) and penetration (i.e. those that have ever used ZT by that year, adopters and disadopters combined, solid line). The lines show typically slow initial diffusion during the 1990s followed by the rapid acceleration of ZT adoption from 2000 onwards.[8] The diffusion thus

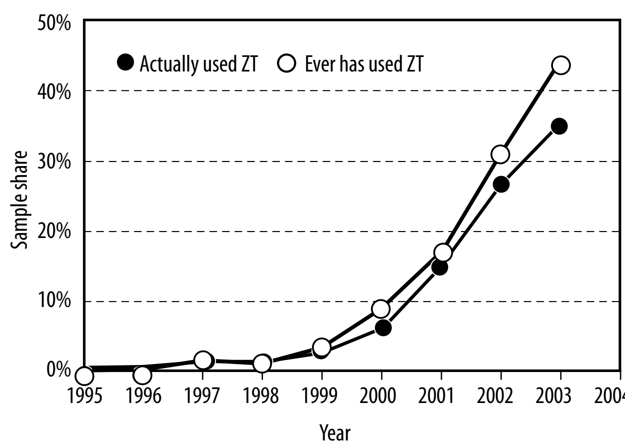

Figure 4. Diffusion of ZT based on first year of use.

Table 9. Distribution of villages by ZT adoption category.

	Adopters	Non-adopters	Disadopters
Number of villages where adoption category dominates (n=50) [a]	19	31	0
Number of villages by adoption category:			
- with 100% of farmers in adoption category	3	8	0
- intermediate	36	37	20
- with 0% of farmers in adoption category	11	5	30
	50	50	50

[a] In case of a tie, adoption dominates disadoption, and disadoption dominates non-adoption.

far follows the typical sigmoid curve, with adoption showing the first signs of deceleration. This suggests 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. The difference between the two lines reflects disadoption, showing a significant increase in disadoption rates during the survey year. However, the actual use of ZT still increased during the survey year, highlighting that new adopters in 2003 far outnumbered disadopters in 2003.

The 10% disadoption is higher than originally expected. It also raises the question of whether the disadoption is temporary or prolonged. Temporary disadoption of ZT may occur when the farmer reverts to conventional tillage in a given year for whatever reason and resumes ZT in a subsequent season. For instance, unavailability of the ZT drill at the appropriate time could be a reason for temporary disadoption. Temporary disadoption could also be associated with unfavorable seasonal conditions for ZT. For instance, untimely rain prior to rice harvesting may cause combiners to create ruts in the fields that need to be evened out through tillage. Untimely rain can also cause a flush of weeds that a farmer prefers to control using a reduced level of tillage. However, in the survey year 2003-04 the critical months of October and November were dry in the study area.[9] Some disadopters perceived that after continuous ZT for 3-4 years, the field must be plowed conventionally for one year, after which they would again revert to ZT. For instance, some worried about soil compaction with continuous ZT, leading them to use conventional tillage for one year or use reduced-tillage systems. Some disadopters reported that the continuous use of ZT in wheat led to slightly undulated fields which hampered irrigation of the subsequent rice crop. Prolonged disadoption may result from a farmer losing access to a functional ZTD or becoming disillusioned with ZT for whatever reason. In the extreme there may be permanent disadoption where a farmer abandons ZT for good, but other disadopters may still revert to ZT under changed circumstances. The next chapter will look further into the factors and constraints affecting the adoption and disadoption of ZT. Our findings suggest that there is no clear single overarching constraint, but a combination of factors at play, including technology performance, technology access, and seasonal constraints. Available data unfortunately do not allow us to fully understand or quantify the nature and underlying rationale of disadoption in the survey year. Better understanding the rationale for disadoption merits further research.

Based on the reported history of ZT-use we can categorize those farmers that have ever used ZT (adopters and disadopters combined) into:

- Prolonged disadopters: farmers who have used ZT in the past but did not use ZT in survey and preceding year.
- Undefined disadopters: farmers who stopped using ZT in survey year but used ZT in preceding year.
- Intermittent adopters: farmers who continue to use ZT in survey year, but with interruption since first use.
- Continuous adopters: farmers who continue to use ZT without interruption since first use.

The categorization of those that have used ZT and for which adoption history is available (n=178), reveals that 74% used ZT continuously (continuous adopters, 131 cases), 4% used ZT intermittently (intermittent adopters, 7 cases) and 4.5% dropped ZT for at least the last two consecutive seasons (prolonged disadopters, 8 cases). The remaining 18% (32 cases) stopped using ZT in the survey year and we can not say whether ZT disadoption is temporary or prolonged (undefined disadopters). However, based on the observed prolonged disadoption and intermittent adoption levels we may assume the undefined disadopters to be similarly split. This implies that the observed 10% disadopters in the survey year for the sample as a whole (40 cases out of 400) would likely comprise around 6.3% prolonged disadopters (8 known + 17 assumed cases) and 3.8% temporary disadopters (15 assumed cases).

Table 10 gives the number of years for which ZT plot data are available—a proxy for the number of years each farmer has used ZT. This shows that half the ZT users have used ZT for only one year. Continuous adopters have typically used ZT for the past one to three years, reiterating the recent acceleration of ZT adoption. Intermittent adopters by definition have used ZT for more than one year, typically 2-3. Prolonged disadopters have all used ZT for a single year, suggesting an unsuccessful experience and/or limited perseverance.

8 The wheat season spans two years. Most wheat data in the present study refer to 2003-04 rabi season unless otherwise indicated. When a single year is mentioned in relation to wheat we refer to the wheat season starting in that year (i.e. 2003 would refer to 2003-04 season).

9 October-November rainfall in Kurukshetra was only 1 mm in 2003 (zero 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) (State Office of the Deputy Director of Agriculture, Kurukshetra, unpublished data).

3.4 Zero-tillage adoption intensity

Surveyed ZT adopters apply ZT to approximately half their total wheat area (Table 11). The fact that farmers do not adopt ZT on their entire wheat area is not surprising in itself. On the one hand farmers may not perceive ZT to be equally suitable to all their land. On the other hand ZT is still a recent arrival, and farmers may gradually increase their farm area under the technology once it has sufficiently proven itself. Stepwise adoption has previously been reported for technological packages (Byerlee and Hesse de Polanco 1986).

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 none of the five years for which (retrospective) data are available is there a discernable difference in ZT area share between these two categories of ZT drill access (Table 12). This suggests that ZT access did not constrain the extent of ZT adoption, provided farmers had some 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 relatively lower tillage costs on-farm (e.g. due to sunk costs of tractor & machinery, assured and timely access, etc) and ZT potentially negatively affecting their future incomes as providers of tractor services. Non-tractor owners indeed had significantly higher ZT adoption intensities (66-91% of wheat area) than tractor owners (around 50% of wheat area), a significant difference persisting over the years (Table 12).

Table 10. Categorization of zero-tillage users based on adoption history (% of farmers, adopters and disadopters only, n=178).

Number of years with ZT plot data	Adoption history				
	Prolonged disadopters	Undefined disadopters	Intermittent adopters	Continuous adopters	Overall
1	4.5	15.2		30.9	50.6
2		2.2	1.7	16.9	20.8
3			1.7	15.2	16.9
4			0.6	7.3	7.9
5		0.6		2.2	2.8
6				1.1	1.1
Total	4.5	18.0	3.9	73.6	100.0

Table 11. Evolution of wheat area share with zero-tillage (%) by adoption category.

Year	Adopters	Disadopters	Overall	Significance (t-test)
2003-04	53 (138)	-	53 (s.d.=37, n=138)	-
2002-03	61 (76)	46 (31)	56 (s.d.=37, n=107)	0.07
2001-02	61 (52)	51 (8)	60 (s.d.=37, n=60)	NS
2000-01	65 (19)	39 (3)	61 (s.d.=38, n=22)	NS
1999-00	70 (8)	80 (3)	73 (s.d.=31, n=11)	NS

Note: Figures in parentheses are number of non-zero cases (n). s.d. = standard deviation.
Non-zero values only, i.e. only includes farmers that used ZT in the respective year in part of their wheat area.

Table 12. Evolution of wheat area share planted with zero-tillage drill (ZTD) (%) by ZTD access and tractor ownership.

	By ZTD access			By tractor ownership		
	Current ZTD owner	Current ZTD rental user	Overall	Tractor owner	Non-tractor owner	Overall
2003-04	57 (55)	51 (83)	53 (s.d.=37, n=138, NS)	48 (99)	66 (39)	53 (s.d.=37, n=138, p=0.01)
2002-03	54 (47)	58 (61)	56 (s.d.=37, n=108, NS)	49 (81)	80 (27)	56 (s.d.=37, n=108, p=0.00)
2001-02	59 (26)	61 (34)	60 (s.d.=37, n=60, NS)	53 (40)	74 (20)	60 (s.d.=37, n=60, p=0.02)
2000-01	56 (6)	63 (16)	61 (s.d.=38, n=22, NS)	47 (15)	91 (7)	61 (s.d.=38, n=22, p=0.01)
1999-00	71 (2)	73 (9)	73 (s.d.=31, n=11, NS)	64 (5)	80 (6)	73 (s.d.=31, n=11, NS)

Note: Figures in parentheses are number of non-zero cases (n). s.d. = standard deviation. p = significance of t-test (comparison between 2 categories).
Non-zero values only, i.e. only includes farmers that used ZT in the respective year in part of their wheat area.

Partial adoption is generally to be expected and in the case of ZT is associated with tractor ownership. More surprising, perhaps, are the limited extent of partial area adoption (only half the wheat area) and the apparent decrease in the ZT area share per farm over time (Table 11). Two factors contribute to this. First, the area share of disadopters is lower than for adopters (Table 11). This is as we would expect, particularly as prolonged disadopters tend to drop ZT after only one year. The disadopters thus somewhat depress the overall area share. Second, and more importantly, recent adopters of ZT are more conservative in terms of their area adoption than early adopters. The increasing numbers of recent adopters thereby both depress the overall area share per farm and explain the decrease in the overall ZT area share per farm over time.

To illustrate this last point, figure 5 plots the ZT share of total wheat area per ZT farm over time for different subsets of ZT adopters. For all adopters and disadopters combined, the area share shows a clear and significant negative trend (y = -0.037 x + 73.901, p=0.05). However, for individual sets of adopters grouped by the number of consecutive years of using ZT prior to 2004 the trend is either positive or non-significant. This underscores that ZT adopters typically maintain or increase their ZT area share over time. Even more striking is the decreasing ZT area share in the first year of adoption. Early adopters who have used ZT for 4-5 consecutive years started initially with a 72-80% area share. This is significantly (p=0.018) higher than the initial 42-43% area share for the late adopters who have used ZT for 1-2 years. The data were collected retrospectively and this may have somewhat biased the estimates of the early adopters for the past years. But for the survey year itself the differences in area share are equally pronounced and significant (p=0.000), with the adoption share for the late adopters being approximately half that of the early adopters. Early adopters having a higher adoption intensity is somewhat contrary to expectations, but can be explained by the relative contribution of tractor owners and non-tractor owners over time. The absolute number of both tractor owners and non-tractor owners adopting ZT has increased over time, but the number of tractor owners (with their lower ZT adoption intensities) increased at a faster rate (Table 12). Consequently, the relative share of non-tractor owners (with their higher ZT adoption intensities) amongst ZT adopters decreased from about half in 1999-2000 to a third in 2000-02 and less than a third in 2002-04 (Table 12).

The adoption intensity discussion has so far focused on the farm level. However, as will be reviewed in the next chapter, adopter categories differ in various other aspects, including farm size. Figure 6 therefore presents the aggregate ZT wheat area share of aggregate wheat area over the 400 farm households combined, an indicator of the area-wise adoption intensity. The figure shows a clear positive linear increase over the last four years, from 3% to 26% of the aggregate wheat area. The increase in the last year suggests a slight leveling off, but on average 7.6% of the aggregate wheat area was converted to ZT per annum.

3.5 Zero-tillage drill ownership

Ownership of a zero-till drill was reported by 15% of households. As expected, drill ownership was significantly higher for adopters (40%), less common for disadopters (10%) and virtually absent amongst

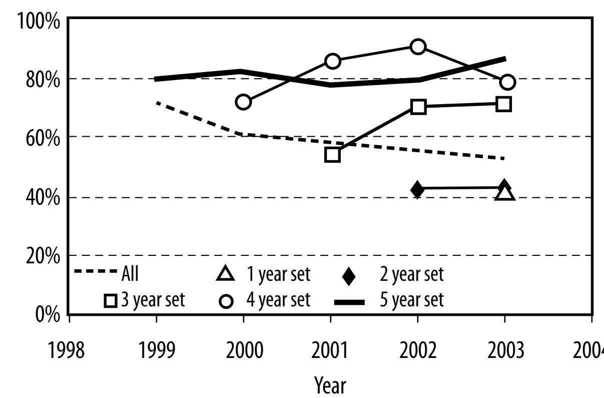

Figure 5. Zero-tillage (ZT) share of total wheat area per ZT farm over time for different subsets of ZT adopters.

Note: Non-zero 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, n=62, 30, 31, 9 and 6 farms respectively).

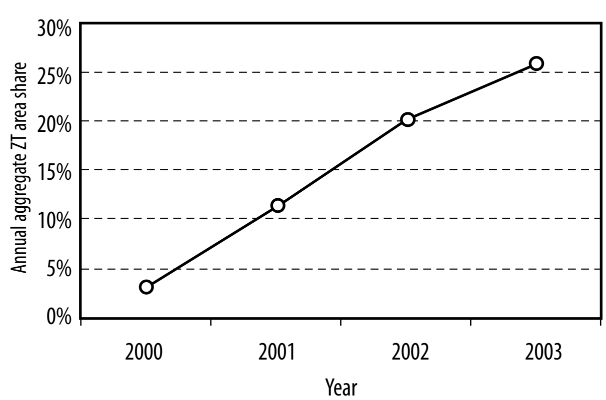

Figure 6. Zero-tillage area share of aggregate wheat area for 400 surveyed farms over time.

non-adopters (1%) (Table 13).[10] All ZTD-owning households also own a tractor. On aggregate, there are 0.23 ZTD per tractor. ZTD-owning farmers often also contract their service to farmers who do not own a drill. This is in line with common tillage practices in these areas, whereby many farmers do not own a tractor and therefore rely on tillage contract services to prepare their fields. Contracted ZT drill services have thereby made the technology divisible and accessible to smallholders without tractors, while tractor owners can put off the investment decision. It is worth highlighting that the current ownership of zero-tillage drills implies that the majority of ZT adopters (60%) relied on contracted ZT drill services at the time of the survey. These current service contractors are more or less equally split between those who have their own tractor and those who do not. Whereas the latter group are likely to remain ZT service contractors unless they acquire a tractor, the former may well acquire their own ZT drill if they continue using the technology. The reliance on contractual services may constrain timely availability of the ZT drill and therefore cause farmers to (partially) forfeit a timely establishment of the wheat crop. However, the reliance on ZTD contractual services did not significantly affect the ZT adoption intensity, as reported above. Also not all ZT drills are available for contract services, something that appears to be an issue limiting adoption in the Punjab, Pakistan (Farooq et al. 2007).

3.6 Zero-tillage information sources

One of the perceived drivers behind the success of ZT in Haryana is the favorable institutional context. Several actors have played key and complementary roles in spreading the ZT technology, including the CCS Haryana Agricultural University (Hisar), the Directorate of Wheat Research (DWR-ICAR, Karnal) and the State Agricultural Department, aided by various sponsored R&D projects from the RWC, CIMMYT, ICAR and the Australian Centre for International Agricultural Research (Laxmi et al. 2007).

ZT adopters and disadopters were asked for their main source of information about this technology. With 70.1% of the 174 responses, fellow farmers clearly emerged as the main source of information for both adopters and disadopters alike. Agricultural extension agencies and scientists were reported by 21% of the respondents (10.9% and 10.3% respectively), with the former category being more common amongst adopters, the latter amongst disadopters. Other infrequently listed sources of information included visits to research station (5.2%), mass media (2.3%), family members (1.7%), input dealers (1.1%) and drill manufacturers (0.6%). Enhanced linkages between public and private sector agents and the possibility of custom hire services of ZT drills may further boost the adoption rate of this technology.

Farmers tend to retain a level of caution about the continuous use of new technologies like this. Some farmers may have expressed worries about the risk associated with zero-tillage because the yield of wheat in a particular year may have been low due to unfavorable weather. To consolidate opinion among farmers and even scientists, it is necessary to demonstrate this technology at permanent sites in a farmer participatory process (Malik et al. 2005a; Malik et al. 2005d).

Table 13. Zero-tillage drill and tractor ownership by adoption category.

	Adopters (n=138)	Non-adopters (n=222)	Disadopters (n=40)	Sample mean (±std.dev.) (n=400)	Significance
Households reporting (%)					
- Tractor	72	53	63	61	0.00
- Zero-till drill	40	1	10	15	0.00
Number per household					
- Tractor	0.83 b	0.55 a	0.70 b	0.66 (±0.61)	0.00
- Zero-till drill	0.40 c	0.01 a	0.10 b	0.15 (±0.30)	0.00

Note: Significance levels are from Chi^2 test (% data) and one-way ANOVA (numerical data). Values followed by different lower-case letters within rows are statistically significantly different (Duncan multiple range test, significance level = 0.10).

[10] The ownership of a ZTD by a non-adopter reflects the use of the ZTD in reduced tillage. Only zero-tillage as such was considered here as adoption. It remains an open question what the disadopters will do with their ZTDs. In case of temporary disadoption, they may continue its use in the subsequent season. The survey did not address the state of the ZTD. Conceivably, some of the owned ZTD may be in disrepair and this may have actually contributed to the disadoption decision.

4 Understanding adoption of zero-tillage

The previous chapter confirmed the rapid and widespread adoption of ZT in Haryana State. However, it also highlighted that adoption is far from universal and that a significant share of households had disadopted ZT. The present chapter analyses the differences at the household level that may help explain the (dis)adoption decision. The first section of this chapter will review the factors that affect ZT adoption. The second section reviews some of the constraints and opportunities in the adoption of ZT drill. The third section presents a multivariate analysis of the foregoing factors.

4.1 Factors affecting adoption

The present section analyzes the various indicators compiled during the adoption survey to identify contrasts and similarities between ZT adopters, disadopters and non-adopters. The various factors that will be presented are (i) farm location, (ii) farmer and household characteristics, (iii) household and farm assets, (iv) land characteristics, (v) sources of farm labor, (vi) access to credit, and (vii) income sources. We present tables of quantitative indicators, providing the mean values for the sample as a whole and for the various adoption classes and highlighting the significance level of the observed differences.

4.1.1 Farm location and village characteristics

Farm location is linked to exposure to various factors that drive and modify farm dynamics, including technology adoption. In the previous chapter mention was made of differential adoption rates between districts, which was in part attributed to the prevalent cropping system in the area. For each household we inventoried the distance to selected locations that were assumed to potentially influence ZT adoption (Table 14). On average, the sample farms were located 21 km from the district head quarters, 20 km from agricultural research stations, 8 km from an agricultural extension office, and 9 km from grain and inputs markets.

Agricultural extension workers and researchers were earlier identified as the second-most important information source about ZT for farmers. Nonetheless, the proximity to an agricultural extension office was the only distance variable that did not differ significantly between adoption classes, possibly as it is an imperfect proxy for farmer extension linkages. On the other hand, disadopters are located closer to agricultural research stations (or KVKs[11]). This explains why, compared to adopters, disadopters more often named researchers as their ZT information source.

Table 14. Distance (km) from sample households to selected locations by adoption category.

	Adopters (n=138)	Non-adopters (n=222)	Disadopters (n=40)	Sample mean (±std.dev.) (n=400)	Significance (ANOVA)
District headquarters	22.9 b	20.0 ab	16.7 a	20.7 (±12.9)	0.02
Agricultural research station (KVK)	22.5 b	19.5 b	15.2 a	20.1 (±13.5)	0.01
Extension office	8.0	7.5	8.4	7.7 (±5.0)	NS
Grain market	9.0 a	8.3 a	10.8 b	8.8 (± 5.6)	0.03
Input market	10.5 b	8.6 a	8.5 a	9.2 (±4.9)	0.00

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

[11] Krishi Vigyan Kendra, outreach stations for Indian agricultural research.

Other distances inventoried included distance to district headquarters, input market and grain market. Disadopters tend to be closest to district headquarters and input markets, and furthest from grain markets, while non-adopters typically take an intermediate position. Proximity to district headquarters (typically the main and nearest urban centre) and input markets both provide incentives for diversification, whereas the reverse is true of proximity to grain markets. The combined effect of these three variables thus provides stronger diversification incentives to disadopters. This may alter the incentives for technology use and thus contribute to the disadoption of ZT, which is primarily used for wheat. On the other hand, proximity to the various locations inventoried is likely associated with access to new information, including new technologies like ZT—which may help explain why they were more likely to try ZT in the first place (compared to non-adopters).

Secondary data from the 2001 population census provide selected village characteristics (ORG 2001). The typically nuclear villages average some 515 households per village (±482 s.d., ranging from 66-2404). Village land ranged from 122 to 3983 hectares, with an average of 754 hectares per village (±674 s.d.). The population pressure on village land was estimated as 4.2 persons/ha (±1.67 s.d., ranging from 1.1-8.5), whereas available village land per village household averaged 1.7 hectares (±0.8 s.d., ranging 0.7–5.3). On average 85% of the village area was cultivated, with nearly all (97%) of the cultivated area irrigated. Widespread rural electrification means 60% of the irrigated area primarily relies on electric tubewells, 32% is primarily canal irrigated and 8% relies on non-electric tubewells. All villages were accessible by paved road (ORG 2001).

4.1.2 Farmer and household characteristics

Technology adoption decisions are part of the livelihood strategy of a farm household, which is to a large extent determined by the assets it commands. The farmer and household social characteristics are important in two respects. First, they comprise elements of the household's human and social capital base. Second, they can in turn modify access to other assets. For each household we determined a number of farmer and household characteristics that were assumed to potentially influence ZT adoption.

On average, the farmer-cum-household head was 42 years old, had 22 years of farming experience and had a family size of 9.6, comprising about equal numbers of male adults, female adults and children (Table 15). Only age was significantly associated with the adoption categories, disadopters being relatively younger. This may be associated with younger farmers being both willing to experiment with new technological options but also less willing to persevere.

Most commonly, the farmer had attended secondary school (39%). The remainder was split between those who had attended no school (23%), primary school (19%), and higher education (19%). Education status was not associated with the adoption categories (Table 16).

Table 16. Educational status of sample farmers by adoption category.

	Non-Adopters (n=138)	Adopters (n=222)	Sample Disadopters (n=40)	Mean (n=400)	Significance
Illiterate (%)	21.0	23.4	25.0	22.8	
Primary school (%)	20.3	19.4	15.0	19.3	
Secondary school (%)	41.3	37.4	42.5	39.3	NS
Higher (%) 17.4	19.8	17.5	18.8		
Total	100	100	100	100	
Education index*	1.6	1.5	1.5	1.5 (±1.0 s.d.)	NS

Note: Significance levels are from Chi^2 test (percentage data) and one-way ANOVA (education index).
* Education index values the education levels as 0, 1, 2, and 3 respectively.

Table 15. Age, farming experience and family composition of sample farmers by adoption category.

	Adopters (n=138)	Non-adopters (n=222)	Disadopters (n=40)	Sample mean (±std.dev.) (n=400)	Significance (ANOVA)
Age (years)	42.8 b	42.7 b	38.2 a	42.3 (±12.3)	0.08
Farming experience (years)	22.5	22.7	18.4	22.2 (±12.6)	NS
Family size (number)	9.9	9.5	9.7	9.6 (±5.5)	NS
- Adult men	3.3	3.4	3.3	3.3 (±2.0)	NS
- Adult women	3.1	2.8	2.9	2.9 (±1.6)	NS
- Children under 16	3.5	3.3	3.4	3.4 (±2.9)	NS

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

About half the farmers belonged either to the Jat Sikh (30%) or Jat (22%) caste, with the remainder split over numerous other castes with 7% or less of the sample. There is an association of caste with the adoption categories (Table 17). Non-adopters are more diverse and less likely to belong to the main two castes. Adopters tend to be Jat Sikh and disadopters Jat.

The majority of the farmers (81%) were members of an organization, with an average of 0.9 memberships per farmer. Most common is the membership of cooperative societies (79%), and to a lesser degree the village panchayat or council (10%). There is an apparent tendency for membership to increase moving from non-adopters, to adopters and disadopters, but for none of the variables is the association significant (Table 18).

4.1.3 Household and farm assets

Farm assets are an indicator of the physical capital a farm household commands, an influential determinant of adoption decisions and the overall livelihood strategy. Physical household assets are not necessarily productive, but they provide further indicators of the relative wealth of the household and its livelihood security. For each household we inventoried a number of farm and household assets. Overall, the surveyed households are well endowed, both in terms of farm and household assets (Table 19 and Table 20).

In terms of farm assets, the possession of a tubewell was near universal (95%), with an average of 1.7 tubewells per household. Tractor ownership was relatively widespread (61%), with an average of 0.7 tractors and 1.1 disc/rotavators per household. However, tractor ownership was significantly less widespread amongst non-adopters (Table 19). Ownership of bullocks (comprising both bulls and male buffalo) was reported by 55% of the households. Bullocks are primarily used for transport from home to field and vice-versa (Erenstein et al. 2007d), with typically a single head per owner. The prevailing tractorisation of tillage and relatively heavy soils means bullock use for land cultivation is now exceptional in the rice-wheat systems of Haryana (only reported in 1% of surveyed wheat plots and 2% of rice plots—see chapter 5), and generally limited to resource-poor farmers with very small holdings. Maintenance cost of bullocks is a constraint, as they must be fed throughout the year, while cultivation needs are seasonal and typically require a pair of bullocks. Ownership of milk animals is near universal, however, with an average of 3.5 milk animals per household.

Ownership of insecticide hand pumps is relatively common (71%), particularly amongst adopters. Other, less-frequently reported, physical farm assets included motorized threshers (17%) and combine harvesters (3%). On average, each household reported 4.6 farm asset categories (excluding ZT drill), this average being significantly higher for adopters than non-adopters (Table 19).

Table 17. Caste category of sample farmers by adoption category (%).

Caste	Adopters (n=138)	Non-adopters (n=222)	Disadopters (n=40)	Sample mean (n=400)	Significance (Chi^2)
Jat Sikh	45	20	30	30	
Jat	14	24	40	22	
Kamboj	7	8	3	7	
Gujar	7	6	3	6	0.00
Saini	3	8	0	6	
Rajput	7	4	5	5	
Others	18	30	20	25	
Total	100	100	100	100	

Table 18. Organizational membership of sample farmers by adoption category.

	Adopters (n=138)	Non- adopters (n=222)	Disadopters (n=40)	Sample mean (n=400)	Significance
Member of :					
- Cooperative societies (%)	79.7	78.4	82.5	79.3	NS
- Village panchayat (%)	10.9	8.6	12.5	9.8	NS
- Market committee (%)	4.3	0.9	2.5	2.3	NA
- Youth club (%)	2.2	0.5	5.0	1.5	NA
- Zila parisad (%)	0.7	0.0	2.5	0.5	NA
Any of the above (%)	81.2	79.3	85.0	80.5	NS
Total number of memberships per farmer	0.98	0.88	1.05	0.93 (±0.58 s.d)	0.12

Note: Significance levels are from Chi^2 (% data) and one-way ANOVA (numerical data).
NA= Not applicable—Chi^2 cannot be interpreted due to many empty cells.

The household assets reflect the households' relative wealth and the prevailing rural electrification levels. In terms of domestic appliances, televisions and sewing machines are near universal (both 93%), with widespread ownership of refrigerators (73%), tape recorders (70%), telephones (57%) and radios (55%). Transport assets are still primarily two-wheeled (bicycle 81%, motorcycle 63%), with car/motor vehicle ownership being reported by 18%. In addition, farm assets such as tractors and bullock carts are also widely used for transportation purposes. On average, each household reported 6.0 household asset categories. Household asset ownership and average asset numbers are significantly associated with adoption categories for a number of assets, typically being significantly higher for adopters and disadopters as compared to

Table 19. Possession of farm assets by adoption category.

	Adopters (n=138)	Non-adopters (n=222)	Disadopters (n=40)	Sample mean (± std.dev.) (n=400)	Significance
Assets (% reporting):					
- Tractor	72	53	63	61	0.00
- Disc/Rotavator	70	54	63	60	0.01
- Tubewell	94	95	93	95	NS
- Combine harvester	3	3	5	3	NS
- Motorized thresher	18	17	8	17	NS
- Insecticide hand pump	83	65	60	71	0.00
- Bullocks	49	58	63	55	NS
- Milk animals	98	98	100	98	NS
- Number of above farm asset categories reported	4.9 b	4.4 a	4.5 ab	4.6 (±1.6)	0.04
Assets (number per household):					
- Tractor	0.83 b	0.55 a	0.70 b	0.66 (±0.61)	0.00
- Disc/Rotavator	1.38 b	0.99 a	1.10 a	1.14 (±1.05)	0.00
- Tubewell	1.86	1.55	1.65	1.67 (±1.47)	NS
- Combine harvester	0.03	0.03	0.05	0.03 (±0.17)	NS
- Motorized thresher	0.18	0.17	0.08	0.17 (±0.37)	NS
- Insecticide hand pump	1.18 b	0.82 a	0.80 a	0.95 (±0.91)	0.00
- Bullocks	0.55	0.66	0.63	0.62 (±0.62)	NS
- Milk animals	3.92	3.28	3.55	3.53 (±2.99)	NS

Note: Significance levels are from Chi^2 (% data) and one-way ANOVA (numerical). Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

Table 20. Possession of household assets by adoption category.

	Adopters (n=138)	Non-adopters (n=222)	Disadopters (n=40)	Sample mean (± std.dev.) (n=400)	Significance
Assets (% reporting):					
- Sewing machine	93	91	100	93	0.14
- Television	93	92	93	93	NS
- Refrigerator	80	68	78	73	0.02
- Tape recorder	79	64	70	70	0.01
- Telephone	67	49	68	57	0.00
- Radio	56	54	60	55	NS
- Bicycle	81	80	88	81	NS
- Motorcycle/Scooter	75	54	70	63	0.00
- Car/Motor vehicle	30	10	23	18	0.00
- Number of above household asset categories reported	6.6 b	5.6 a	6.5 b	6.0 (±2.1)	0.00
Assets (number per household):					
- Sewing machine	1.14	1.09	1.43	1.15 (±.98)	NS
- Television	1.11	1.09	1.17	1.11 (±.78)	NS
- Refrigerator	0.90ab	0.79a	1.05b	0.85 (±.77)	0.10
- Tape recorder	0.86	0.72	0.85	0.78 (±.68)	NS
- Telephone	0.74ab	0.57a	0.80b	0.65 (±.68)	0.02
- Radio	0.57	0.58	0.75	0.60 (±.65)	NS
- Bicycle	1.01	0.88	1.05	0.95 (±.71)	NS
- Motorcycle/Scooter	0.86ab	0.65a	0.98b	0.76 (±.20)	0.01
- Car/Motor vehicle	0.32b	0.12a	0.22ab	0.20 (±.45)	0.00

Note: Significance levels are from Chi^2 (% data) and one-way ANOVA (numerical). Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

non-adopters (Table 20).

Overall, both farm and household assets thus convey a similar message. Adopters are typically endowed with a higher asset base than non-adopters, with disadopters taking an intermediate or similar position. This suggests that the asset base is an important determinant of the ZT adoption decision, likely associated with the farm household's risk-bearing capacity and ability to innovate.

The rice-wheat cropping system in Haryana is primarily located in irrigated areas with tubewell irrigation, sometimes in combination with canal irrigation sources. Farmers universally reported the use of tubewells for the irrigation of rice and wheat. Tubewell ownership is near universal amongst the sample as indicated above; tubewells can also be rented at INR 26 per hr, though this practice is relatively uncommon for wheat and rice cultivation. Farmers rely primarily on electric tubewells (88%) and to a lesser extent diesel tubewells (22%). The pump tends to be 6-10 HP and located at the surface. The inlet tube is typically 4-5 inches and the outlet tube 3-4 inches. The groundwater table depth averages 16 meters, while the average depth of tubewell hole was estimated to be 55 meters.

Interestingly, the reported groundwater table and tubewell depth is greatest for ZT adopters, which may add to their interest in the potential water savings of ZT, as water extraction from greater depth consumes more energy. The adopters tend to have bigger pumps and larger inlet and outlet tubes (Table 21), associated with the greater depths of the groundwater but also reflecting their larger asset base. Groundwater quality is generally adequate, with only 2% of farmers reporting poor quality water.

4.1.4 Land characteristics

Land is a key natural capital for a farm household and access to land is therefore an influential determinant of adoption decisions and overall livelihood strategy. For each household we inventoried land access by season and selected indicators of land use and land quality.

The average land holding size of the surveyed farmers in the study area was 6.7 hectares. This is relatively high compared to the average farm size in Haryana state (2.3 hectares) (MoA 2006), but is consistent with the average reported for rice-wheat systems in Punjab and Haryana (Sharma et al.

Table 21. Characteristics of tubewells by adoption category.

	Adopters	Non-adopters	Disadopters	Sample mean (±std.dev.)	Significance
Tubewell power source (n=393) (% reporting)[a]					
- Electric	90	88	85	88	NS
- Diesel	26	21	20	22	NS
Position of pump (n=395) (% reporting)a					
- Surface	55	66	53	61	0.05
- Submerged	50	39	50	44	0.07
Average depth (m)					
- Water table	17 b	15 ab	14 a	16 (±7, n=397)	0.05
- Tubewell	64 b	50 a	47 a	55 (±29, n=463)	0.00
Average rental rate for tubewell (INR/hr)	28	26	24	26 (±13, n=177)	NS
Pump size (n=394) (% reporting)[a]					
< 6 HP	22	33	25	29	
6-10 HP	49	67	68	61	NA
>10 HP	61	26	25	38	
Diameter of inlet tube (n=395) (% reporting)[a]					
- 7.6 cm (3″)	1	2	8	2	
- 10.2 cm (4″)	41	63	43	53	NA
- ≥12.7 cm (5″)	73	46	55	56	
Diameter of outlet tube (n=395) (% reporting)[a]					
- 5.1 cm (2″)	0	3	8	3	
- 7.6 cm (3″)	50	65	43	57	NA
- 10.2 cm (4″)	58	36	50	45	
- 12.7 cm (5″)	7	2	3	4	

Note: Significance levels are from Chi^2 (% data) and one-way ANOVA (numerical). Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).
[a] Multiple response variable—column sum over response categories ≥ 100% .

2004:104). There is a significant association between operational holding size and zero-tillage adoption (Table 22). Non-adopters of ZT have significantly smaller holdings (5.1 hectares) than farmers who adopted (9.1 hectares) or disadopted (7.4 hectares). The smaller land holdings of non-adopters may reduce their willingness to take the risk of experimenting with a new technology like ZT on part of their holding. The size of operational holding varied very little by season.

Owner operators are predominant (58%) followed by owner-cum-tenants (41%), with pure tenancy being uncommon (2%). The average operational holding (6.7 hectares) comprises primarily owned self-cultivated land (5.1 hectares) and to a lesser extent rented-in land (1.65 hectares). Land tenure reveals two differences amongst adoption categories (Table 22). Non-adopters own significantly less land than adopters or disadopters, reflecting a more limited resource base. Adopters rent in significantly more land than disadopters or non-adopters, suggesting these farmers are less resource-constrained and more commercial, as renting in typically supplements self-cultivated land. In proportional terms, 81% of the land holding is owned—a proportion which is relatively constant over adoption classes (Table 23).

Rice-wheat systems in Haryana rely on irrigation. Tubewells are the predominant irrigation source for the surveyed farmers, with 64% of the operational

Table 22. Land holding (ha) and tenure status by adoption category (rabi 2003-04).

Land tenure category	Adopters (n=138)	Non- adopters (n=222)	Disadopters (n=40)	Sample mean (± std.dev.) (n=400)	Significance (ANOVA)
A. Owner cultivated	6.79 b	3.83 a	6.21 b	5.09 (±6.02)	0.00
B. Net rented/shared in of which:	2.29 b	1.23 a	1.20 a	1.59 (±3.80)	0.03
B1. Rented in	2.39 b	1.24 a	1.42 a	1.65 (±3.70)	0.01
B2. Rented out	-0.10	-0.06	-0.22	-0.09 (±0.63)	NS
B3. Shared in	0.00	0.06	0.00	0.03 (±0.46)	NS
C. Total operational holding (A+B)	9.07 b	5.07 a	7.41 b	6.69 (±7.36)	0.00

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison). Column sums may vary from sums given due to rounding.

Table 23. Share of land owned and land tenure status by adoption category.

Land tenure category	Adopters (n=138)	Non- adopters (n=222)	Disadopters (n=40)	Sample mean (± std.dev.) (n=400)	Significance
Average share of operational area owned (%)	80	82	79	81 (±27)	NS
Tenancy status (% of farmers)					
- Owner operator	52	62	58	58	
- Owner-cum-tenant	46	37	40	41	NA
- Tenant	1	1	3	2	
Sum	100	100	100	100	

Note: Significance levels from one-way ANOVA and Chi^2 respectively. Column sums may not add up to 100% due to rounding.

Table 24. Land use intensity, fallowing, and irrigation source by adoption category.

	Adopters (n=138)	Non-adopters (n=222)	Disadopters (n=40)	Sample mean (±std.dev.) (n=400)	Significance (ANOVA)
Land use intensity (LUI)[a] (%)					
- Kharif 2003	100	99	100	99 (±6)	NS
- Rabi 2003-04	100	99	100	100 (±4)	NS
- Annual	200	198	200	199 (±9)	0.07
Fallow (% reporting)					
- Kharif 2003	0	3.2	0	1.8	0.06
- Rabi 2003-04	0.7	2.7	0	1.8	NS
- Annual	0.7	4.1	0	2.5	0.08
Share of operational area by irrigation source (%) [b]					
- Canal only	1	2	2	1 (±10)	NS
- Tubewell only	55 a	69 b	65 ab	64 (±47)	0.02
- Both canal & tubewell	44 b	29 a	33 ab	35 (±47)	0.02

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

[a] Seasonal LUI = (seasonal area cultivated)/(operational area). Annual LUI = kharif LUI + rabi LUI.

[b] No significant change between the kharif and rabi seasons.

area relying on tubewells only and 35% on tubewells in combination with canal irrigation (Table 24). Non-adopters tended to rely more heavily on tubewells only and adopters on the combination. The prevalence of assured irrigation allows a land use intensity of 199%. The average fallow area amounted to 0.04 hectares per household in each season. Fallow was more frequently reported by non-adopters (4% of households), resulting in a somewhat lower but nonetheless high land use intensity (198%) (Table 24).

For each household we inventoried the main soil type and drainage class (Table 25). Lands were typically well drained, with no significant difference in drainage between adoption classes. In part this reflects the prevailing loamy soils. Sandy loam soils were more frequent amongst non-adopters, whereas clay soils were more frequent amongst adopters and disadopters. The association of soil type with ZT adoption may reflect the prevailing cropping system and therefore adoption incentives, with sandy loam soils favoring more diversified cropping systems.

4.1.5 Sources of farm labor

For each household we inventoried the contribution of the different labor sources to overall farm labor use. On average, family sources still provide approximately half the labor, with casual hired sources contributing 40% and permanent hired sources 12%. There are two marked differences amongst adoption categories (Table 26). First, adopters tend to rely on significantly less family labor. Second, the contribution of permanent labor sources is highest for adopters, significantly lower for disadopters and lowest for non-adopters. There is no significant difference between adoption categories in terms of casual labor. Labor-use patterns are likely associated with family labor availability relative to land. Earlier we have seen that there was no significant difference in terms of household size or composition between adoption classes, but there were significant differences in the size of holding. The relative contribution of permanent hired labor sources seems to reflect this. Adopters also are economically better off and therefore can more easily opt to hire in permanent labor to substitute for family labor. This result also reiterates that adopters seem to be more commercially oriented.

4.1.6 Access to credit

Credit can alleviate financial constraints on a farm household and thereby enable access to productive assets. It can thus be an influential determinant of adoption decisions and overall livelihood strategy. For each household we inventoried credit access and related indicators.

Access to credit sources was reportedly widespread (86%), comprising both formal (68%) and informal (69%) credit sources. Cooperative banks were the main formal credit source and moneylenders the main informal source. There was no significant association between the credit source or availability

Table 25. Soil type and drainage categories by adoption category.

	Adopters (n=138)	Non-adopters (n=222)	Disadopters (n=40)	Sample mean (n=400)	Significance (Chi²)
Main soil type (% of farmers) [a]					
- Sandy loam	12	20	10	17	
- Loam	71	72	80	73	NA
- Clay	36	29	43	33	
Only (sandy) loam type (% of farmers)	64	71	58	67	0.16
Well drained land (% of farmers)	96	97	100	97	NA

[a] Multiple responses possible, so that sums exceed 100%.

Table 26. Relative contribution of labor sources to overall farm labor use (% share) by adoption category.

Labor type	Adopters (n=138)	Non-adopters (n=222)	Disadopters (n=40)	Sample mean (± std.dev.) (n=400)	Significance (ANOVA)
Family	40 a	51 b	50 b	47 (±28)	0.00
Permanent hired	19 c	8 a	13 b	12 (±19)	0.00
Casual hired	41	41	37	40 (±23)	NS
Total	100	100	100	100	

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

Table 27. Sources of credit by adoption category (% of households reporting).

	Adopters (n=138)	Non-adopters (n=222)	Disadopters (n=40)	Sample mean (n=400)	Significance (Chi²)
Credit source:					
- Commercial bank	17	17	8	16	NS
- Cooperative bank	64	62	70	64	NS
- Moneylender	73	67	60	69	NS
- Input dealer	0.7	0.0	0.0	0.3	NA
- Relative	0.0	0.5	0.0	0.3	NA
Any credit source	84	86	88	86	NS
Any formal credit source	68	67	73	68	NS
Any informal credit source	73	67	60	69	NS

and adoption classes (Table 27). Access to credit is facilitated by the widespread rural presence in Haryana State of both formal banking facilities, and credit societies (respectively reported in 20% and 62% of Haryana's villages, ORG 2001).

The average total credit was INR 129,000 per household, with informal sources contributing INR 76,000 and formal sources INR 53,000. Adopters had the highest total credit amounts, primarily a reflection of having the highest informal amounts whereas formal amounts were not significantly different (Table 28). Credit was primarily used for production purposes, irrespective of credit source. Duration of credit from moneylenders and cooperative banks averaged six months, suggesting it is used primarily for working capital, whereas credit from commercial banks averaged several years, suggesting investment purposes (Table 29).

Two issues merit highlighting here. First, the relative contribution of informal sources is noteworthy, both in terms of their prevalence and actual amounts in comparison with formal sources. Second, the association of informal credit with adopters is noteworthy, particularly as various other indicators suggest adopters to be better-endowed and more commercially oriented. This raises questions about the exploitative relationships often associated with informal moneylenders. Moneylenders charged 2.1% per month, double the rate of formal sources (1%) (Table 29). Although adopters did report the lowest monthly interest rate these still amounted to 2%. The relative ease of obtaining a loan from a moneylender—in terms of short response time to loan requests, less stringent demands for collateral or the ability to pay back in farm produce at the time of harvesting—likely contributes to their widespread use. The formal interest rate also does not reflect the generally higher transaction costs, which may involve commissions charged by mediators. The cooperative societies generally provide seasonal crop loans whereby each farmer has a credit limit according to his operational land holding. For instance, if a farmer with 5 hectares has a credit limit of INR 20,000, (s)he would need to meet additional credit needs from other sources such as moneylenders. The credit from cooperative societies also needs to be repaid within a specified period and no new loans will be extended until repayment, whereas moneylenders may be more flexible.

Table 28. Amounts of credit from different sources by adoption category (000 INR).

	Adopters (n=138)	Non-adopters (n=222)	Disadopters (n=40)	Sample mean (± std.dev.) (n=400)	Significance (ANOVA)
Formal credit	63	48	48	53 (±107)	NS
Informal credit	105 b	60 a	66 a	76 (±121)	0.00
Total credit	167 b	108 a	113 a	129 (±187)	0.01

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

4.1.7 Income sources

Household income sources reflect the outcome of the underlying livelihood strategy. For each household we inventoried the proportional breakdown of income, firstly in terms of farming and non-farming, and secondly in terms of contributing activities.

Farming was the main income source across households, contributing 84% of overall household income. The share of farming was significantly higher for adopters than for non-adopters and disadopters (Table 30), highlighting that adopters are more reliant on agriculture. This specialization in part reflects their larger land holding and more commercial orientation. The combination of these factors likely enhances the incentives for adopters to innovate and cut production costs.

Rice and wheat provide the bulk of the farm income, on average an 85% share (Table 31). Other significant contributors are sugarcane (5%), milk

Table 29. Selected credit indicators by adoption category (non-zero values only).

	Adopters	Non-adopters	Disadopters	Sample mean (±std.dev., n)	Signifi-cance (ANOVA)
Credit duration (months)					
- Commercial bank	44	27	36	34 (±34, 65)	NS
- Cooperative bank	6.0 a	6.0 a	6.2 b	6.0 (±6.0, 254)	0.02
- Moneylender	6.1	6.0	6.0	6.0 (±6.0, 273)	NS
Interest rate (%/month)					
- Commercial bank	1.0	1.0	1.0	1.0 (±0.1, 65)	NS
- Cooperative bank	1.0	1.0	1.0	1.0 (±0.1, 254)	NS
- Moneylender	2.0 a	2.1 ab	2.1 b	2.1 (±0.3, 273)	0.10

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

(5%) and vegetables (2%), with a range of other crops as minor contributors. The dominance of rice and wheat income reflects the underlying cropping system. Three issues merit highlighting in terms of differences amongst adoption categories:

- adopters have taken the rice-wheat specialization furthest, with 89% of the farm income share;
- disadopters have the highest contribution of sugarcane (12% farm income share);
- non-adopters have the highest contribution of vegetables (3% farm income share).

Adopters' rice-wheat specialization further strengthens their incentives to adopt new cost- and time-saving technologies like zero-tillage, specifically developed for wheat and widely promoted in these systems. Conversely, non-adopters and disadopters tend to be more diverse in their income sources, reducing their incentives for adoption and possibly reducing their exposure to the ZT technology. Indeed, in crops other than wheat, zero-tillage has not been widely recommended. The relative importance of sugarcane for disadopters may also help explain their disadoption, as sugarcane is often grown in a two-year rotation with wheat.

Non-farm income contributed 16% of overall income across households. Non-agricultural employment was the main contributor (75% non-farm income share), followed by family businesses (16%) and other sources (10%). The share of both non-farm income and non-agricultural employment were significantly lower for adopters than non-adopters and disadopters (Table 32).

Table 30. Relative contribution of farm and non-farm sources to overall income (% share) by adoption category.

	Adopters (n=138)	Non-adopters (n=222)	Disadopters (n=40)	Sample mean (± std.dev.) (n=400)	Significance (ANOVA)
Farm income	89 b	81 a	83 a	84 (±34)	0.00
Non-farm income	11 a	19 b	17 b	16 (±34)	0.00
Sum	100	100	100	100	

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

4.2 Zero-tillage adoption constraints

Each household was requested to rate a number of technical, extension and financial factors in terms of the degree it constrained the adoption of the ZT technology. The results are presented in table 33.

As a group, extension factors rated highest in terms of constraining adoption. All three extension indicators used were rated similarly at an average constraint index of 0.5, implying that they are

Table 31. Relative contribution of farm sources to farm income (% share) by adoption category.

Farm income source	Adopters (n=138)	Non-adopters (n=222)	Disadopters (n=40)	Sample mean (±std.dev.) (n=400)	Significance (ANOVA)
Rice	46.2 b	41.9 a	40.4 a	43.2 (±9.8)	0.00
Wheat	42.7 b	41.8 b	39.1 a	41.9 (±8.4)	0.06
Pulses	0.0	0.8	0.0	0.4 (±3.9)	0.16
Oilseed	0.3	0.2	0.1	0.2 (±1.3)	NS
Vegetable	0.5 a	2.9 b	0.8 a	1.9 (±6.9)	0.00
Sugarcane	4.1 a	4.9 a	11.7 b	5.3 (±13.5)	0.01
Cotton	0.2	0.8	0.5	0.5 (±3.3)	NS
Other crops (e.g. fodder, millet)	1.3	1.6	2.2	1.6 (±5.4)	NS
Milk	4.6	5.1	5.2	4.9 (±5.1)	NS
Total farm	100	100	100	100	

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

Table 32. Relative contribution of non-farm sources to non-farm income (% share) by adoption category.

Farm income source	Adopters (n=35)	Non-adopters (n=104)	Disadopters (n=13)	Sample mean (±std.dev.) (n=152)	Significance (ANOVA)
Family business	25	13	15	16 (±34)	NS
Non-agri. employment	62	79	71	75 (±35)	0.05
Other	13	8	15	10 (±17)	NS
Total non-farm	100	100	100	100	

Note: Column sums may not add up to 100% due to rounding.

moderate constraints. Interestingly, the three indicators highlighted significant and consistent differences between adoption categories (Table 33). Firstly, they were rated highest by non-adopters, suggesting that non-adopters were lacking 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 as the technology continues to diffuse. Indeed, informal sources have been the prevailing source of ZT information (see section 3.6 above). Secondly, adopters and disadopters gave similar ratings. This suggests that knowledge of ZT technology was not an underlying reason for discontinuing its use.

As a group, financial factors rated second in terms of constraining adoption (Table 33). The most serious constraint was the perceived high cost of the ZT drill (constraint index of 0.4). This was particularly seen as a constraint by non-adopters. However, disadopters also rated this constraint significantly higher than adopters, suggesting this is one factor that contributed to their discontinuation of ZT. For the three other financial indicators, non-adopters' ratings were consistently highest, but there was no significant difference between adopters and disadopters. This reiterates that the non-adopters are more resource-constrained, and that this may have contributed to their reluctance to adopt ZT so far.

As a group, technical factors were rated relatively low in terms of constraining adoption. There were also only a few factors that were significantly different between adoption categories (Table 33). The two most important constraints were the non-availability of high-quality ZT drills and the lack of local manufacturing and/or repair facilities for ZT drills. Interestingly, these constraints were primarily raised by non-adopters, and considered insignificant by adopters and disadopters. This again suggests that there is still scope for further diffusion of the technology, and that these constraints were not related to discontinuation. Relatively minor constraints related to the time of planting included the standing stubbles and crop residues, dense populations of weeds and lack of appropriate soil moisture, but none of these showed significant differences between adoption categories.

The list of factors to be rated was largely similar for all households irrespective of adoption category, although some factors were solely rated

Table 33. Constraint indexes for zero-tillage adoption by adoption category (0: no constraint; 1: very serious constraint).

Factor groups / factors	Adopters	Non-adopters	Disadopters	Sample mean (±std.dev., n)	Significance
Technical factors					
- Non-availability of high-quality ZT drills	0.03 a	0.44 b	0.09 a	0.26 (±0.41)	0.00
- Lack of local manufacturing/ repair facility for ZT drills	0.04 a	0.40 b	0.05 a	0.24 (±0.40)	0.00
- Standing stubbles/crop residues at time of planting	0.14	0.18	0.18	0.17 (±0.30)	NS
- Dense population of weeds at the time of planting	0.07	0.09	0.13	0.09 (±0.23)	NS
- Lack of appropriate soil moisture at time of planting	0.05	0.09	0.05	0.07 (±0.22)	NS
- Risk of increased problem with insect pests and diseases	0.02	0.02	0.03	0.02 (±0.13)	NS
- Hardening of upper soil	0.02	0.02	0.03	0.02 (±0.11)	NS
- Early harvesting of rice	0.04	0.10	-	0.07 (±0.22)	0.01
- Straw burning	0.00	0.00	-	0.05 (±0.359)	NS
- Lack of good irrigation water	0.00 a	0.04 b	0.00 a	0.02 (±0.13)	0.01
- No significant difference in yield	-	-	0.50 (±44,39)	-	NA
- Increased weed problem following adoption of ZT	-	-	0.15 (±35,39)	-	NA
- No significant cost savings	-	-	0.08 (±24,39)	-	NA
- Increased irrigation water requirement	-	-	0.03 (±11,39)	-	NA
Extension factors					
- Lack of technical assistance from extension worker	0.37 a	0.61 b	0.35 a	0.50 (±37, 399)	0.00
- Non-availability of extension literature on ZT methods	0.38 a	0.59 b	0.34 a	0.49 (±37, 399)	0.00
- Lack of coverage of ZT method by mass media	0.34 a	0.57 b	0.38 a	0.47 (±36, 399)	0.00
Financial factors					
- High cost of ZT drill	0.18 a	0.50 c	0.31 b	0.37 (±43, 399)	0.00
- Farmer lacks resources to purchase ZT drill	0.11 a	0.36 b	0.16 a	0.25 (±37, 399)	0.00
- No credit available for purchasing ZT drill	0.09 a	0.29 b	0.13 a	0.21 (±35, 399)	0.00
- No credit available for purchasing other inputs	0.07 a	0.22 b	0.10 a	0.16 (±30, 399)	0.00

Note: ANOVA used for 3-column comparisons; data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison). For 2-column comparisons t-test used.

by disadopters. For the disadopters the lack of a significant difference in yield stood out as the single most serious constraint (constraint index of 0.5), contributing to their discontinuation of the technology. Relatively minor constraints for disadopters related to the increased weed problem following adoption of ZT and the lack of significant cost savings.

4.3 Logit analysis

The previous sections have reviewed the linkages between various indicators and the adopter categories on a bivariate basis. The present section employs multivariate analysis, whereby various indicators are included in a single adoption model to analyze their combined effect on the likelihood of ZT adoption. The factors affecting the farm-level decision to adopt ZT were analyzed using the logit regression model, a standard limited-dependent variable approach.

We present two different binomial logit models. The first model reflects the penetration of ZT, using as dependent variable whether the household ever used ZT. The second model reflects current use of ZT, using as dependent variable whether the household used ZT in the survey year (2003-04). The dependent variable is dichotomous, and takes the value of one when ZT is used and zero when it is not (Table 34). The contrasts between the two models highlight some of the factors particularly associated with disadoption.

The independent variables included in the adoption models cover a range of relatively fixed and exogenous characteristics of farm households that are expected to be associated with the ZT adoption decision. The adoption models allow us to test whether the previously hypothesized factors affect—positively or negatively—the farm-level decision to adopt ZT (Morris 2003). Not all variables originally hypothesized could be included in the final models: some variables proved to be highly correlated, and some were not unambiguously measured or proved non-discriminating. For consistency reasons, we retained the same explanatory variables as in the Pakistan study (Farooq et al. 2007). The descriptive statistics of the independent variables included in the empirical models are given in table 34.

The independent variables cover a range of livelihood indicators. The distance to district headquarters (typically the main and nearest urban centre) is a proxy for remoteness of the farm and thereby is expected to modify access to resources, markets and information. The exact effect of ZT is ambiguous though, particularly as proximity to district headquarters combines the ZT-favoring 'exposure effect' with the ZT-undermining 'diversification effect' (see 4.1.1). ZT promotion in the district enhances the relative exposure of farm households to the technology and is expected to be

Table 34. Descriptive statistics for variables used in empirical models.

Description	Mean	Std.dev.	Min.	Max.	Cases
Independent variables					
Distance to district headquarters (km)	20.7	12.9	4.0	50.0	400
ZT Promotion in district (1:yes, 0:no)	0.60	0.49	0	1	400
Farm size (total operational holding, rabi 2003-04, ha)	6.7	7.4	0.4	59.9	400
Only (sandy) loam soils (1:yes, 0:no)	0.67	0.47	0	1	400
Share operational area with canal irrigation	0.36	0.47	0.0	1.0	400
Asset index (number of assets owned by household/16)	0.66	0.20	0.13	1.0	400
Any formal credit source (1:yes, 0:no)	0.68	0.47	0	1	400
Age of household head	42	12	19	80	400
Education index for household head	1.5	1.0	0	3	400
Family size	9.6	5.5	2	30	400
Household head belongs to prevailing caste (Jat (Sikh), 1:yes, 0:no)	0.52	0.50	0	1	400
Number of organizational memberships	0.93	0.58	0	3	400
Specialization index (fraction of household income from rice-wheat)	0.72	0.23	0.10	1.00	400
Dependent variables					
Ever used ZT (1:yes, 0:no)	0.445	0.498	0	1	400
Used ZT in 2003-04 (1:yes, 0:no)	0.345	0.476	0	1	400

positively associated with ZT adoption.

Three land resource-related indicators include farm size, the prevalence of (sandy) loam soils and the relative area with canal irrigation. Farm size is expected to be positively associated with adoption for a number of reasons, including returns to scale, risk-bearing capacity and access to resources and information. ZT also potentially alleviates serious timeliness constraints on wheat establishment on larger farms. The prevalence of (sandy) loam soil type is expected to be negatively associated with rice-wheat systems and farmers' interest in ZT. Light soils are easier to plow and so the potential time saving of ZT would be less important since turnaround is already faster (P.R. Hobbs, personal communication, 2007). The expected association between relative area with canal irrigation and adoption is uncertain. With the prevalence of tubewell irrigation, canal irrigation reflects a higher asset base. However, it also means cheaper and more diverse irrigation sources, which could reduce the incentives for using resource-conserving technologies such as ZT.

The asset index is a proxy for the physical asset base and wealth of the household and is closely associated with tractor ownership. It is expected to be positively associated with ZT adoption through enhancing investment and risk-bearing capacity and access to resources and information. Access to formal credit enhances the financial asset base and is expected to be positively associated with investment in agricultural machinery such as ZT.

The models include five human and social indicators, including farmer age, farmer education, family size, whether the farmer belongs to a prevailing caste and the farmer's number of organizational memberships. Age is closely correlated with farming experience and is expected to be negatively associated with ZT in view of the more entrepreneurial nature of younger farmers. Education reflects human capital and access to information and is expected to be positively associated with ZT. Family size is expected to be negatively associated with ZT through the likely availability of family labor. Belonging to the prevailing caste is expected to be associated with adoption. On the one hand, it could imply more social capital and better access to resources and information. On the other hand, minority castes may be more entrepreneurial and willing to take on new technologies. Organizational membership is expected to be positively associated with adoption through enhancing social capital and enabling access to resources and information.

The final independent variable is the rice-wheat specialization index, reflecting the livelihood strategy of the household. Specialization in rice-wheat means less reliance on both non-farm income sources and other farm income sources like livestock and other crops. It is expected to be positively associated with ZT adoption, as specialization strengthens the incentive to adopt new time- and cost-saving technologies like zero-tillage for wheat.

Results

The results of the two logit models are presented in table 35. The model predict 67-71% of the cases correctly. Several of the explanatory variables are statistically significant in explaining ZT adoption, and significant variables also have the expected algebraic signs.

The ZT penetration model highlights the significant role of seven independent variables. In decreasing order of significance: ZT promotion, remoteness and farm size (at the 1% level), canal irrigation, assets and rice-wheat specialization (5% level), and (sandy) loam soils (negative) (10% level). The ZT current-use model highlights five significant independent variables: rice-wheat specialization, remoteness and ZT promotion (1% level), and farm size and assets (5% level). The models thereby reiterate that ZT adoption is closely associated with a more favorable

Table 35. Factors affecting ZT use (2 binomial logit models, normalized on non-users of technology).

	Model 1: ZT use ever	Model 2: ZT use 2003-04
Independent variable	**Regression coefficient**	
Constant	-4.00 (0.92)***	-5.31 (0.97)***
Distance to district headquarters (km)	0.036 (0.012)***	0.035 (0.012)***
ZT Promotion in district (dummy)	1.64 (0.34)***	0.97 (0.33)***
Farm size (ha)	0.065 (0.022)***	0.046 (0.019)**
Only (sandy) loam soils (dummy)	-0.42 (0.24)*	-0.17 (0.24)
Share operational area with canal irrigation	0.64 (0.27)**	0.36 (0.27)
Asset index	1.55(0.71)**	1.64 (0.74)**
Any formal credit source (dummy)	-0.22 (0.27)	-0.28 (0.27)
Age of household head	-0.0058 (0.010)	0.0064 (0.011)
Education index for household head	-0.024(0.13)	0.033 (0.13)
Family size	-0.017 (0.024)	-0.0072 (0.0251)
Household belongs to main caste (dummy)	0.32 (0.24)	0.0013 (0.2487)
Number of organizational memberships	0.22 (0.22)	0.084 (0.213)
Rice-wheat specialization index	1.16 (0.54)**	2.38 (0.60)***
Model parameters		
Cases predicted correctly (%)	67	71
Log-likelihood	-234	-225
Chi-squared	82	66
Degrees of freedom	13	13
Significance level	.000	.000
Valid cases	400	400

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

resource base and rice-wheat specialization. However, they also highlight the importance of location, both in terms of exposure to ZT promotion and remoteness. The significant contribution of remoteness suggests that the 'diversification effect' dominates the 'exposure effect' for ZT.

The contrast between our two models also generates some insights into current adopters and disadopters. ZT promotion, remoteness and assets appear equally important in both models, suggesting their importance for adopters and disadopters alike. The relative role of farm size and rice-wheat specialization differs between the models. Farm size played an important role in trying out the technology, but less so in continuing with its use. Conversely, rice-wheat specialization played a particularly important role in continuing with the technology, and less so in trying it out initially. The two other significant variables are specific to the penetration model. In this regard, canal irrigation enhanced and predominantly (sandy) loam soils reduced the likelihood of trying out the technology, but did not significantly affect the likelihood of its continued use.

Characteristics of farm households therefore contribute significantly to the explanation of the observed adoption and disadoption patterns. Granted, 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. Similarly, they do not capture variations in the prevailing cropping pattern (e.g. importance of sugarcane and/or crop diversification) that were alluded to when considering district-level adoption differences in the previous chapter. In the end though, adoption and disadoption can be expected to reflect the underlying performance of the technology in the farmers' fields, an issue we explore in the next chapter.

5 Technical impact of zero-tillage 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 carry-over effects on the subsequent rice crop are reported (Inayatullah et al. 1989; Srivastava et al. 2005). The present chapter presents the technical impact of the ZT technology in farmers' fields, by analyzing 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 contrast the ZT fields with conventional fields, distinguishing between the conventional fields of ZT adopters, non-adopters and disadopters (see methodology). This differentiation allows us to test for eventual differences between the three types of plots. Indeed, the previous chapter has highlighted significant differences at the household level that helped explain the (dis)adoption decision, but these are also likely to influence crop management practices. Adopters and disadopters may also have adapted their 'conventional' crop management practices after having used ZT. However, contrasting our data on conventional plots with earlier diagnostic studies (Harrington et al. 1993) suggests this is not the case. Furthermore, in the absence of a 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 conventional tillage 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 using conventional tillage on better ones because ZT is still under evaluation in the early adoption phase and/or conventional tillage performs poorly there. Although we cannot control for all such considerations, the available data at least show no significant difference in terms of soil type between ZT and conventional plots on adopter farms. Therefore, we prefer to err on the side of caution and assume that the comparison between the ZT plots and the conventional plots of adopters is the least biased assessment of ZT's impact. The first section of this chapter will review the effects on the wheat crop. The second section reviews the carry-over effects on the rice crop.

5.1 Wheat crop

The 499 surveyed wheat plots were mainly made up of loam (53.3%) and to a lesser extent sandy loam soils (12.8%), clay (17.4%) and mixed soils (16.4%). There was no significant difference between the soil types in ZT plot types (Table 36). The average wheat plot size was 5.6 hectares. With an average farm size of 6.7 hectares, this reemphasizes the prevalence of wheat in the cropping system. The conventional plot of ZT adopters was significantly larger than the other types, reiterating both the underlying farm size differences and the prevalence of partial adoption (in terms of wheat area) (Table 36).

Table 36. Selected characteristics of wheat survey plots reported by adoption category.

		Conventional wheat				
	Adopters, ZT plot (n=138)	Adopters, non ZT plot (n=99)	Non-adopters (n=222)	Disadopters (n=40)	Overall (n=499)	Significance
Plot size (ha)	5.01 a	7.45 b	5.03 a	5.63 a	5.61 (±6.97 s.d.)	0.01
(Sandy) loam soil type (% reporting)	65	62	70	60	66	NS

Note: Significance levels are from one-way ANOVA and Chi^2 respectively. Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

5.1.1 Impact of zero-tillage on wheat management

Land preparation and establishment

ZT intrinsically affects land preparation and wheat establishment. Conventional land preparation for wheat is primarily mechanized using 4-wheel tractors, with only 1.4% of plots also reporting the use of animal traction (Table 37). Conventional land preparation practices are very intensive, with an average of 4-5 tractor plowings (with a maximum of 8) and 3 tractor plankings (with a maximum of 5) per plot (Table 37). The combination of widespread tractor ownership and availability of tractor custom hire services in the surveyed area seems to have contributed to this extravagance in tillage operations in the rice-wheat cropping system.

ZT wheat requires the use of a tractor-drawn ZT drill and seeding is achieved in a single pass. Conventional wheat establishment is primarily manual (seed broadcasting) and to a lesser extent tractor-drawn seed drills are used. Mechanized planting in conventional plots was least common in non-adopters' plots (26%) and significantly higher in the adopters' conventional plots (45%) and disadopters' plots (38%) (Table 37). This likely reflects their more widespread ownership of tractors and larger farm sizes, and therefore is not unambiguously linked to their use of ZT as such. The advent of ZT, however, fits in with the trend towards mechanization, with half of the surveyed wheat plots now being established mechanically.

Land preparation and establishment involve an average of 8 tractor operations for conventional wheat plots (with a maximum of 13), against a single operation for ZT (Table 37). An earlier diagnostic study reported an average of 8 tillage operations in Haryana-India, 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 conventional tillage practices deviate little from the earlier study, although mechanized sowing has gained ground and is now reported in 32% of conventionally tilled fields. The total number of tillage operations in conventionally tilled wheat plots (8.2 including any cultivation to cover broadcast seed) did not vary between soil types or adopter categories. Adopters did reportedly use slightly fewer plowings in their conventional plots, but this was canceled out by their increased reliance on mechanized planting. The results therefore confirm that ZT drastically reduces tractor operations in farmers' ZT fields. However, contrary to expectations, there is no significant spillover effect in terms of reducing tillage intensity in 'conventional' plots. Moreover, the reported intensity of tillage is such that only 1 case (0.2%, a non-adopter) could be classified as using reduced tillage (i.e. a maximum of two plowings).

The number of tractor operations translates into equally pronounced differences in number of tractor hours and diesel use (Table 38). Conventional tillage entails a per hectare use of 8-8.5 tractor hrs and 48-49 liters of diesel. This contrasts with the 2.2 tractor hours and 12 liters of diesel reported for ZT, which

Table 37. Wheat establishment operations reported by plot category.

		Conventional wheat				
	Adopters, ZT plot (n=138)	Adopters, non ZT plot (n=99)	Non- adopters (n=222)	Disadopters (n=40)	Overall (±std.dev., n) (n=499)	Significance (ANOVA)
Tillage operations with tractor (number/season)						
- Plowing	0 a	4.45 b	4.83 c	4.73 c	3.41 (±2.34)	0.01
- Planking	0 a	3.09 b	3.12 b	2.93 b	2.23 (±1.59)	0.01
- Mechanized planting	1.00 c	0.45 b	0.26 a	0.38 b	0.51 (±0.50	0.00
Total number with tractor	*1.00 a*	*7.99 b*	*8.20 b*	*8.03 b*	*6.15 (±3.54)*	*0.01*
Tillage operations with animal (number/season)						
- Plowing	0	0.02	0.09	0	0.04 (±0.36)	NS
- Planking	0	0.01	0.07	0	0.03 (±0.28)	NS
Total number with animals	*0*	*0.03*	*0.15*	*0*	*0.07 (±0.63)*	*NS*
Total tillage operations (tractor or animal, number/season)	*1.00 a*	*8.02 b*	*8.36 b*	*8.03 b*	*6.23 (±3.48)*	*0.01*
Use of animal traction (% reporting)	0	1.0	2.7	0	1.4	NS

Note: Significance levels are from one-way ANOVA, except last row from Chi^2 test. Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).
Column sums may not be the same as sums given due to rounding.

give a saving of some 6 tractor hours and 36 liters of diesel (compared to adopters' conventional plots). For the planting operation alone, ZT plots report higher resource use (of time and diesel) (Table 38), reflecting both less widespread use of mechanized planting in the non-ZT plots and less resource consumption by mechanized planting in non-ZT plots as the field is already plowed and so less tractor power is required. Farmers' urge to save time and money on tillage operations is likely to enhance the spread of this technology in rice-wheat systems and spill over to other cropping systems. The overall time saving enhances farmers' ability to complete the wheat establishment operation well good time, while the diesel savings are increasingly attractive in view of rising oil prices.

Overall, the mean sowing date for wheat reported by farmers was 12 November, with a standard deviation of some 10 days across plots. As expected, ZT plots were established earliest on average (Table 39), which will contribute to enhanced wheat yields. However, the margin of 3-5 days as compared to non-adopter and disadopter plots is perhaps less than expected, while the dates were not significantly different from the conventional plots of adopters. Ownership of a ZTD did not significantly alter the sowing date for ZT plots, suggesting that reliance on ZT service providers did not delay wheat establishment. Ownership of a tractor did significantly advance the wheat sowing date, albeit by only 2 days (11 November vs 13 November, p=0.01). The type of preceding rice crop proved more influential. Average

Table 38. Duration and diesel use of mechanized wheat establishment operations reported by plot category.

		Conventional wheat				
	Adopters, ZT plot (n=138)	Adopters, non ZT plot (n=99)	Non-adopters (n=222)	Disadopters (n=40)	Overall (±std.dev., n) (n=499)	Significance (ANOVA)
Duration of tillage operations (tractor hrs/ha)						
- Plowing	0.00 a	5.55 b	6.03 c	5.90 bc	4.25 (±3.03)	0.00
- Planking	0.00 a	1.96 bc	2.02 c	1.85 b	1.44 (±1.03)	0.00
- Mechanized Planting [1]	2.22 c	0.70 b	0.40 a	0.61 b	0.97 (±1.02)	0.00
Total duration	*2.22 a*	*8.19 b*	*8.44 b*	*8.36 b*	*6.67 (±3.33)*	*0.00*
Diesel consumption for tillage operations (l/ha)						
- Plowing	0.00 a	33.4 b	36.1 c	34.8 bc	25.5 (±18.3)	0.00
- Planking	0.00 a	11.3 b	11.3 b	10.5 b	8.1 (±6.2)	0.00
- Mechanized Planting [1]	12.1 c	3.2 b	1.9 a	2.9 b	5.1 (±5.4)	0.00
Total diesel consumption	*12.1 a*	*48.0 b*	*49.3 b*	*48.2 b*	*38.7 (±20.2)*	*0.00*

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

[1] Across all plots, irrespective of whether they use mechanized planting or broadcasting (i.e. includes 0 values). Taking out 0 values, ZT plots and non-ZT plots still differ significantly, both in terms of duration (2.22 vs 1.55, p=0.00, n=254) and diesel use (12.1 vs 7.3, p=0.00, n=254). Non-ZT plots do not differ amongst themselves.

Table 39. Wheat seed and planting practices reported by plot category.

		Conventional wheat				
	Adopters, ZT plot (n=138)	Adopters, non ZT plot (n=99)	Non- adopters (n=222)	Disadopters (n=40)	Overall (±std.dev., n) (n=499)	Significance
Planting date (day in November)	10 a	12 ab	13 b	15 c	12 (±9.85)	0.01
Labor required for planting (hrs/ha)	2.07 b	1.98 b	1.77 a	1.74 a	1.87 (±0.53)	0.01
Seed rate (kg / ha)	109	110	110	109	109 (±13)	NS
Main variety (% reporting)						
- PBW 343	91.2	87.9	88.3	92.5	89.4	NS
- Others	8.8	12.1	11.7	7.5	10.6	
Seed source (% reporting)						
- Own	61.6	60.6	60.8	75.0	62.1	NS
- Purchased	38.4	39.4	39.2	25.0	37.9	

Note: Significance levels are from one-way ANOVA (numerical data) and Chi^2 (%). Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

wheat planting date varied significantly depending on the farms' rice specialization: for superfine rice it was 9 November, evolved basmati 13 November, and traditional basmati 15 November (p=0.00, n=474). Earlier wheat sowing is a major factor that could increase wheat yields in the region. Terminal heat means that wheat yield potential falls by 1-1.5% per day of delay if planting occurs after 20th November (Hobbs and Gupta 2003a; Ortiz-Monasterio et al. 1994; Randhaw et al. 1981).

Farmers reported an average seed rate of 109 kg/ha, somewhat above the recommended seed rate of 100 kg/ha for timely-sown wheat. The use of the ZTD is potentially seed saving as compared to broadcasting, without any yield loss, but no significant difference in reported seed rates was observed between plots (Table 39). This may reflect farmers' reluctance to reduce seed rates. The results show that labor needs for the sowing operation are somewhat higher for ZT plots as compared to conventional plots (Table 39). This is associated with the general practice of having a laborer sit behind the ZTD to ensure the smooth operation of the ZTD and directly solve any problems caused by the crop residues that remain in the field.

In terms of variety use, the results confirm the widespread preference of farmers for PBW 343—reported in 89% of the wheat plots. The prevalence of a single variety over large areas is worrying in view of the underlying risk from any resistance breakdown. This concern has become even more pressing in view of their susceptibility to Ug99, a virulent new strain of wheat stem rust (Mackenzie 2007; Raloff 2005). Although seed reuse still prevails (62%), 38% reported the use of purchased seed.

Nutrient management

All wheat plots received applications of chemical fertilizers, with a near-universal use of urea and di-ammonium phosphate (DAP) and sporadic use of single super phosphate (SSP), zinc, potash and bio-fertilizers. The use of farmyard manure (FYM) in wheat plots was negligible.

Overall, 246 kg of NPK per hectare were applied to wheat on average, comprising 187 kg of nitrogen, 58 kg of phosphorus and 1 kg of potash. Nitrogen use is more than the recommended dose of 150 kg N/ha. Prevailing rice residue management practices and soils entail limited need for additional potash, which is recommended only in some districts of Haryana (Ambala and Yamunanagar). The increased use of fertilizer over the last 40 years has been a major contributor to yield growth in rice-wheat systems. The use of ZT is potentially fertilizer-saving, particularly using the ZT seed-cum-fertilizer drill which places the basal fertilizer in the row at time of planting. However, there was no significant difference in phosphorus use, and in fact the highest average nitrogen-use rates were reported in ZT plots (197 kg N/ha), the lowest in disadopters plots (176 kg N/ha) (Table 40). This could be associated with the perception of some farmers that slightly higher

Table 40. Wheat fertilization practices reported by plot category.

		Conventional wheat				
	Adopters, ZT plot (n=138)	Adopters, non ZT plot (n=99)	Non- adopters (n=222)	Disadopters (n=40)	Overall (±std.dev., n) (n=499)	Significance
Chemical nutrient application rates						
- Nitrogen (kg N/ha)	197 c	188 bc	183 ab	176 a	187 (±37)	0.01
- Phosphorus (kg P_2O_5/ha)	58.7	57.6	57.0	57.9	57.7 (±11.6)	NS
- Potash (kg K_2O/ha)	0.81	1.87	0.67	0	0.89 (±7.74)	NS
- Zinc (kg/ha)	0.23	0.18	0.22	0.22	0.22 (±1.34)	NS
- Sulfur (kg/ha)	0.22	0.09	0.11	0.11	0.14 (±0.93)	NS
- Total nutrients (kg NPK/ha)	256 c	247 bc	241 ab	234 a	246 (±41)	0.01
Main types of chemical fertilizer (% reporting)						
- Urea	100	100	100	100	100	NS
- DAP	99.3	99.0	99.1	100	99.2	NS
- Zinc Fertilizer	2.9	2.0	2.7	2.5	2.6	NS
- SSP Fertilizer	0.7	0	0	0	0.2	NS
- Potash Fertilizer	1.4	3.0	0.9	0	1.4	NS
Bio-fertilizer use (% reporting)	2.9	3.0	1.4	0	2.0	NS
FYM use (% reporting)	0	0	0.9	0	0.4	NS

Note: Significance levels are from one-way ANOVA (numerical data) and Chi^2 (%). Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).
SSP= single super phosphate, FYM = farmyard manure.

N rates help in the decomposition of stubbles and loose straw and compensate for N immobilization, and thus avoid yellowing of the crop. However, the observed differences in N application rates in the survey seem primarily associated with relatively high N use by the adopters, as the ZT plot rates do not differ significantly from their conventional plots. The higher N use by adopters is likely associated with their more favorable resource base. Long-term on-farm sites across 6 locations in Haryana, run for the last 8 years by CCS HAU, Hisar, also show no increase in nitrogen use with zero-tillage under farmers' practice. Since N is the principal nutrient, total nutrient use shows a similar pattern across adoption categories (Table 40).

Weed, pest and disease management

Nearly all sample wheat plots were weeded, whereas only 1% of plots received any pesticide or fungicide application. The latter seems associated with the incidence of wheat aphids during the late winter in some pockets of Haryana during the survey year. Chemical weed control was the sole method reported (96% of plots). Typically only one weed control application is applied, resulting in an overall average of 1.0 weedings per plot. The prevalence of weeding is slightly below average for adopters, but relatively similar in their ZT and conventional plots (Table 41). We cannot therefore unambiguously attribute this to ZT. Other studies in the area have reported that farmers who have used ZT continuously for the last five years skipped herbicide use at least once every two or three years (Yadav and Malik 2005). The major weed affecting wheat in the area is Phalaris minor, which shows emerging resistance to isoproturon herbicide after repeated and widespread use. By reducing soil movement, ZT serves as an effective control measure on P. minor (Malik et al. 2002b).

Indeed, reduced incidence of P. minor has reportedly been one of the reasons for rapid ZT adoption in Haryana.

Water management

Wheat cultivation in sample plots is irrigated and only 2% of wheat fields were reported to have experienced water shortage during the season (i.e. where applied irrigation water plus rainfall was insufficient to meet wheat water needs). Nonetheless, actual evapotranspiration of wheat is generally lower than the potential requirement in rice-wheat systems in the northwestern IGP, implying a level of water stress (Ahmad et al. 2002; Jehangir et al. 2007). Tubewells are the major source of irrigation, with 80% of sample plots relying solely on tubewell irrigation and 17% of plots on a combination of canal and tubewell water. Non-adopters tend to be more dependent on tubewells only, whereas adopters have relatively more widespread access to both irrigation sources.

On average, a wheat plot received 3.4 irrigations per season, comprising 3.05 tubewell irrigations and 0.35 canal irrigations. ZT is reportedly water-saving and it has been suggested that it could lead to a saving of one irrigation. Adopters indeed report the lowest total number of irrigations (3.2), but report a relatively similar number for both their ZT and conventional plots (Table 42). Therefore, we again cannot unambiguously attribute this to ZT.

ZT also reportedly reduces the duration of irrigations, particularly of the first irrigation, as irrigation water flows more quickly over untilled fields. The reported duration for the first tubewell irrigation does indeed highlight significant differences that support this (Table 42). In the ZT plots, the first tubewell irrigation averaged 12 hours per hectare, as against 14 hours in the conventional plots of adopters and 15.5 hours in non-adopter and disadopter plots. Consequently, less irrigation water is generally applied to ZT plots during the first irrigation. This tends to be beneficial as often in tilled fields too much water is applied to parts of the field with the prevailing flood irrigation practices, resulting in waterlogging and yellowing of wheat plants. For subsequent tubewell irrigations, ZT does

Table 41. Wheat weed, pest and disease management practices reported by plot category.

	Adopters, ZT plot (n=138)	Conventional wheat Adopters, non ZT plot (n=99)	Conventional wheat Non-adopters (n=222)	Conventional wheat Disadopters (n=40)	Overall (±std.dev., n) (n=499)	Significance
Use of weed control (% reporting, herbicide only)	93.5	94.9	98.6	97.5	96.4	0.06
Number of weed controls (applications/season)	0.98	0.97	1.03	1.00	1.00 (±0.27)	0.17
Pesticide/fungicide application (% reporting)	1.4	1.0	0.9	0.0	1.0	NS

Note: Significance levels are from one-way ANOVA (numerical data) and Chi^2 (% data).

not significantly reduce irrigation time, and nor does it for the first or subsequent canal irrigations. The total irrigation time (tubewell and canal by themselves or combined) is the lowest for ZT plots and highest for disadopters. However, this again seems to be primarily associated with adopters as the total hours do not differ significantly between their ZT and conventional plots. Contributing to these divergences between adopter categories are the underlying variations in tubewell characteristics (Table 21). Average water use per hectare was estimated at 2,100 m^3 irrigation water and 3,100 m^3 gross, showing a similar contrast between adopters and non-/disadopters.

The results, therefore, provide some support to the postulated water-saving nature of ZT. However, the results presented so far relate to the adoption survey findings, which means that we can not control some of the underlying sources of variation between farms that are likely to affect irrigation water use. For instance, there is significant variation in terms of tubewell specifications (e.g. power source, pump size—see previous chapter). The presence of two different types of irrigation (canal and tubewell) in some fields is another source of noise. These confounding effects may mask some of ZT technology's effects, if any, in the adoption survey.

An additional water user survey was conducted in the area to avoid some of these shortcomings (see methodology section.) and the results are presented in table 43. The table confirms that there is a significant difference between canal and tubewell irrigation indicators, leading us to present the data for the two sources separately. Unfortunately, the number of observations for canal irrigation is limited.

The results of the water use survey show that wheat plots received an average of 3.5 irrigations per season in the case of tubewell irrigation and 2.5 irrigations in the case of canal irrigation. These figures are similar to those found in the adoption survey and again there is no significant difference in terms of number of irrigations between ZT and conventional tillage (Table 43).

The results of the water use survey confirm that ZT saves irrigation time. The time savings are, however, not limited to the first irrigation, and were also apparent in the second irrigation and total irrigation

Table 42. Wheat irrigation practices reported by plot category (adoption survey).

		Conventional wheat				
	Adopters, ZT plot (n=138)	Adopters, non ZT plot (n=99)	Non-adopters (n=222)	Disadopters (n=40)	Overall (±std.dev., n) (n=499)	Significance
Irrigation source (% reporting)						
- Canal	4.3	3.0	0.9	7.5	2.8	
- Tubewell	69.6	73.7	89.6	77.5	80.0	0.00
- Canal and tubewell	26.1	23.2	9.5	15.0	17.2	
Number of irrigations per season						
- Canal	0.54 b	0.38 ab	0.19 a	0.45 b	0.35 (±0.84)	0.00
- Tubewell	2.69 a	2.89 a	3.31 b	3.23 b	3.05 (±1.13)	0.00
- Total	3.23 a	3.27 a	3.50 b	3.68 b	3.39 (±0.77)	0.00
Duration of irrigations (hrs/ha) [a]						
- 1st canal (hrs/ha)	7.5	9.1	8.8	10.2	8.4 (±4.3, n=88)	NS
- Subsequent canal (hrs/ha/irrigation)	5.7	6.4	5.9	7.8	6.1 (±3.3, n=88)	NS
- Total canal (hrs/ha/season)	11.9 a	12.4 a	14.2 a	18.4 b	13.2 (±7.1, n=88)	0.10
- 1st Tubewell (hrs/ha)	12.2 a	13.8 b	15.3 c	15.5 c	14.2 (±5.5, n=481)	0.00
- Subsequent tubewell (hrs/ha/irrigation)	10.5	10.5	11.6	11.4	11.1 (±4.2, n=481)	0.04
- Total tubewell (hrs/ha/season)	32.7 a	35.1 a	43.0 b	45.2 b	38.8 (±20.6, n=481)	0.00
- Total canal + tubewell (hrs/ha/season)	33.8 a	36.6 a	44.0 b	44.4 b	39.7 (±19.7, n=499)	0.00
Estimated water use (m^3/ha)						
- Irrigation water [b]	1830a	1970a	2330b	2390b	2130 (±1020)	0.00
- Gross water (rain + irrigation) [c]	2760a	2900a	3260b	3320b	3060 (±1020)	0.00
Water scarcity (% reporting)	1.4	1.0	2.3	2.5	1.8	NS

Note: Significance levels are from one-way ANOVA (numerical data) and Chi^2 (%). Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

[a] Non-zero values only. [b] Assumes 52.5 m^3/hour for tubewell and 69.4 m3/hour for canal (averages from water survey). [c] Assumes seasonal rainfall of 93 mm (2003-04, State Office of the Deputy Director of Agriculture, Kurukshetra, unpublished data).

Table 43. Wheat irrigation practices by irrigation source and tillage technology (water user survey).

	Canal				Tubewell			
	CT (n≤7)	ZT (n≤6)	Average (n≤13)	P (t-test)	CT (n≤44)	ZT (n≤41)	Average (n≤85)	P (t-test)
Total number of irrigations ***	2.43	2.50	2.46 (±0.77, n=13)	NS	3.45	3.46	3.46 (±0.50, n=85)	NS
Time per irrigation (hrs/ha) [a]								
- presowing ***	2.3	2.1	2.2 (±3.5, n=13)	NS	11.2	10.2	10.7 (±7.8, n=85)	NS
- 1st irrigation***	10.9	8.4	9.8 (±2.7, n=13)	0.08	16.0	13.3	14.7 (±2.7, n=85)	0.00
- 2nd irrigation***	11.6	9.3	10.5 (±1.9, n=13)	0.02	14.3	12.9	13.6 (±2.4, n=85)	0.01
- 3rd irrigation***	2.1	2.1	2.1 (±5.1, n=13)	NS	10.6	9.4	10.0 (±6.0, n=85)	NS
- Total ***	27.0	21.7	24.6 (±5.5, n=13)	0.09	52.1	45.7	49.0 (±10.2, n=85)	0.00
Water quantity per irrigation (m^3/ha) [a]								
- presowing ***	0	0	0	NA	463	418	441 (±406, n=32+30=62)	NS
- 1st irrigation	857	686	772 (±290, n=3+3=6)	NS	854	678	769 (±257, n=62)	0.01
- 2nd irrigation	857	686	772 (±290, n=6)	NS	735	643	690 (±219, n=62)	0.10
- 3rd irrigation***	0	0	0	NA	465	439	452 (±340, n=62)	NS
- Total***	1,715	1,372	1,543 (±581, n=6)	NS	2,516	2,178	2,352 (±632, n=62)	0.03

Note: CT = conventional tillage, ZT = zero-tillage. P = p value, i.e. significance level.
*** Indicates canal and tubewell averages differ significantly at 0.01 level
[a] Across all plots, including zero values. Particularly affects values for presowing and 3rd irrigation. For instance, shares of zero values in irrigation time for presowing, 1st, 2nd and 3rd were 31%, 0%, 1% and 24% respectively.

Table 44. Wheat harvesting practices reported by plot category.

		Conventional wheat				
	Adopters, ZT plot (n=138)	Adopters, non ZT plot (n=99)	Non-adopters (n=222)	Disadopters (n=40)	Overall (±std.dev., n) (n=499)	Significance
Harvesting date (day in April)	7	8	7	7	7 (±5, n=496)	NS
Crop duration (days)	148 c	147 bc	146 b	143 a	146 (±9, n=496)	0.01
Manual harvesting (% reporting)	28.3	32.3	53.2	67.5	43.3	0.00
Harvesting time [a]						
- Manual (days/ha)	17.7 a	17.6 a	19.1 b	17.8 a	18.5 (±2.6, n=216)	0.00
- Combine (hrs/ha)	1.22	1.22	1.22	1.25	1.22 (±0.12, n=283)	NS
Residue management (% reporting) [b]						
- Remove	94.2	100	100	100	98.4	NA
- Burn	12.3	12.1	9.5	10.0	10.8	NS
- Leave in field/ incorporate	3.6	3.0	2.7	5.0	3.2	NS

Note: Significance levels are from one-way ANOVA (numerical data) and Chi^2 (%). Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).
[a] Non-zero values only. [b] Column sum ≥ 100% as multiple responses possible.

time, both for canal and tubewell sources (Table 43). As expected, the shorter irrigation time translates into reduced volumes of water being applied to ZT, although we can only substantiate this in the case of tubewell sources in view of limited canal observations (Table 43). Total tubewell water volume applied to ZT amounted to 2,200 m^3 on average, compared to 2,500 m^3 for conventional tillage, a statistically significant water saving of 13.4%. Most of this was achieved in the first irrigation: a saving of 176 m^3, corresponding to 20.6% of the water used for conventional tillage.

Harvest practices

The mean wheat harvesting date was 7 April. The slightly earlier wheat sowing in ZT plots did not affect the harvesting date, but does translate into the longest crop duration in the field of 148 days (Table 44). Forty-three percent of the wheat plots were harvested manually. The remaining 57% of plots were mechanically harvested using combine harvesters. Combine use was significantly more widespread on adopter plots as compared to non-adopter and disadopter plots (Table 44), again reflecting their greater resource base. Combine use also tends to be the preferred option for larger fields in view of scale and synchronization. For instance, a combine operator may not be prepared to come to harvest a single small field if adjoining fields are not ready to harvest. Manual harvesting is laborious, taking 18.5 labor days per hectare as compared to 1.2 hours per hectare with a combine harvester.

Wheat straw is widely used as animal feed (Erenstein et al. 2007d), and removal of wheat residues from the plot is a near-universal practice. With most of the wheat residues removed, leftover wheat residues were burned in situ in 11% of the plots, and were left in the field and/or incorporated in 3% of the plots.

5.1.2 Impact of zero-tillage on wheat productivity

The mean farmer-estimated wheat yield was 4.2 t/ha. The highest yields were reported in ZT plots (4.4 t/ha), being significantly different from all the conventional plots (Table 45). Compared to the conventional plots of adopters, this represents a significant 4.0% yield increase. The lowest yields were recorded in the disadopter plots, possibly a reflection of the combined effect of stress (e.g. weeds) and crop management (e.g. lower fertilizer application rates).

Part of the observed positive yield effect of ZT is associated with the more timely wheat establishment. Indeed, there is a significant negative correlation between wheat yield and sowing date (correlation coefficient=-0.145, p=0.00). Wheat plots that

Table 45. Wheat productivity indicators by plot category (adoption survey).

	Adopters, ZT plot (n=138)	Conventional wheat: Adopters, non ZT plot (n=99)	Conventional wheat: Non-adopters (n=222)	Conventional wheat: Disadopters (n=40)	Overall (±std.dev., n) (n=499)	Significance (ANOVA)
Grain yield (t/ha)	4.38 c	4.21 b	4.17 b	4.02 a	4.22 (±0.50)	0.00
Irrigation water productivity indicators						
- t/irrigation	1.43 c	1.35 c	1.26 b	1.16 a	1.31 (±0.36)	0.00
- kg/m^3	3.11 c	2.65 b	2.20 a	2.02 a	2.53 (±1.65)	0.00
Gross water productivity (kg/m^3)	1.76 c	1.59 b	1.41 a	1.32 a	1.54 (±0.56)	0.00

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

Table 46. Reported wheat yields (t/ha) under different tillage systems over time (adoption survey, farmer recall).

	Zero-tillage	Conventional tillage	Overall	Significance
2003	4.38 (138) x	4.17 (361) x	4.22 (±0.50, n=499)	0.00
2002	4.63 (108) y	4.61 (359) y	4.62 (±0.65, n=467)	NS
2001	4.66 (60) y	4.62 (375) y	4.62 (±0.63, n=435)	NS
2000	4.61 (22) y	4.57 (296) y	4.58 (±0.64, n=318)	NS
Across years	4.53 (±0.59, n=328)	4.49 (±0.65, n=1391)	4.50 (±0.64, n=1719)	
Significance	0.00	0.00		

Note: Figures in parentheses are standard deviation, number of non-zero cases (n). Significance levels from t-test (within row) and one-way ANOVA (within column). Data followed by different letters (of x and y) differ significantly (Duncan multiple range test, significance level = 0.10, within column comparison).

were established before November 16 yielded significantly more (4.3 t/ha, n=373) than plots established thereafter (4.1 t/ha, n=126, p=0.00). The relative performance of zero-tillage also tends to be better in timely sown wheat (Malik et al. 2002a). Wheat yields on (sandy) loam soils did not differ significantly from heavier soils.

To further explore yield effects farmers were asked to recall the wheat yields they had achieved with either ZT or conventional tillage over the last couple of years. The results show that ZT yields were only significantly higher in the survey year (2003-04), with similar yields being reported for ZT and conventional tillage in the three preceding years (Table 46, row-wise comparison). The ZT yields averaged 4.5 tons per hectare over the 4 year period and were found to be significantly lower in the survey year than in the previous 3 years (Table 46, column-wise comparison). The same applies to conventional tillage. The relatively low yields in the survey year 2003-04 are likely associated with conditions being relatively dry. This seems to have had less adverse effects on ZT relative to conventional tillage, possibly through better soil moisture conservation. The survey year was indeed dry and maximum temperatures were more than 10 ºC above the thirty-year average in both March and April (Central Soil Salinity Research Institute, Karnal, unpublished data). High temperatures adversely affect wheat yields. Interestingly, in 2002 current ZT adopters reported significantly higher yields for ZT fields than current disadopters (4.71 vs 4.41 t/ha, p = 0.015). The lower yields for current disadopters may therefore have contributed to their decision to discontinue with ZT in 2003.

Irrigation water productivity averages 1.3 tons of wheat per irrigation and 2.5 kg wheat per m^3. Gross water productivity amounts to 1.5 kg of wheat per m^3. ZT consistently has the highest water productivity indicators (Table 45). In terms of volumetric water productivity (both irrigation and gross), ZT significantly outperforms the conventional plots of adopters, and non-adopters' and disadopters' plots perform worst.

The results from the water use survey largely confirm the adoption survey findings (Table 47). In tubewell-irrigated fields, ZT yielded significantly more, and this contributed to significantly higher volumetric water productivity indicators (both irrigation and gross). The findings in the canal fields are less conclusive due to the limited number of observations. The results of both surveys thereby confirm that ZT significantly enhances water productivity for wheat in farmers' fields in rice-wheat systems of Haryana.

5.2 Rice crop

The 468 surveyed rice plots for kharif 2003 are largely similar to the 499 wheat plots for rabi 2003-04 (see methodology).[12] Therefore, the rice plots report a similar prevalence of (sandy) loam soil types, highest in adopters' rice fields sown after ZT wheat and non-adopters' plots (Table 48). The average rice plot size was 5.75 hectares. As in the case of wheat plots, the conventional plots of ZT adopters were significantly larger (Table 48).

Table 47. Wheat productivity indicators by irrigation source and tillage technology (water user survey).

	Canal				Tubewell			
	CT (n≤7)	ZT (n≤6)	Average (n≤13)	P (t-test)	CT (n≤44)	ZT (n≤41)	Average (n≤85)	P (t-test)
Yield (t/ha)	4.37	4.54	4.45 (±0.39, n=13)	NS	4.36	4.62	4.49 (±0.60, n=40+37)	.06
Irrigation water productivity indicators								
- t/irrigation***	1.90	1.94	1.92 (±0.39, n=13)	NS	1.31	1.37	1.34 (±0.22, n=77)	.19
- kg/m^3	2.77	3.69	3.23 (±1.60, n=6)	NS	1.84	2.23	2.03 (±0.61, n=62)	.01
Gross water productivity (kg/m^3)	1.63	1.99	1.81 (±0.52, n=3+3=6)	NS	1.30	1.51	1.40 (±0.33, n=32+30)	.01

Note: CT = conventional tillage, ZT= zero-tillage. P = p value, i.e. significance level.
*** Indicates canal and tubewell averages differ significantly at 0.01 level.

12 The main exception is the rice sown after ZT wheat plot category, which now comprises 31 such plots for disadopters in addition to the 76 such plots for adopters.

5.2.1 Impact of zero-tillage wheat on subsequent rice crop management

Land preparation & establishment

The prevailing practice in rice cultivation is to transplant seedlings into puddled fields and keep the fields ponded. Land preparation for rice is primarily mechanized, using 4-wheel tractors, with only 1.7% of plots also reporting the use of animal traction. Land preparation practices for rice are intensive, with an average of 5.3 tillage operations, comprising on average 3.9 tractor plowings (under dry and wet conditions), 1.4 tractor plankings (primarily under wet conditions) and 0.1 animal tillage operations (Table 49). Compared to the 7.5-8 tillage operations reported earlier for conventional wheat (Table 37, excluding mechanized planting), land preparation for rice involves fewer tillage passes but does include tillage under wet conditions. Tillage for rice requires an average per hectare use of 8 tractor hours and 47 liters of diesel. These figures are similar to those reported earlier for conventional wheat land preparation (Table 38).

The only significant difference between rice plots was the significantly higher number of total tillage operations for non-adopters (Table 49). It seems unlikely that this is due to a positive spillover of ZT, whereby ZT adopting farmers have subsequently reduced the intensity of their rice land preparation. The observed difference most likely reflects structural differences between adoption categories, as non-adopters also used intensive tillage operations for wheat (Table 37). In the case of adopters and disadopters, prior use of ZT wheat in the plot had no significant effect on total number of operations for rice as compared with rice after conventional wheat (Table 49). The composition of tillage operations also showed no ZT-induced variation between plots (Table 49). There is no significant difference in terms of total tractor hours and total diesel use between rice plots (Table 50).

Table 48. Selected characteristics of rice plots reported by plot category.

	Rice sown After ZT wheat (n=107)	Rice sown after conventional wheat: Adopters, non ZT plot (n=107)	Rice sown after conventional wheat: Non-adopters (n=221)	Rice sown after conventional wheat: Disadopters (n=33)	Overall (±std.dev., n) (n=468)	Significance
Plot size (ha)	5.09 a	8.92 b	4.63 a	5.14 a	5.75 (±7.14, n=468)	0.01
(Sandy) loam soil type (% reporting)	71	60	71	55	67	0.08

Note: Significance levels are from one-way ANOVA (numerical data) and Chi^2 (%). Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

Table 49. Number of rice establishment operations reported by plot category.

	Rice sown after ZT wheat (n=107)	Rice sown after conventional wheat: Adopters, non ZT plot (n=107)	Rice sown after conventional wheat: Non-adopters (n=221)	Rice sown after conventional wheat: Disadopters (n=33)	Overall (±std.dev.) (n=468)	Significance
Tillage operations with tractor (number/season)						
- Dry plowing	2.14	2.09	2.14	2.09	2.13 (±0.70)	NS
- Dry planking	0.05	0.05	0.05	0.06	0.05 (±0.23)	NS
- Wet plowing	1.69	1.67	1.73	1.85	1.72 (±0.56)	NS
- Wet planking	1.30	1.36	1.38	1.21	1.34 (±0.52)	NS
Total number with tractor	*5.18*	*5.17*	*5.29*	*5.21*	*5.23 (±0.96)*	*NS*
Tillage operations with animal (number/season)						
- Dry plowing	0.01	0.01	0.05	0	0.03 (±0.22)	NS
- Dry planking	0	0	0	0	0.00 (±0.05)	NS
- Wet plowing	0.01	0.01	0.05	0	0.03 (±0.22)	NS
- Wet planking	0.01	0.01	0.04	0	0.02 (±0.19)	NS
Total number with animals	*0.03*	*0.03*	*0.15*	*0*	*0.08 (±0.64)*	*NS*
Total tillage operations (tractor or animal, number/season)	*5.21 a*	*5.20 a*	*5.44 b*	*5.21 a*	*5.31 (±0.73)*	*0.01*
Use of animal traction (% reporting)	0.9	0.9	2.7	0	1.7	NS

Note: Significance levels are from one-way ANOVA (numerical data) and Chi^2 (%). Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

The results therefore confirm that so far ZT has had no significant spillover effect in terms of affecting tillage intensity for the subsequent rice crop, refuting any fear of a negative spillover in terms of tillage intensity being increased in rice to compensate for prior ZT use.

Rice is raised in nurseries and subsequently transplanted to the main field, using 11 kg/ha of rice seed. Own and purchased seed were about equally used in the surveyed rice plots. The mean transplanting date in the study area was 24 June with a standard deviation of 18 days across plots. Transplanting is labor-intensive and takes an average of 12 labor days per hectare. Rice establishment did not differ significantly across field types, except for non-adopters using higher seed rates (Table 51).

Farmers grow two groups of high quality rice varieties in the rice-wheat systems of Haryana. Superfine rice varieties were reported in 46.5% of plots and include a range of 16 long-duration varieties. Basmati rice varieties were reported in the remaining plots, comprising evolved basmati (or dwarf basmati, 30.2% of plots) and traditional basmati (or tall basmati, 23.3% of plots). Haryana is the leading state in terms of basmati rice exports, particularly high quality basmati rice (traditional basmati). Basmati varieties are relatively more widely grown by non-adopters, whereas superfine varieties were more common amongst disadopters. The rice plots after ZT wheat and the rice plots after conventional wheat for adopters, however, report relatively similar varietal use (Table 51). Rice varieties are closely associated with variations in rice management practices. For instance, the mean transplanting date varies significantly between the three types: superfine 19th June, evolved basmati 24th June and traditional basmati 5th July (p = 0.00).

Nutrient management

All rice plots received applications of chemical fertilizers, with a near universal use of urea and

Table 50. Duration and diesel use of mechanized rice establishment operations reported by plot category.

		Rice sown after conventional wheat				
	Rice sown after ZT wheat (n=107)	Adopters, non ZT plot (n=107)	Non-adopters (n=221)	Disadopters (n=33)	Overall (±std.dev.) (n=468)	Significance (ANOVA)
Duration of tillage operations (hrs/ha)						
- Plowing	6.01	5.92	6.25	6.51	6.14 (±1.55)	0.11
- Planking	1.68	1.71	1.80	1.62	1.74 (±0.76)	NS
Total duration	*7.70*	*7.63*	*8.05*	*8.13*	*7.88 (±1.87)*	*0.15*
Diesel consumption for tillage operations (l/ha)						
Plowing	36.9	36.4	37.6	38.7	37.3 (±9.5)	NS
Planking	9.6	10.0	10.4	9.1	10.0 (±4.3)	NS
Total diesel consumption	*46.5*	*46.4*	*48.1*	*47.8*	*47.3 (±11.5)*	*NS*

Table 51. Rice seed and planting practices reported by plot category.

		Rice sown after conventional wheat				
	Rice sown after ZT wheat (n=107)	Adopters, non ZT plot (n=107)	Non-adopters (n=221)	Disadopters (n=33)	Overall (±std.dev.) (n=468)	Significance
Transplanting date (day in June)	25	21	25	25	24 (±17.9, n=468)	NS
Labor required for planting (days/ha)	11.8	12.1	12.0	11.8	12.0 (±1.7, n=468)	NS
Seed rate (kg / ha)	11.0a	10.9a	11.7b	11.4ab	11.3 (±2.2, n=468)	0.01
Main variety (% reporting)					(n=467)	
- Superfine [a]	49.5	51.9	40.7	57.5	46.5	
- Evolved basmati [b]	21.5	25.5	36.2	33.3	30.2	0.03
- Traditional basmati [c]	29.0	22.6	23.1	9.1	23.3	
Seed source (% reporting)					(n=468)	
- Own	47.7	51.4	46.6	45.5	47.9	NS
- Purchased	52.3	48.6	53.4	54.5	52.1	

Note: Significance levels are from one-way ANOVA (numerical data) and Chi^2 (%). Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).
[a] Includes Gobind, Pusa 44, PR 106, PR 114, PR 113, Sarbati, HKR 120, PR 111, PR 116, HKR 126, IR 64, Pioneer 71, Hybrid 6111, Parmal, PR 108 and Hybrid 6444. [b] Includes Pusa Basmati 1 (Muchhal). [c] Includes Trawari Basmati and CSR 30.

widespread use of di-ammonium phosphate (DAP, 85% of plots) and zinc (86% of plots). Use of potash (7%), bio-fertilizers (6%) and single super phosphate (SSP, 1%) was sporadically reported. Fourteen percent of the sample rice plots received farmyard manure (FYM). Overall, 204 kg of NPK per hectare were applied to the transplanted rice in the field (excluding nursery), comprising 156 kg nitrogen, 44 kg phosphorus and 4 kg potash, in addition to 7 kg of zinc and 4 kg of sulfur. Chemical fertilizer use rates of NP for rice are somewhat lower than those reported for wheat. However, rice scores higher than wheat in terms of the use of organic manures and micronutrients including bio-fertilizers (Table 40). The more widespread use of FYM for rice than wheat has been reported previously (Sidhu et al. 1998) and is associated with having more turnaround time after the wheat harvest to allow for decomposition in the field (including time when rice seedlings are in nursery).

Rice fertilization practices did not differ significantly across field types, except for some variations in phosphorus use (Table 52). Fertilizations do, however, vary significantly by rice variety type (Table 53). Basmati is prone to lodging and requires less N, particularly the relatively tall traditional basmati, explaining the observed differences in N use rates. Rice varieties also are associated with variations in phosphorus and potash use. Recommended fertilizer applications (N:P2O5:K2O) indeed vary over the rice types: 150:60:60 for superfine, 90:60:0 for evolved basmati and 60:30:0 for traditional basmati. However, for each of the three rice types average N application rates are still above the recommended level.

Weed, pest and disease management

Sample rice plots were almost universally weeded. Chemical weed control is the dominant method in the area (98% of plots), often supplemented by manual

Table 52. Rice fertilization practices reported by plot category.

		Rice sown after conventional wheat				
	Rice sown after ZT wheat (n=107)	Adopters, non ZT plot (n=107)	Non-adopters (n=221)	Disadopters (n=33)	Overall (±std.dev.) (n=468)	Significance
Chemical nutrient application rates (kg/ha)						
- Nitrogen (kg N/ha)	149	165	154	160	156 (±51.8)	0.10
- Phosphorus (kg P_2O_5/ha)	41.6 ab	39.6 a	46.9 bc	51.7 c	44.4 (±22.2)	0.00
- Potash (kg K_2O/ha)	4.09	3.74	3.29	5.61	3.74 (±14.5)	NS
- Zinc (kg Zn/ha)	6.85	6.49	7.37	7.03	7.03 (±3.26)	0.13
- Sulfur (kg S/ha)	3.42	3.52	3.67	3.44	3.56 (±1.96)	NS
- Total nutrients (kg NPK/ha)	194	209	204	217	204 (±61.5)	0.19
Main types of chemical fertilizer (% reporting)						
- Urea	100	100	99.5	100	99.8	NS
- DAP	83.2	80.4	87.3	93.9	85.3	0.16
- Zinc Fertilizer	85.0	80.4	89.1	87.9	86.1	0.19
- SSP	0.9	2.8	0.9	0	1.3	NS
- Potash Fertilizer	8.4	7.5	5.4	12.1	7.1	NS
Biofertilizer use (% reporting)	3.7	6.5	7.2	0	5.8	NS
Farmyard manure use (% reporting)	15.9	8.4	14.0	21.2	13.7	NS

Note: Significance levels are from one-way ANOVA (numerical data) and Chi^2 (%). Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

Table 53. Rice fertilization practices reported by rice variety.

	Superfine (n=217)	Evolved Basmati (n=141)	Traditional Basmati (n=109)	Overall (n=467)	Significance (ANOVA)
Chemical nutrient application rates (kg/ha)					
- Nitrogen (kg N/ha)	180 c	159 b	103 a	156 (±51.8)	0.00
- Phosphorus (kg P_2O_5/ha)	39.7 a	53.3 b	42.3 a	44.4 (±22.2)	0.00
- Potash (kg K_2O/ha)	3.6 ab	5.9 b	1.2 a	3.7 (±14.5)	0.04
- Zinc (kg Zn/ha)	6.7	7.3	7.3	7.0 (±3.3)	0.18
- Sulfur (kg S/ha)	3.5	3.6	3.7	3.6 (±2.0)	NS
- Total nutrients (kg NPK/ha)	223 b	218 b	147 a	204 (±61.5)	0.00

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

weed control (60% of plots). Typically one to two weed control applications are applied, resulting in an overall average of 1.7 weedings per plot. Rice weeding practices are thereby more intensive than those for wheat, reported earlier. Rice weeding practices did not differ significantly across field types, thereby showing no spillover from ZT wheat on subsequent rice (Table 54).

Nearly 90% of the sample rice plots received pesticide and/or fungicide application. No association with ZT wheat is apparent, as rice plots sown after ZT wheat showed a similar rate to the overall average. There was also no clear association between plant protection practices and rice varieties.

Water management

Rice cultivation in sample plots is irrigated and only 4.5% of rice fields were reported to have experienced water shortage during the season. Compared to the rabi season the kharif season involves a greater contribution from rainfall and an increased reliance on canal irrigation water. However, tubewells are still the major source of irrigation for sample rice plots, with 67% relying solely on tubewells as source of irrigation and 32% on combined application of canal and tubewell water. On average, a rice plot received 34.3 irrigations per season, comprising 31.9 tubewell irrigations and 2.4 canal irrigations. This corresponds with a total of 344 hours of irrigation per season and an estimated per hectare use of 18,000 m^3 irrigation water and 23,000 m^3 gross water (for kharif 2003). The water use survey (for kharif 2004 and with a different format) generated a somewhat lower average of 26.1 tubewell irrigations per season (±4.9, n=25) but a significantly higher estimate of 702 irrigation hours per season (±167, n=25) with an irrigation water supply to rice of 35,500 m^3/ha (±8,900, n=25).

Rice irrigation practices differ significantly across field types (Table 55). To a large extent this seems related to the irrigation source and tubewell characteristics. Non-adopters and disadopters tend to rely more on tubewell only, while there is a tendency for their tubewells to have lower horsepower and smaller outlet tubes compared to those of adopters (Table 21). Indeed, the total irrigation time is significantly larger for non-adopters and disadopters. However, no significant difference is apparent in terms of total irrigation between adopters' rice plots after ZT wheat and their rice plots after conventional wheat. This suggests that the observed differences are not directly attributable to a positive spillover effect of ZT wheat on subsequent rice, but more likely a reflection of structural differences between plots/farms. Furthermore, reports of water scarcity tended to be more common amongst non-adopters and disadopters, which may also have contributed to increased irrigation time and reflect variations in rainfall patterns in kharif 2003. A further confounding factor is the association between rice varieties and irrigation practices. For instance, the total number of irrigations varied significantly between each of the three groups of rice varieties and irrigation duration and estimated water application rates were significantly less for superfine varieties (Table 56). Contributing to the observed variation between rice types is the different duration and timing of rice crops (Table 58).

Harvest practices

The mean rice harvesting date was 22nd October, giving a crop duration of 120 days, with no significant variation between rice plot categories (Table 57). This compares with the average wheat establishment date of November 12thto give an

Table 54. Rice weed, pest and disease management practices reported by plot category.

	Rice sown after ZT wheat (n=107)	Rice sown after conventional wheat: Adopters, non ZT plot (n=107)	Rice sown after conventional wheat: Non-adopters (n=221)	Rice sown after conventional wheat: Disadopters (n=33)	Overall (±std.dev.) (n=468)	Significance
Use of weed control (% reporting)						
- Hand weeding	65.4	60.7	59.7	45.5	60.3	NS
- Herbicide application	97.2	98.1	97.7	97.0	97.6	NS
- Hand or herbicide	98.1	99.1	99.5	97.0	98.9	NS
Number of weed controls (applications/season)						
- Hand weeding	0.72	0.69	0.68	0.58	0.68 (±0.62)	NS
- Herbicide application	0.97	0.98	0.98	0.97	0.98 (±0.15)	NS
- Hand or herbicide	1.69	1.67	1.66	1.55	1.66 (±0.64)	NS
Labor use for manual weeding (labor days/ha)	5.98	5.33	5.61	3.89	5.51 (±5.33)	NS
Pesticide/fungicide use (% reporting)	87.9	94.4	88.7	69.7	88.5	0.00

Note: Significance levels are from one-way ANOVA (numerical data) and Chi^2 (% data).

Table 55. Rice irrigation practices reported by plot category.

	Rice sown after ZT wheat (n=107)	Rice sown after conventional wheat: Adopters, non ZT plot (n=107)	Non-adopters (n=221)	Disadopters (n=33)	Overall (±std.dev.) (n=468)	Significance
Irrigation source (% reporting)						
- Canal	2.8	0.9	0.5	0.0	1.1	
- Tubewell	57.0	62.6	73.3	72.7	67.1	0.04
- Both canal & tubewell	40.2	36.4	26.2	27.3	31.8	
Number of irrigations per season						
- Canal	4.2 b	2.3 a	1.8 a	1.2 a	2.4 (±5.0)	0.00
- Tubewell	28.3 a	31.0 b	34.0 c	32.1 bc	31.9 (±31.9)	0.00
- Total	32.5 a	33.2 a	35.8 b	33.3 a	34.3 (±6.1)	0.00
Duration of irrigations (hrs/ha) [a]						
- 1st canal (hrs/ha)	12.4 a	10.8 a	13.3 a	17.0 b	12.6 (±7.2, n=152)	0.09
- Subsequent canal (hrs/ha/irrigation)	6.4 a	5.4 a	6.5 a	8.9 b	6.3 (±3.9, n=152)	0.10
- Total canal (hrs/ha/season)	73.0 b	37.9 a	51.6 ab	42.6 ab	53.9 (±65.5, n=152)	0.09
- 1st tubewell (hrs/ha)	20.2 a	18.7 a	20.9 a	25.0 b	20.5 (±10.2, n=463)	0.02
- Subsequent tubewell (hrs/ha/irrigation)	9.8 a	9.1 a	10.2 a	11.6 b	10.0 (±4.8, n=463)	0.05
- Total tubewell (hrs/ha/season)	289 a	300 a	360 b	350 b	330 (±155, n=463)	0.00
- Total canal + tubewell (hrs/ha/season)	312 a	311 a	372 b	361 b	344 (±154, n=468)	0.00
Estimated water use (000 m^3/ha)						
- Irrigation water [b]	16.5 a	16.1 a	19.2 b	18.6 b	17.8 (±7.9)	0.00
- Gross water (rain + irrigation) [c]	21.6 a	21.2 a	24.3 b	23.7 b	22.9 (±7.9)	0.00
Water scarcity (% reporting)	2.8	2.8	5.4	9.1	4.5NA	

Note: Significance levels are from one-way ANOVA (numerical data) and Chi[2] (% data). Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).
[a] Non-zero values only. [b] Assumes 51 m^3/hour for tubewell and 69.4 m^3/hour for canal (averages from water survey). [c] Assumes seasonal rainfall of 509 mm (2003, State Office of the Deputy Director of Agriculture, Kurukshetra, unpublished data).

Table 56. Rice irrigation practices reported by rice variety.

	Superfine (n=217)	Evolved Basmati (n=141)	Traditional Basmati (n=109)	Overall (±std.dev.) (n=467)	Significance (ANOVA)
Number of irrigations (per season)	33.1 a	36.1 c	34.3 b	34.3 (±6.1)	0.00
Duration of irrigations (canal + tubewell, hrs/ha/season)	323 a	366 b	357 b	344 (±154)	0.02
Estimated water use (000 m^3/ha)					
- Irrigation water [a]	16.7 a	18.8 b	18.9 b	17.9 (±7.9)	0.02
- Gross water (rain + irrigation) [b]	21.8 a	23.9 b	23.9 b	23.0 (±7.9)	0.02

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison). [a] Assumes 51 m^3/hour for tubewell and 69.4 m^3/hour for canal (averages from water survey). [b] Assumes seasonal rainfall of 509 mm (2003, State Office of the Deputy Director of Agriculture, Kurukshetra, unpublished data).

Table 57. Rice harvesting practices reported by plot category.

	Rice sown after ZT wheat (n=107)	Rice sown after conventional wheat: Adopters, non ZT plot (n=107)	Non-adopters (n=221)	Disadopters (n=33)	Overall (±std.dev.) (n=468)	Significance
Harvesting date (day in October)	24	20	23	21	22 (±23)	NS
Crop duration (transplant to harvest) (days)	121	121	120	119	120 (±12)	NS
Manual harvesting (% reporting)	59.8	55.1	67.0	57.6	62.0	0.18
Operation time [a]						
- Manual harvesting (days/ha)	12.9	13.0	12.6	13.5	12.8 (±1.56,n=290)	0.07
- Manual threshing (days/ha)	19.2	19.8	19.8	19.9	19.7 (±1.53,n=290)	0.02
- Combine (hrs/ha)	1.28	1.28	1.29	1.32	1.29 (±0.20,n=178)	NS
Residue management (% reporting) [b]						
- Remove	45.8	53.3	66.5	54.5	57.9	0.00
- Burn	40.2	46.7	48.4	57.6	46.8	NS
- Leave in field/incorporate	28.0	25.2	12.2	24.2	19.7	0.00

Note: Significance levels from one-way ANOVA (numerical data) and Chi[2] (% data).
[a] Non-zero values only. [b] Column sum ≥ 100% as multiple responses possible.

average turnaround time of three weeks. Harvesting date is, however, closely associated with the variety, superfine varieties being harvested the earliest on average (October 14) and traditional basmati the latest (November 4) (Table 58). Superfine varieties thus vacate the field three weeks earlier than traditional basmati. This reflects the combined effect of the longer crop duration of basmati rices (123 days between transplanting and harvest for both basmatis versus 117 days for superfine rice) and their later establishment (see earlier discussion of table 51).

Manual harvesting of rice still prevails in the area and was reported in 62% of rice plots; the remaining plots were combine harvested. Manual harvesting is laborious, needing 13 labor days per hectare for harvesting alone and an additional 20 days for threshing, as compared to 1.3 hours per hectare using a combine harvester. Manual harvesting is closely related to rice variety, being universal practice for basmati varieties but only applied to 18% of superfine rice plots (Table 58). Basmati is manually 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). Where superfine rice plots are harvested manually this tends to be associated with such factors as small plot size, field inaccessibility, resource constraints and labor availability.

Across all rice plots, rice residues were (partially) removed in 58% of plots. Residues were burned (generally in situ) in 47% of plots, and they were left in the field (loose residues and anchored stubble) and/or incorporated in 20% of plots. Partial application and combinations of these practices are widespread. Rice residue management practices are closely associated with harvest practices. The manual harvesting of basmati entails that the whole crop (grain plus residues) is removed from the field to a place for manual threshing. As a result, rice residue is removed in all traditional basmati plots and 88% of evolved basmati plots, against only 17% of superfine plots (Table 58). With the residues already automatically removed from the field, they are either used for animal feed or for other purposes, or, particularly in the case of evolved basmati, burned. The preferential use of traditional basmati straw for feed is associated with perceived palatability differences in rice straws as livestock feed (Erenstein et al. 2007d). The crop residue management by non-adopters stood out as being more extractive, with residues being less commonly left in the field and/or incorporated. In addition to non-adopters' increased reliance on manual harvesting, this might be associated with a higher pressure on the rice residues for feed purposes. Residue removal was least widespread in rice plots after ZT wheat, possibly reflecting a lesser need to remove residues in view of the potential to establish the subsequent wheat crop in the standing rice stubble. The low removal rates for non-basmati rice (compared to wheat and basmati rice) go a long way in explaining the observed prevalence of in situ burning and/or retention of residues in the plot.

5.2.2 Impact of zero-tillage wheat on subsequent rice crop productivity

The mean farmer-estimated rice yield was 4.7 t/ha. Irrigation water productivity averages 158 kg rice per irrigation and 0.34 kg rice per m^3. Gross water productivity amounts to 0.23 kg rice per m^3. These water productivity indicators are markedly lower than those reported earlier for wheat, largely a reflection of significantly higher water inputs in rice cultivation needed to maintain standing water in the paddies during the hot monsoon season. Rice grown

Table 58. Rice harvesting practices reported by rice variety.

	Superfine (n=217)	Evolved Basmati (n=141)	Traditional Basmati (n=109)	Overall (±std.dev.) (n=467)	Significance
Harvesting date	Oct 14 a	Oct 26 b	Nov 4 c	Oct 22 (±23)	0.00
Crop duration (transplant to harvest) (days)	117 a	123 b	123 b	120 (±12)	0.00
Manual harvesting (% reporting)	18 a	100 b	100 b	62	0.00
Residue management (% reporting) [a]					
- Remove	17 a	88 b	100 c	58	0.00
- Burn	67 c	51 b	1 a	47	0.00
- Leave in field/incorporate	38 c	7 b	0 a	20	0.00

Note: Significance levels from one-way ANOVA (numerical data) and Chi^2 (%). Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

[a] Column sum ≥ 100% as multiple responses possible.

on (sandy) loam soils yielded significantly less (4.6 t/ha) than rice grown on heavier soils (5.0 t/ha, p = 0.01).

There is no significant difference in rice yields between rice plots (Table 59). The marked differences in water management between rice plots translate into significantly higher volumetric water productivity indicators for adopters as compared to non-adopters and disadopters. However, these observed differences are again likely a reflection of structural differences between plots/farms, as no significant difference in terms of these indicators is apparent between adopters' rice plots after ZT wheat and after conventional wheat.

The productivity indicators are markedly different between rice varieties (Table 60): traditional basmati yielding 2.6 tons per hectare as against evolved basmati 4.5 tons and superfine varieties 5.9 tons. Basmati varieties (particularly traditional basmati) are higher value, which in part compensates for yield differences. The yield differences translate into equally marked differences in water productivity indicators between rice varieties.

Therefore we can conclude that, in the case of Haryana, ZT had significant positive effects on yield and water productivity for the wheat crop. The study thereby confirms that the generally favorable implications of ZT reported in trials, in terms of enhancing wheat yield and saving water, are also achieved in farmers' fields. However, there were no significant effects on yield and water productivity for the subsequent rice crop. The study also confirms the drastic reductions in tractor time and diesel use in wheat land preparation and establishment, which imply substantial cost savings.

Table 59. Rice productivity indicators by plot category.

		Rice sown after conventional wheat				
	Rice sown after ZT wheat (n=107)	Adopters, non ZT plot (n=107)	Non-adopters (n=221)	Disadopters (n=33)	Overall (±std.dev.) (n=468)	Significance (ANOVA)
Grain yield (t/ha)	4.59	4.97	4.61	4.93	4.71 (±1.55)	0.16
Irrigation water productivity indicators						
- kg/irrigation	152	157	161	159	158 (±288)	NS
- kg/m^3	0.35 ab	0.40 b	0.31 a	0.30 a	0.34 (±0.32)	0.08
Gross water productivity (kg/m^3)	0.24 ab	0.27 b	0.22 a	0.22 a	0.23 (±0.13)	0.01

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

Table 60. Rice productivity indicators by rice variety.

	Superfine (n=217)	Evolved Basmati (n=141)	Traditional Basmati (n=109)	Overall (±std.dev.) (n=467)	Significance (ANOVA)
Grain yield (t/ha)	5.93 c	4.45 b	2.58 a	4.71 (±1.55)	0.00
Irrigation water productivity indicators					
- kg/irrigation	217 b	126 a	79 a	158 (±288)	0.00
- kg/m^3	0.47 c	0.26 b	0.16 a	0.34 (±0.32)	0.00
Gross water productivity (kg/m^3)	0.31 c	0.20 b	0.12 a	0.23 (±0.13)	0.00

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

6 Financial impact of zero-tillage 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). However, where such analysis is included, the 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 the plot level. The first section of this chapter will review the effects of ZT 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.

6.1 Wheat profitability

6.1.1 Revenue

The gross revenue from wheat cultivation comprises the value of the wheat grain and the value of the wheat residues/straw. Wheat marketing and prices are regulated in India and at the time of the survey there was a Minimum Support Price (MSP) of INR 6.3 per kg. Farm households typically have a significant surplus wheat production, despite wheat being the traditional food crop in the area. The combination of an assured market and a commercial orientation led us to value the wheat grain at the prevailing MSP. Revenue from the wheat grain is thus estimated as the product of the farmer-reported wheat yield and the prevailing MSP, and averaged INR 26,600 per hectare.

Wheat straw ('bhusa') is an important livestock feed in the study area and is widely harvested and traded (Erenstein et al. 2007d). During the adoption survey farmers were requested to estimate the value of the wheat straw/residue on a per area basis, averaging INR 3,100 per hectare. The reported wheat straw value differs significantly by harvest method: it averaged INR 2,250 per hectare for combine harvesting and INR 4,250 per hectare for manual harvesting (n=275+216, p = 0.00). The price differential primarily reflects the higher straw recovery with manual harvesting, as well as higher quality (due to less foreign matter). We estimate wheat straw yield in manually-harvested fields to amount to some 4-5 t/ha in the study area, against 2-3 t/ha in combine harvested fields. Assuming a harvest index (ratio of grain weight to total plant weight) of 50% and using the average grain yield of 4.22 t/ha, the wheat straw price would be INR 1.01 per kg in manually-harvested fields. Applying similar assumptions but with a correction factor of 56% (based on the midpoint of estimated straw recovery range) the wheat straw price would be INR 0.96 per kg in combined fields. These values are somewhat lower than the INR 1.3 per kg reported for selected villages in the Kurukshetra district in Haryana (Erenstein et al. 2007d).

The gross revenue from wheat grain plus straw averages INR 29,700 per hectare. Wheat straw therefore contributes a significant 10.5%. Gross revenue is significantly higher for ZT plots compared to all other plots, averaging INR 30,500 per hectare (Table 61, section A). The observed difference is the net result of two opposing variations in terms of grain and straw revenue. The variations in grain revenue mirror those observed earlier for wheat yield given the constant price, with the highest revenues in ZT plots and the lowest in disadopter plots (Table 61, section A). Straw revenue is, however, significantly higher for the non-adopter and disadopter plots compared to the ZT and conventional pots of adopters (Table 61, section A). This reflects the underlying differences in harvest practice, whereby the former rely more on manual harvesting. ZT itself does not seem to influence the value of the straw, as shown by the adopters reporting the same average value for wheat straw in ZT and conventional plots.

6.1.2 Production costs

Total wheat production costs average INR 28,100 per hectare and include the variable costs, land, and a 9% interest rate. Production costs are valued at the prevailing market rates as reported by the individual farmer or in the area (e.g. Annex 2). 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. Land is thus valued at its seasonal rental value. The seasonal cost of land is INR 14,000 per hectare in the area (Erenstein et al. 2007d), making it the single most important production cost, amounting to half the average production costs (49.8%). After land, the three most important cost factors are harvesting expenditures (11.6%), land preparation and crop establishment (11.2%), and fertilizer cost (10.4%). Other costs include plant protection (including weeding, 6.0%), irrigation cost (2.7%), and interest on capital (8.3%).

The production costs in ZT plots are significantly lower than in conventional plots (Table 61, section B). Two factors are at play. First, adopters have inherently lower production costs than non-adopters and disadopters (INR 29,000 per hectare), irrespective of whether they use ZT. This largely reflects their crop management practices and inherently lower harvesting and irrigation costs. Second, adopters achieve significantly lower production costs in their ZT plots (INR 26,200 per hectare) as compared to their conventional plots (INR 28,100 per hectare). The ZT-induced savings are primarily a reflection of the halving of land preparation and crop establishment costs, which are INR 3,600-3,700 per hectare for conventional tillage and only INR 1,800 for ZT. Compared to the conventional plots of adopters, ZT represents a significant cost saving of 7.0% on total costs, or 15.3% on operational costs (excluding land).

6.1.3 Performance indicators

The net revenue (or gross margin) of wheat production averages a meager INR 1,600 per hectare, with a standard deviation of INR 3,900 per hectare. The average net revenue highlights that that average gross revenue (INR 29,700 per hectare) surpasses average total costs (INR 28,100 per hectare), giving an average return of 6% to production costs. However, only 68% of wheat plots had a positive net revenue (i.e. 32% were below breakeven). Production costs amount to INR 6.8 per kg wheat grain on average, surpassing the MSP and highlighting the importance of the additional revenue from wheat straw as byproduct.

Table 61. Crop budget (000 INR/hectare) for wheat crop by plot category.

		Conventional wheat				
	Adopters, ZT plot (n=107)	**Adopters, non ZT plot (n=98)**	**Non-adopters (n=222)**	**Disadopters (n=40)**	**Overall (±std.dev.) (n=498)**	**Significance (ANOVA)**
A. Gross revenue	*30.5 b*	*29.3 a*	*29.6 a*	*28.8 a*	*29.7 (±3.2)*	*0.01*
- Grain	27.6 c	26.4 b	26.3 b	25.3 a	26.6	0.00
- Straw	2.9 a	2.9 a	3.3 b	3.5 b	3.1	0.00
B. Total cost	*26.2 a*	*28.1 b*	*29.1 c*	*28.9 c*	*28.1 (±2.2)*	*0.00*
B1. Land preparation	0.0	2.3	2.5	2.5	1.8	0.00
- Plowing	0.0	1.8	2.0	2.0	1.4	0.00
- Planking	0.0	0.5	0.5	0.5	0.4	0.00
B2. Crop establishment	1.8	1.3	1.2	1.1	1.4	0.00
- Seed drill	0.8	0.2	0.1	0.2	0.3	0.00
- Labor for planting	0.2	0.2	0.1	0.1	0.2	0.00
- Seed for planting	0.9	0.9	0.9	0.8	0.9	NS
Subtotal B1+B2	*1.8 a*	*3.6 b*	*3.7 b*	*3.6 b*	*3.1 (±1.0)*	*0.00*
B3. Fertilizer cost	3.0	2.9	2.9	2.8	2.9	.00
B4. Plant protection cost	1.7	1.6	1.7	1.7	1.7	NS
B5. Irrigation cost	0.6	0.7	0.9	0.8	0.8	0.00
B6. Harvesting expenditures	2.8	3.0	3.6	3.6	3.3	0.00
B7. Land rent	14.0	14.0	14.0	14.0	14.0	NA
B8. Interest on capital invested	2.2	2.3	2.4	2.4	2.3	0.00
C. Net revenue (A – B)	*4.3 c*	*1.2 b*	*0.4 ab*	*-0.1 a*	*1.6 (±3.9)*	*0.00*
% plots with positive NR	92	67	55	60	68	0.00
Benefit:cost ratio (A/B)	1.17 c	1.05 b	1.02 ab	1.00 a	1.06 (±0.14)	0.00
Production cost (INR/kg)	6.1 a	6.8 b	7.1 c	7.3 c	6.8 (±1.1)	0.00

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison). Only included for line item totals (A,B,B1+B2,C) and A sub-items.

One may argue that the inclusion of land rent inflates production costs and thereby depresses net income for wheat farmers. As shown earlier, owner-cultivators prevail and 81% of the crop area is owned, implying that in most cases no land rent is actually paid as such. However, even for owner-cultivators the prevailing value of land (rented or owned) implies significant opportunity costs that need to be included for an appropriate assessment. At the very least, it suggests that a number of households (particularly amongst non-adopters and disadopters) would have been better off renting out their land and using their resources for other, more remunerative, activities.

The net revenue from ZT plots (INR 4,300) is significantly higher than that achieved in conventional plots, which ranges from INR 1,200 in the conventional plots of adopters to about breakeven in disadopter plots (Table 61, section C). 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. They also highlight the relative significance of the ZT-induced income enhancement, which boosts returns well above breakeven. Indeed, 92% of ZT plots had a positive net revenue. In view of differences between the types of wheat plots that are other than purely ZT-related, the most objective comparison is between the ZT and conventional plots of adopters. These show a conclusive advantage for ZT over conventional till of INR 3,100 per hectare in the survey year, composed of a yield effect of INR 1,200 and a cost saving effect of INR 1,900. To further put this advantage in perspective, this represents a near threefold increase in net income. The ZT plots of adopters thus achieve a significantly higher return on production costs (a respectable 17%) and have significantly lower production costs (INR 6.1 per kg, below the MSP).

The survey results clearly challenge the traditional farmer view that frequent tillage is necessary for higher wheat yields. In fact the opposite was true in the survey year, and at a significantly lower cost. Even if there is no significant yield effect (as seems to be the case in the preceding years), the cost saving effect seems robust enough to make adoption worthwhile. It goes a long way in explaining the rapid spread and widespread acceptance of ZT in Haryana, despite the initial and sometimes strong opposition amongst farmers.

Table 62 provides financial water productivity indicators for wheat. It presents two sets of indicators, one based on net revenue and one based on gross revenue. Reflecting the relative low net revenue of wheat production, net revenue-based water productivity indicators average only INR 553 per irrigation, INR 1.5 per irrigation m^3 and INR 0.8 per gross m3. Gross revenue-based indicators appear more favorable, but ignore the underlying production costs. The net revenue-based indicators are the most relevant, reflecting the combined effect of gross revenue, production costs and water input differentials.

The net revenue income-based indicators for ZT are always significantly higher than for conventional tillage, irrespective of the type of conventional plot. In fact, these ZT indicators are at least double the overall average. The gross revenue indicators—despite ignoring the cost saving aspect of ZT—also convey the superiority of ZT over CT.

6.2 Rice profitability

6.2.1 Revenue

The gross revenue from rice cultivation averages INR 38,600 per hectare, comprising the value of the rice and the value of the residues/straw. Rice is primarily produced for the market and we value the rice at the

Table 62. Financial water productivity indicators for wheat by plot category.

		Conventional wheat				
	Adopters ZT plot (n=138)	Adopters, non ZT plot (n=98)	Non-adopters (n=222)	Disadopters (n=40)	Overall (±std.dev., n) (n=498)	Significance (ANOVA)
Net revenue-based water productivity indicators						
- INR/irrigation	1,410 c	385 b	183 ab	69 a	553 (±1,248)	0.00
- INR/irrigation m^3	3.6 c	1.1 b	0.6 ab	0.0 a	1.5 (±3.8)	0.00
- INR/gross m^3 (rain + irrigation)	1.9 c	0.6 b	0.3 ab	0.0 a	0.8 (±1.7)	0.00
Gross revenue-based water productivity indicators						
- INR/irrigation	9,910 c	9,450 bc	8,900 b	8,260 a	9,240 (±2,430)	0.00
- INR/irrigation m^3	22 c	18 b	16 a	14 a	18 (±11)	0.00
- INR/gross m^3 (rain + irrigation)	12 c	11 b	10 a	9 a	11 (±4)	0.00

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

prevailing market rates, which vary significantly by variety (superfine INR 5.5 per kg, evolved basmati INR 10 per kg, and traditional basmati INR 15.5 per kg). Revenue from rice is thus estimated as the product of the farmer-reported rice yield and the prevailing price, and averaged INR 37,900 per hectare.

Rice straw is not a preferred livestock feed in the study area and is not widely harvested or traded (Erenstein et al. 2007d). During the adoption survey farmers were requested to estimate the value of the rice straw/residue on a per area basis, averaging INR 600 per ha—less than a fifth of the corresponding wheat straw value. Rice straw thus contributes only 1.6% to the gross revenue.

ZT wheat does not significantly affect gross revenue from the subsequent rice crop. The four types of rice plot do differ in terms of straw value between rice plots, with non-adopters reporting the highest average value (Table 63, section A). However, this is a reflection of the underlying varieties being grown, with non-adopters primarily cultivating basmati varieties (Table 51). Indeed, the type of rice variety has a significantly more pronounced effect on the revenue indicators than the preceding wheat crop (Table 64, section A). Basmati has significantly higher straw values (INR 1,000-1,100 per hectare) than superfine (INR 200 per hectare).

The gross revenue is lowest for superfine rice (INR 32,800 per hectare), the higher yields thus being insufficient to compensate for the lower rice price in the survey year and with a marginal contribution from straw. Evolved basmati achieved the highest gross revenue (INR 45,500 per hectare) in the survey year, with traditional basmati having an intermediate value (INR 41,100 per hectare). However, superfine rice prices are relatively stable, being associated with the minimum support price, whereas basmati prices tend to fluctuate significantly year to year and thereby increase market risk.

6.2.2 Production costs

Total rice production costs average INR 34,400 per hectare and include the variable costs, land, and a 9% interest rate. Production costs are again valued at the prevailing market rates as reported by the individual farmer or in the area (e.g. Annex 2). The seasonal cost of land is INR 14,000 per hectare in the area (Erenstein et al. 2007d), making it by far the single most important production cost (40.7%). After land, the cost factors include irrigation (19.1%), land preparation & crop establishment (10.0%), fertilizer (7.9%), plant protection (including weeding, 7.7%), harvesting expenditures (6.3%), and interest on capital (8.3%).

Table 63. Crop budget (000 INR/hectare) for rice crop by plot category.

		Rice sown after conventional wheat				
	Rice sown after ZT wheat (n=107)	Adopters, non ZT plot (n=107)	Non-adopters (n=221)	Disadopters (n=33)	Overall (±std.dev.) (n=468)	Significance (ANOVA)
A. Gross revenue	*37.6*	*38.7*	*39.2*	*36.4*	*38.6 (±8.3)*	*0.17*
- Grain	37.1	38.2	38.5	35.8	37.9	NS
- Straw	0.5 a	0.5 a	0.7 b	0.6 ab	0.6	0.00
B. Total cost	*33.3 a*	*33.7 ab*	*35.2 c*	*34.5 bc*	*34.4 (±4.1)*	*0.00*
B1. Land preparation	2.2	2.2	2.4	2.4	2.3	0.01
- Plowing	1.9	1.8	2.0	2.0	1.9	0.00
- Planking	0.4	0.4	0.4	0.3	0.4	NS
B2. Crop establishment	1.2	1.1	1.2	1.1	1.2	NS
- Seed drill	0.0	0.0	0.0	0.0	0.0	NA
- Labor for planting	0.9	1.0	1.0	0.9	1.0	NS
- Seed for planting	0.2	0.2	0.2	0.2	0.2	NS
Subtotal B1+B2	3.4	3.3	3.5	3.5	3.4 (±0.5)	0.03
B3. Fertilizer cost	2.6	2.7	2.8	2.9	2.7	0.11
B4. Plant protection cost	2.8	2.9	2.5	2.1	2.6	0.01
B5. Irrigation cost	5.7	6.0	7.2	7.0	6.6	0.00
B6. Harvesting expenditures	2.1	2.1	2.3	2.2	2.2	NS
B7. Land rent	14.0	14.0	14.0	14.0	14.0	NA
B8. Interest on capital invested	2.8	2.8	2.9	2.8	2.8	0.00
C. Net revenue [A-B]	*4.3*	*5.0*	*4.1*	*1.9*	*4.2 (±8.9)*	*NS*
% plots with positive NR	68	76	65	49	67	0.03
Benefit:cost ratio [A/B]	1.14	1.16	1.13	1.07	1.13 (±0.26)	NS
Production cost (INR/kg)	8.3	7.9	8.8	7.6	8.4 (±3.8)	0.10

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison). Only included for line item totals (A,B,B1+B2, C) and A sub-items.

ZT wheat does not significantly affect production costs of the subsequent rice crop (Table 63, section B), with adopters reporting similar total costs for rice after ZT and rice after conventional wheat. Non-adopters report the highest rice production costs, but this again seems to be more associated with the types of rice varieties and overall efficiency. Total production costs are significantly different for each of the varietal groups (Table 64, section B), being the lowest for superfine rice (INR 33,400 per hectare), followed by traditional basmati (INR 34,500 per hectare) and highest for evolved basmati (INR 35,800 per hectare). The cost differences primarily reflect differences in irrigation and harvesting, since basmati varieties are manually harvested and threshed, entailing higher costs than combine harvesting.

6.2.3 Performance indicators

The net revenue (or gross margin) of rice production averages INR 4,200 per hectare, with a standard deviation of INR 8,900 per hectare. The net revenue is thus highly variable, although on average, gross revenue (INR 38,600 per hectare) easily surpasses average total costs (INR 34,400 per hectare), implying an average return of 13% to production costs. Still, only 67% of rice plots had a positive net revenue (i.e. 33% were below breakeven). Production costs amount to INR 8.4 per kg rice grain on average.

ZT wheat did not significantly affect net revenue of the subsequent rice crop (Table 63, section C). However, varietal differences again contributed significantly. Net revenue is significantly different for each of the varietal groups (Table 64, section C). Superfine rice did not break even, reporting a minor net loss (INR 600 per hectare). This contrasts with the significant net returns for traditional basmati (INR 6,600 per hectare) and evolved basmati (INR 9,700 per hectare). These imply average returns of 20% and 28% for traditional and evolved basmati, with respectively 81% and 87% of plots achieving a positive return. In view of the relatively favorable returns for basmati one might expect more farmers to grow basmati instead of the prevalent superfine rice. However, basmati prices are more variable and are dictated by market forces. Basmati also requires manual harvesting and so means foregoing the possibility of combining.

Table 65 provides financial water productivity indicators for rice, again presenting two sets of indicators, one based on net revenue and one based on gross revenue. Net revenue-based water productivity indicators average only INR 152 per irrigation, INR 0.38 per irrigation m^3 water and INR 0.25 per gross m^3 water (rain + irrigation). Therefore, compared to wheat, the higher net revenues for rice are more than cancelled out by the higher water inputs. The net revenue income-based water productivity indicators do not differ significantly over rice plot types, but are significantly

Table 64. Crop budget (000 INR/hectare) for rice crop by rice variety.

	Superfine (n=217)	Evolved Basmati (n=141)	Traditional Basmati (n=109)	Overall (±std.dev.) (n=467)	Significance (ANOVA)
A. Gross revenue	*32.8 a*	*45.5 c*	*41.1 b*	*38.6 (±8.3)*	*0.00*
- Grain	32.6 a	44.5 c	40.0 b	37.9	0.00
- Straw	0.2 a	1.0 b	1.1 b	0.6	0.00
B. Total cost	*33.4 a*	*35.8 c*	*34.5 b*	*34.4 (±4.1)*	*0.00*
B1. Land preparation	2.2	2.4	2.3	2.3	0.00
- Plowing	1.8	2.0	2.0	1.9	0.00
- Planking	0.4	0.4	0.3	0.4	0.14
B2. Crop establishment	1.1	1.1	1.3	1.2	0.00
- Seed drill	0.0	0.0	0.0	0.0	NA
- Labor for planting	0.9	1.0	1.0	1.0	NS
- Seed for planting	0.2	0.2	0.3	0.2	0.00
Subtotal B1+B2	*3.3 a*	*3.5 b*	*3.6 b*	*3.4 (±0.5)*	*0.00*
B3. Fertilizer cost	2.9	3.0	2.1	2.7	0.00
B4. Plant protection cost	2.8	2.3	2.8	2.6	0.00
B5. Irrigation cost	6.2	7.2	6.5	6.6	0.01
B6. Harvesting expenditures	1.5	2.8	2.7	2.2	0.00
B7. Land rent	14.0	14.0	14.0	14.0	NA
B8. Interest on capital invested	2.8	3.0	2.8	2.8	0.00
C. Net revenue [A-B]	*-0.6 a*	*9.7 c*	*6.6 b*	*4.2 (±8.9)*	*0.00*
% plots with positive NR	47	87	81	67	0.00
Benefit:cost ratio [A/B]	1.00 a	1.28 c	1.20 b	1.13 (±0.26)	0.00
Production cost (INR/kg)	5.8 a	8.3 b	13.8 c	8.4 (±3.8)	0.00

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison). Only included for line item totals (A,B,B1+B2, C) and A sub-items.

associated with rice varietal groups (Table 66). Gross revenue water productivity indicators are more favorable for adopters, reflecting their lower water inputs, but do not differ significantly between their plots after ZT and conventional wheat. Gross revenue water productivity indicators are relatively similar across varietal groups, grain value differentials compensating for the biophysical water productivity differentials observed earlier (section 5.2.2).

6.3 Rice-wheat system profitability

The current section presents the aggregate implications of ZT for system profitability—i.e. its combined effect on the wheat and subsequent rice crop. We aggregate before averaging, i.e. aggregation is done for each individual plot and subsequently averaged by plot type (see section 2.3). As a result, the number of observations is reduced and averages may differ from those reported earlier based on all plot observations.

The aggregate gross revenue for rice-wheat cultivation averages INR 68,100 per hectare against an aggregate total production cost of INR 62,700 per hectare, giving an aggregate net revenue of INR 5,400 per hectare. On average, rice contributes over half of the aggregate gross revenue and costs, but approximately three-quarters of the net revenue. However, the rice averages also tend to be more variable than wheat, as highlighted by significantly higher standard deviations. Overall, the return to rice-wheat cultivation amounts to 9%.

The aggregate plots show some significant variations between plot types in performance indicators related to the use of ZT on the wheat crop, particularly in terms of costs, net revenues and benefit:cost ratio. There is no significant effect of ZT wheat on aggregate gross revenue (Table 67). The higher wheat gross revenue with ZT is annulled by the non-significant variation in rice gross revenue. The aggregate total costs are significantly lower for the ZT plots, with the significant variation in cost savings for the rice crop reinforcing the significant variation in cost savings for the wheat crop. The variations in rice costs, however, are more a reflection of the underlying class of rice variety and overall efficiency of adopters. The significantly higher ZT net revenues for wheat translate into significantly higher net revenues at the system level for ZT plots of adopters as against conventional plots of non-adopters and disadopters. In case of the ZT plots, wheat and rice contribute about

Table 65. Financial water productivity indicators for rice by plot category.

	Rice sown after ZT wheat (n=107)	Rice sown after conventional wheat: Adopters, non ZT plot (n=98)	Rice sown after conventional wheat: Non-adopters (n=222)	Rice sown after conventional wheat: Disadopters (n=33)	Overall (±std.dev.) (n=468)	Significance (ANOVA)
Net revenue-based water productivity indicators						
- INR/irrigation	136	176	164	41	152 (±518)	NS
- INR/irrigation m^3	0.39	0.51	0.34	0.21	0.38 (±0.76)	0.16
- INR/gross m^3 (rain + irrig)	0.26	0.33	0.22	0.14	0.25 (±0.45)	0.13
Gross revenue-based water productivity indicators						
- INR/irrigation	1,220	1,220	1,270	1,140	1,240 (±1,568)	NS
- INR/irrigation m^3	2.8 bc	3.0 c	2.5 ab	2.2 a	2.6 (±1.7)	0.04
- INR/gross m^3 (rain + irrig)	1.9 bc	2.0 c	1.8 ab	1.7 a	1.9 (±0.7)	0.00

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

Table 66. Financial water productivity indicators by rice variety.

	Superfine (n=217)	Evolved Basmati (n=141)	Traditional Basmati (n=109)	Overall (±std.dev.) (n=467)	Significance (ANOVA)
Net revenue-based water productivity indicators					
- INR/irrigation	37 a	282 b	212 b	152 (±518)	0.00
- INR/irrigation m^3	0.16 a	0.64 c	0.49 b	0.38 (±0.76)	0.00
- INR/gross m^3 (rain + irrigation)	0.06 a	0.47 c	0.34 b	0.25 (±0.45)	0.00
Gross revenue-based water productivity indicators					
- INR/irrigation	1,200	1,290	1,250	1,240 (±1,568)	NS
- INR/irrigation m^3	2.6	2.7	2.6	2.6 (±1.7)	NS
- INR/gross m^3 (rain + irrigation)	1.7 a	2.0 c	1.9 b	1.9 (±0.7)	0.00

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

equally to net revenue, in contrast to conventional plots where rice is the prime contributor. In much the same way, ZT plots achieve significantly higher benefit:cost ratios. However, compared to the conventional plots of adopters the more favorable net revenue and benefit:cost ratio are not statistically significant.

Table 68 provides financial water productivity indicators for the rice-wheat system. The system-level water productivity indicators naturally take an intermediate value between the low rice values and the higher wheat values. Since the water inputs into rice are higher, the aggregate water productivity indicators fall in the lower end of the range. Net revenue-based water productivity indicators average only INR 165 per irrigation, INR 0.45 per irrigation m^3 and INR 0.29 per gross m^3. All net revenue water productivity indicators show a largely similar pattern whereby the ZT plots achieve the highest values and disadopters the lowest, with a significant difference between these two classes but with these not necessarily being different from the intermediate types of plots. Gross revenue water productivity indicators for the rice-wheat system are more favorable for adopters, reflecting their lower water inputs, but do not differ significantly between their plots after ZT and conventional wheat.

Therefore, we can conclude that the aggregate system performance generally reflects the effects of ZT on wheat performance, although the effects tend to be more subdued. Overall there are no significant positive or negative carryover effects on the crop budget and water productivity indicators considered for the rice-wheat system as a whole. For significant improvements at the system level farmers would need to start growing dry direct-seeded rice and 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 67. System-level profitability indicators (000 INR/ha/year) by plot category (rice + wheat, aggregation before averaging).

		Conventional rice-wheat				
	Adopters, ZT plot (n=76)	Adopters, non ZT plot (n=86)	Non-adopters (n=221)	Disadopters (n=33)	Overall (±std.dev., n) (n=416)	Significance (ANOVA)
Gross revenue (000 INR/ha)	67.5	68.1	68.8	64.9	68.1 (±9.0)	0.12
- Rice crop	37.1	39.0	39.2	36.4	38.6 (±8.4)	0.10
- Wheat crop	30.4 c	29.1 ab	29.6 bc	28.5 a	29.5 (±3.2)	0.01
Total costs (000 INR/ha)	58.9 a	61.7 b	64.3 c	63.4 c	62.7 (±5.6)	0.00
- Rice crop	32.7 a	33.6 ab	35.2 c	34.5 bc	34.4 (±4.2)	0.00
- Wheat crop	26.2 a	28.1 b	29.1 c	28.9 c	28.4 (±2.1)	0.00
Net revenue (000 INR/ha)	8.6 c	6.4 bc	4.5 b	1.5 a	5.4 (±10.2)	0.00
- Rice crop	4.4	5.4	4.1	1.9	4.2 (±8.9)	NS
- Wheat crop	4.2 c	1.0 b	0.4 ab	-0.4 a	1.2 (±3.9)	0.00
Benefit/cost ratio	1.15 c	1.11 bc	1.08 b	1.03 a	1.09 (±0.17)	0.00

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

Table 68. System-level financial water productivity indicators by plot category (rice + wheat, aggregation before averaging).

		Conventional rice-wheat				
	Adopters, ZT plot (n=76)	Adopters, non ZT plot (n=86)	Non-adopters (n=221)	Disadopters (n=33)	Overall (±std.dev., n) (n=416)	Significance (ANOVA)
Net revenue-based water productivity indicators						
- INR/irrigation	269 c	198 bc	137 b	35 a	165 (±319)	0.00
- INR/irrigation m^3	0.76 c	0.55 bc	0.35 ab	0.17 a	0.45 (±0.81)	0.00
- INR/gross m^3 (rain + irrig)	0.47 c	0.36 bc	0.23 ab	0.11 a	0.29 (±0.49)	0.00
Gross revenue -based water productivity indicators						
- INR/irrigation	2,060	1,950	1,850	1,830	1,910 (±880)	NS
- INR/irrigation m^3	4.9 b	4.6 b	3.8 a	3.5 a	4.1 (±2.2)	0.00
- INR/gross m^3 (rain + irrig)	3.3 b	3.1 b	2.7 a	2.6 a	2.9 (±1.0)	0.00

Note: Data followed by different letters differ significantly (Duncan multiple range test, significance level = 0.10, within row comparison).

7 Farm and regional impacts of zero-tillage

The impact of the ZT technology has so far been assessed in technical and financial terms at the plot level. The present section considers some of the higher system level implications. Firstly, we assess the farm level implications of ZT for the adopting farms. Secondly, we assess the regional implications of ZT, including social and environmental considerations.

7.1 Farm-level impacts of zero-tillage

In order to explore the farm level impact a number of additional queries were posed to ZT adopters and disadopters.[13] Adopters and disadopters were near unanimous that they spent less time cultivating wheat after adopting ZT. The wheat cultivation time saved was primarily used for other agricultural activities, and to a lesser extent other non-agricultural activities and more leisure time (Table 69). Adopters and disadopters were again near unanimous that the adoption of ZT did not reduce the time for cultivating rice.

Adopters and disadopters differed significantly in terms of whether ZT had increased the family's income. Whereas over 90% of adopters reported an increase, only 25% of disadopters did so. Of those adopters that reported an increase, nearly all (95%) reinvested some of the proceeds in farming activities; less commonly they were used for debt repayment, investment in children's schooling, expenditure on social activities, investment in housing and others purposes (Table 69). The limited number of disadopters who reported an increase in income does not allow for strong inferences, but also showed preferential reinvestment of some of the proceeds in farming activities. Adopters and disadopters were near unanimous that the adoption of ZT did not increase the family's food consumption, likely reflecting their superior asset status and that their food consumption is not seriously constrained.

Adopters and disadopters were also asked to list the main changes that ZT had brought to their farming activities and family. The range of open responses was subsequently categorized and is presented in

Table 69. Selected impact indicators of adoption of zero-tillage technology reported by plot category (adopters and disadopters only).

	Adopters	Disadopters	Sample mean	Significance (Chi^2)
Farmer spends less time cultivating wheat after adopting ZT (% reporting)	99	93	97 (n=137+40=177)	NA
Reported use of wheat cultivation time saved (% of those reporting savings)			(n=135+37=172)	
- Other agricultural activities	93	87	91	NS
- Other non-agricultural activities	27	19	25	NS
- More leisure time	13	16	14	NS
- Other	4	5	5	NS
Farmer spends less time cultivating rice after adopting ZT (% reporting)	2	0	1 (n=177)	NA
Family's income has increased after adopting ZT (% reporting)	92	25	77 (n=177)	0.00
Reported use of extra income (% of those reporting increase)			(n=126+10=136)	
- Investment in farming activities	95	100	96	NS
- Debt repayment	40	10	38	0.06
- Investment in children's schooling	36	50	37	NS
- Expenditure on social activities	32	10	30	0.15
- Investment in housing	20	0	18	0.12
- Investment in non-farming business	10	10	10	NS
- Expenditure on food	10	0	9	NS
- Purchase of appliances (TV, fridge)	8	0	7	NS
- Investment in vehicle for transport	2	0	2	NA
Family's food consumption has increased after adopting ZT (% reporting)	3	0	2 (n=177)	NA

[13] Two issues should be noted. First, that the responses only reflect a subset of the sample (178 households, comprising 138 adopters and 40 disadopters). Second, that there are an increased number of missing responses. Care should therefore be taken in interpreting the shares presented in the text and tables

Table 70. In terms of changes in farming activities, the responses primarily reflect productivity effects of ZT proper, with most farmers reporting time savings and costs savings, and to a lesser extent diesel savings, production increases and less wear and tear of tractors (or increase in tractor longevity). The limited number of disadopters who reported changes in farming again does not allow for strong inferences, but it is interesting to note that the various ZT-related benefits were less pronounced, which suggests they typically had less successful experiences with ZT, leading to their discontinuing with the technology. There were few responses in relation to changes to the family, and these primarily revolved around more time being available to the family members.

This study provides some support to the postulated water savings of ZT wheat at the field level. In particular the water use survey showed that ZT in wheat saves irrigation time (6.4 hours per hectare per season), saves irrigation water (340 m^3 per hectare per season) and enhances wheat yield (260 kg/ha). The absence of any reported significant change in farm activities or area cultivated suggests that these water savings generally did not lead to an immediate alternative use of the saved water on-farm. Instead, the reduced water applications seem to have primarily saved irrigation time and irrigation costs and reduced groundwater extraction for the ZT wheat crop compared to the conventional wheat crop. Another study in the Punjab, Pakistan 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). However, in Haryana any significant expansion in area was unlikely, as rabi fallow is uncommon (only 1.8% of households reported some rabi fallow, with on average 99% of the operational area being cultivated during rabi season).

The present study has highlighted that adopters typically have a more favorable resource base and tend to outperform nonadopters and disadopters, irrespective of their use of ZT. The carryover effects on the rice crop were typically insignificant, and their inclusion tends to dampen the significance of the observed effects of ZT at the system level, not least due to the rice varietal effect. The present section, therefore, limits itself to scaling up the observed significant differences between the adopters' ZT plots and conventional till plots for the wheat crop.

With an average ZT wheat area of 5.0 hectares per household, ZT adopters save an average of 180 liters of diesel and 30 tractor hours, and yield an additional 0.9 tons of grain per wheat season. This results in a seasonal cost saving of INR 9,500 on top of an increase of INR 6,000 in gross return, resulting in an increase of INR 15,500 in net revenue.

Most ZT-adopting households have postponed the investment decision to buy a ZT drill, with the majority of adopters (60%) being dependent on service providers 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. To put the investment in a ZT drill in meaningful terms, we have estimated the ZT drill investment recovery indicator—the number of wheat seasons needed to recoup the investment. With an average ZTD cost of INR 18,000 and some simplifying assumptions (e.g. no interest, no renting out), the cost saving alone implies that the investment in a ZTD would be recovered within 1.9 wheat seasons. Adding in the yield gain, ZTD investment recovery would be in 1.2 wheat seasons. ZT adopters have an average additional farm area of 4.0 hectares per household primarily planted with conventionally-tilled wheat. Were they to extend ZT to the entire farm area during the rabi season, ZT adopters would nearly double their gains, including an extra 1.5 tons of grain and INR 28,100 net revenue per season. In this case they would recover their investment in a ZTD within 1.0 wheat seasons based on costs savings alone, and 0.6 seasons if we add in the yield gain. Providing ZT drill rental services would further shorten the time needed to recap the investment. This suggests the ZT drill investment cost is not prohibitive for an average ZT adopter who already owns a tractor.

Table 70. Main changes that zero-tillage has brought to farming activities and families by adoption category (adopters and disadopters only) [categorized open responses to three main changes reported].

	Adopters	Disadopters	Sample mean
Reported changes to farming activities (% reporting)	(n=104)	(n=23)	(n=127)
Time saving	64	30	58
Cost saving	61	39	57
Diesel saving	31	0	25
Production increase	15	0	13
Machine saving/tractor age increase	8	4	7
Reported changes to family (n reporting)	(n=15)	(n=0)	(n=15)
More time available to family members	11	0	11

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. The disadopter households, with an average of 5.6 hectares of wheat, could potentially gain INR 17,500 net revenue per season. They would thereby recover a ZTD investment within 1.7 wheat seasons based on costs savings alone, and 1.0 season if we add in the yield gain. The nonadopter households, with 5.0 hectares of wheat, could potentially reap the same levels of benefits as adopters are currently already gaining from their ZT area. Tractor ownership is also least common amongst non-adopters (53%). This highlights that the investment in a ZT drill is typically less attractive for disadopters and particularly for non-adopters than for adopters, unless they would be able to benefit by providing significant ZT drill rental services.

The diesel and tractor time saving 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 used for a number of purposes 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 countered by a greater decrease in traditional tillage services.

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

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

7.2 Regional impacts of zero-tillage

According to expert estimates, 0.35 million hectares of wheat were planted by ZT drill during 2003-04 in Haryana alone (Laxmi et al. 2007). Extrapolating our plot level findings to this area, ZT entailed a saving of 12.6 million liters of diesel and 2.1 million tractor hours, and a gain of 60,000 tons of grain in the 2003-04 season. In financial terms, this gives a net income increase of INR 1,085 million per season, comprising a cost saving effect of INR 665 million and a yield effect of INR 420 million. If we assume that ZT can be extended to a third of the total rice-wheat area in Haryana of 2.19 million hectares (Laxmi et al. 2007), these aggregate benefits would be increased by a factor 2.1. If we assume that ZT can be extended to a third of the total rice-wheat area in India of 10.4 million hectares (Laxmi et al. 2007), the factor would be 9.8.

Water is a major concern for the sustainability of intensive cropping systems in Haryana and for the Indian 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 may be due to measurement error, as our survey relied on estimates by farmers. The farmer responses imply there is some water saving, but it may be less significant than is often suggested. Only the water use survey verified that ZT generated significant water savings in wheat fields.

The present study concurs with other studies that resource-conserving technologies like ZT can be successful in improving field-level 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 simply be 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).

Notwithstanding, the irrigation water savings with ZT in wheat are modest. To put the water savings of ZT wheat further into perspective it is useful to recall that the irrigation input needed for rice is a multiple of that for wheat; on average the input for rice is higher by a factor of 8.4 according to our survey data. In part, this reflects rice's higher potential evapotranspiration than wheat (640 mm versus 330 mm per crop season) (Ullah et al. 2001). In wheat the actual evapotranspiration is generally lower than the potential requirement (Ahmad et al. 2002; Jehangir et al. 2007). However, in 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. In terms of regional water savings, enhancing the water productivity of the rice component of the rice-wheat system will be imperative. Significant irrigation water savings of some 30-40% can indeed be achieved with resource-conserving technologies in rice, although these are typically derived from the recycled water component and do not reduce actual evapotranspiration (Ahmad et al. 2007; Humphreys et al. 2005).

Water rights and institutional arrangements further confound the picture. Despite a gradual increase in water scarcity at the sub-basin and basin levels, improving water productivity and achieving real water savings remain secondary concerns for most rice-wheat farmers (Ahmad et al. 2007). The current attraction for farmers of ZT in wheat is primarily the cost savings and not the water savings as such. This is likely to be the case as long as farmers are not charged according to their actual water use and do not pay the real (economic) cost of water. However, this would involve making politically unpopular adjustments to water rights, particularly to groundwater, 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 Haryana. In principle ZT is accessible to smallholders through service providers. However, the differential adoption rates suggests that some constraints have limited its uptake amongst smallholders, possibly associated with greater difficulty in accessing ZT drills and knowledge and lower risk-bearing capacity. In the present context, the tractor and cost saving effects of ZT wheat have relatively limited implications for labor use. Consequently, whereas ZT by its nature has bypassed the landless, it also seems to have had limited negative impact on the landless through labor displacement. However, monitoring and better understanding the equity implications of extending ZT and other RCTs to the rice component of the rice-wheat system is imperative.

The ZT-induced fuel savings imply a significant positive environmental externality by reducing CO2 emissions, the major contributor to global warming. The widespread burning of non-basmati rice residues when land is being prepared for the subsequent wheat crop is generating a significant negative externality in terms of 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 residue burning. Further adaptations to crop residue management practices and/or to the drill could alleviate the perceived need to burn loose residues.

From a conservation agriculture point of view there is a need to maintain some crop residue cover on the soil surface and to move beyond ZT's application only to the wheat crop. The environmental and soil impacts of ZT wheat on 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 may act as a stepping stone to a more comprehensive conservation agriculture approach, but this will require changes to the way rice is grown, managing crop residues so as to maintain some soil cover and enhancing crop rotation.

From a national perspective, the rice-wheat systems in Haryana and Punjab are of extreme strategic importance for national food security. As a result, rice-wheat systems in these states have received significant public sector support (World Bank 2005). Despite this, productivity growth has stagnated and competitiveness is under pressure. The present survey highlights the relatively minor net revenues derived from wheat cultivation, which underscore 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 needs to be complemented by varietal renewal (e.g. use of more diverse and stem rust resistant wheat varieties and non-puddled rice varieties); other resource-conserving technologies (e.g. laser leveling for improved rice cultivation); and diversification of rice-wheat systems. Furthermore, the advent of Ug99, the virulent new strain of wheat stem rust (Mackenzie 2007; Raloff 2005) and worsening global warming (Ortiz et al. 2006) could have far-reaching consequences across the IGP.

8 Conclusions and recommendations

The study confirmed widespread adoption of ZT wheat (34.5%) in the rice-wheat systems of India's Haryana. 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. Thus, the prime driver for ZT adoption is monetary gain, not water savings or natural resource conservation; water savings are only an added benefit.

The adoption of ZT for wheat accelerated significantly from insignificant levels from 2000 onwards. Geographic penetration of ZT is far from uniform, suggesting potential for further diffusion. However, the study also showed significant ZT disadoption (10%) in the survey year. Better understanding the rationale for disadoption merits further study. Our findings suggest that there is no single major constraint on ZT, but that a combination of factors are at work, including technology performance, technology access, and seasonal constraints. In terms of technology performance the yield under ZT relative to conventional tillage was particularly influential: disadopters reported the lack of a significant yield effect as a major contributor to their disillusionment. The ZT-induced time savings in land preparation did not translate into timelier establishment in ZT plots, thereby contributing to the lack of a yield increase. Knowledge blockages, resource constraints, the perceived high cost of the ZT drill ZT drill availability, and diversification incentives all also constrained adoption. This suggests that there is potential to further enhance the access to ZT technology and thereby its penetration.

The study highlights that ZT has been primarily adopted by the larger and more productive farmers. The structural differences between the adopters and the non-adopters and disadopters in terms of resource base, crop management and performance therefore easily confound the assessment of ZT impact across adoption categories. For this reason this study compares the ZT plots and conventional plots of adopters. Whether this introduces others biases merits further scrutiny. The plot comparison shows significant advantages of ZT in the wheat crop, although the significance of some of these effects is lost at the rice-wheat system level.

The present study confirmed significant ZT-induced resource savings in farmers' fields in terms of water, diesel, and tractor time for wheat cultivation. ZT-induced effects primarily apply to wheat crop establishment, production costs, and yield. There are limited implications for the overall wheat crop management, the subsequent rice crop, and the rice-wheat system as a whole. The higher yield and water savings result in significantly higher water productivity indicators for ZT wheat. The ZT-induced yield enhancement and cost savings provide a much needed boost to the returns to and competitiveness of wheat cultivation.

Recommendations

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

There is scope to more emphatically stress timeliness of wheat establishment. The average planting date shows that a significant share of wheat plots is still established late, constraining wheat productivity. The potential of ZT to significantly improve timeliness has 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 smallholders' access to ZTD service providers. The majority of ZT adopters (60%) so far are large farmers who relied on contracted ZT drill services. Such services have much merit, but only when they are timely, reliable, knowledgeable and widely accessible. Many of the potential benefits from ZT are easily negated by a late or uncertain arrival of the ZTD or its improper use. This calls 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 ZTDs for smallholders.

There is a need to enhance smallholders' access to knowledge about ZT. Penetration of ZT is still uneven, both geographically and within communities. Alleviating knowledge blockages can further equitable access to this promising technology. There is particular scope for more field days, farmer exchanges, farmer to farmer extension, and a more participatory, farmer field school approach throughout the IGP.

There is a need for additional water-saving technologies, particularly to reduce the water consumption of the rice component in rice-wheat systems. ZT wheat is water-saving but alone is 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.

From a conservation agriculture perspective there is a need to maintain some crop residue cover on the soil surface and to move beyond the application of ZT to the wheat crop only. The environmental and soil impacts of ZT wheat on the rice-wheat system as a whole remain short-lived as long as the subsequent rice crop remains intensively tilled and puddled. ZT may be a stepping stone to a more comprehensive conservation agriculture approach, but this will require changes to the way rice is grown, managing residues so as to maintain some soil cover and enhancing crop rotation. This calls for changes in the prevailing design of ZT equipment 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 current 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 a sustainable system of agriculture that includes crop rotation and promotes economical resource use. This could easily prove even more significant, particularly for water savings, but implies addressing some thorny policy issues, such as the subsidy and taxation schemes (e.g. flat water charges, underpriced/free irrigation water, and an 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 present study primarily relied on a household survey which allowed us to quantify and test for significance of observed differences. However, the study would have benefited from complementary informal surveys to shed more light on understanding, for instance, the reasons for disadoption 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 would be valuable and would enhance the relevance and equity of research and development interventions.

This study also identifies 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 disadoption process, particularly in terms of disentangling the underlying causes. The present study generated some insight but could not resolve a number of issues, such as the site-specific circumstances disadopters faced in terms of their access to a 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 for partial adoption and the underlying field selection criteria and eventual biases this may imply in terms of technology performance.
- A better understanding of the adoption and impacts of ZT in the eastern Indo-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 with reseources and has more intensive rice-wheat systems then the eastern plains (Erenstein et al. 2007c; Erenstein et al. 2007b). A closer scrutiny of the adoption, impacts and implications of ZT there would be valuable now that the uptake of ZT in the eastern plains has started to gather pace.
- The refinement and extrapolation of recommendation domains for technologies like ZT—for instance, the implications and potential use of ZT in wheat-cotton systems with low cotton residue retention levels and the extrapolation to other systems like maize-wheat and the rainfed systems.
- More intensive, participatory and timely monitoring of the performance and impact of new technologies like ZT in farmers' fields.

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Annex

Annex 1 List of sample villages and sample breakdown.

District	Tehsil	Block	Villages	Sample size
Ambala	Ambala	Ambala	Balana, Dangdehri, Kardhan, Sukhraon, Sullar	40
Fatehabad	Tohana	Tohana	Chander Khurd, Diwana, Nangla, Pirthala, Puran Majra	40
Jind	Safidon	Safidon	Anchra Khurd, Hatt, Muana, Rampura, Singhowa	40
Kaithal	Kaithal	Kaithal, Pundri*	Jagdishpur, Khanpur, Naina Dhauns, Sampli Khurd*, Ujha	40
Karnal	Karnall	Karnal	Darar, Kurali, Salaru, Sanghowa, Uchana	40
Kurukshetra	Pehowa	Pehowa	Bakhali, Diwaana, Gumthala Ghadu, Satora, Syonsar	40
Panipat	Panipat, Samalkha*	Panipat, Bapoli*	Chandoli, Deewana, Mirzapur*, Sewah, Shimla Balan	40
Sirsa	Rania	Rania	Bhardiyan Wali, Ferozabad, Nagrana, Nakora, Rampur Thairi	40
Sonipat	Ganaur, Sonipat*	Ganaur, Sonipat*	Bali Kutubpur, Datoli, Daturi*, Ghasoli, Larsouli	40
Yamunanagar	Jagadhari	Radaur	Bakana, Bhagu Majra, Kanjnu, Sikandra, Topra Kalan	40
Total districts = 10	Total tehsils = 12	Total blocks = 13	Total Villages = 50	Total = 400

Annex 2 Resource implications (time, diesel and monetary) of tillage operations by crop.

Traction	Operation	Indicator (per operation)	Rice	Wheat	Overall (±std.dev.)	Significance (t-test)
Tractor	Dry plowing	Time (hr/ha)	1.24 (n=460)	1.25 (n=345)	1.24 (±0.18, n=805)	NS
		Diesel (l/ha)	7.44 (n=460)	7.42 (n=345)	7.43 (±0.98, n=805)	NS
		Rental cost (IRs/ha)	410 (n=460)	409 (n=345)	410 (±46, n=805)	NS
	Dry planking	Time (hr/ha)	0.67 (n=22)	0.64 (n=230)	0.64 (±0.07, n=252)	NS
		Diesel (l/ha)	3.76 (n=22)	3.65 (n=230)	3.66 (±0.83, n=252)	NS
		Rental cost (IRs/ha)	162 (n=22)	163 (n=230)	163 (±28, n=252)	NS
	Wet plowing	Time (hr/ha)	2.05 (n=461)	1.23 (n=132)	1.87 (±0.47, n=593)	0.01
		Diesel (l/ha)	12.54 (n=461)	7.43 (n=132)	11.40 (±2.74, n=593)	0.01
		Rental cost (IRs/ha)	594 (n=461)	413 (n=132)	554 (±119, n=593)	0.01
	Wet planking	Time (hr/ha)	1.27 (n=460)	0.68 (n=132)	1.13 (±0.83, n=592)	0.01
		Diesel (l/ha)	7.32 (n=460)	3.54 (n=132)	6.48 (±1.97, n=592)	0.01
		Rental cost (IRs/ha)	267 (n=460)	159 (n=132)	243 (±64, n=592)	0.01
	Planting	Time (hr/ha)	-	1.91 (±0.48, n=254)		NA
		Diesel (l/ha)	-	9.93 (±3.07, n=254)		NA
		Rental cost (IRs/ha)	-	616 (±220, n=254)		NA
Animal	Dry plowing	Rental cost (IRs/ha)	486 (n=8)	494 (n=4)	486 (±18, n=12)	NS
	Dry planking	Rental cost (IRs/ha)	124 (n=1)	173 (n=3)	161 (±32, n=4)	NS
	Wet plowing	Rental cost (IRs/ha)	618 (n=8)	479 (n=4)	571 (±70, n=12)	0.01
	Wet planking	Rental cost (IRs/ha)	256 (n=8)	151 (n=4)	221 (±66, n=12)	0.01

Annex 3 Questionnaires for (i) drill manufacturers survey; (ii) water use survey

Diffusion of Zero Till Seed Drills in Haryana and Punjab

Questionnaire for Drill Manufacturers

Enumerator: ______________________ Date: ____________________

Name of drill manufacturer: ____

Address: ____

____

____

____

Telephone: ____

FAX: ____

Year company established: ___________ (1)

First year in which ZT drills were sold: ____________ (2)

Recent sales history:

Year	Total number of drills sold	With subsidy	Without subsidy
2003	(3)	(4)	(5)
2002	(6)	(7)	(8)
2001	(9)	(10)	(11)
2000	(12)	(13)	(14)
1999	(15)	(16)	(17)
1998	(18)	(19)	(20)
1997	(21)	(22)	(23)
1996	(24)	(25)	(26)
1995	(27)	(28)	(29)

Study on Adoption and Impact of Resource Conservation Technologies in the Irrigated Plains of India
Adoption and Impacts Survey – Questionnaire 2
Irrigation water requirements: zero till vs. conventional tillage

1. Village information

Village	(1)	Block	(2)	Tehsil	(3)	District	(4)

2. Farmer information

Farmer's name	(5)

3. Irrigation information

Source of irrigation *(1 = canal, 2 = tubewell)*	(6)

Please provide the following information for irrigation practices for WHEAT:

	Zero till		Conventional tillage	
Irrigation	Quantity of water used (units)	Time needed (hours)	Quantity of water used (units)	Time needed (hours)
Pre-sowing irrigation	(7)	(16)	(25)	(34)
First irrigation	(8)	(17)	(26)	(35)
Subsequent irrigations				
1.	(9)	(18)	(27)	(36)
2.	(10)	(19)	(28)	(37)
3.	(11)	(20)	(29)	(38)
4.	(12)	(21)	(30)	(39)
5.	(13)	(22)	(31)	(40)
6.	(14)	(23)	(32)	(41)
7.	(15)	(24)	(33)	(42)

4. Yield information

	Zero till	Conventional tillage
Wheat yield (mun/ac)	(43)	(44)
Plot size (m^2)	(45)	(46)

Annex 4 Questionnaire for adoption survey

Study on Adoption and Impact of Resource Conservation Technologies in the Irrigated Plains of India

Adoption and Impacts Survey Questionnaire

1. Village information

Village	(1)	Block	(2)
Tehsil	(3)	District	(4)

Distance of village in km from:		Nearest grain market	(7)
ADO headquarters	(5)	Input market	(8)
Research station or KVK	(6)	District headquarters	(9)

2. Farmer information

Farmer's name			(10)
Age	(11)	Caste	(12)

Farmer's education	*Codes: 1 = none 2 = primary school 3 = high school 4 = higher*	(13)

Composition of farmer's family	
Adult men	(14)
Adult women	(15)
Children under 16 years	(16)

Farmer's memberships in organizations		Village panchayat	(19)
Cooperative societies	(17)	Zila parisad	(20)
Market committee	(18)	Youth club	(21)

Farmer's years of farming experience	(22)

3. Household and farm assets

3.1 Ownership of household and farm assets

Household assets	Number	Farm assets	Number
Refrigerator	(23)	Tractor	(32)
Bicycle	(24)	Disc / Rotovator	(33)
Motorcycle / Scooter	(25)	Zero-till drill	(34)
Car / Vehicle	(26)	Tubewell	(35)
Tape recorder	(27)	Combine harvester	(36)
Radio	(28)	Motorized thresher	(37)
Television	(29)	Insecticide hand pump	(38)
Telephone	(30)	Bullocks	(39)
Sewing machine	(31)	Milk animals	(40)

3.2 Access to CULTIVATABLE land –Kharif 2003 (acres)

Land category	Canal irrigated only	Tubewell irrigated only	Canal and tubewell irrigated	Main soil Type	Drainage
Land owned	(41)	(42)	(43)	(44)	(45)
Land rented-in	(46)	(47)	(48)	(49)	(50)
Land rented-out	(51)	(52)	(53)	(54)	(55)
Land shared in	(56)	(57)	(58)	(59)	(60)
Land shared out	(61)	(62)	(63)	(64)	(65)
Total					
of which:					
Cultivated	(66)	(67)	(68)	(69)	(70)
Fallow	(71)	(72)	(73)	(74)	(75)

Soil type codes: 1 = sandy, 2 = sandy loam, 3 = loam, 4 = clay
Drainage codes: 1 = well drained, 2 = poorly drained

3.3 Access to CULTIVATABLE land – Rabi 2003-04 (acres)

Land category	Canal irrigated only	Tubewell irrigated only	Canal and tubewell irrigated	Main soil Type	Drainage
Land owned	(76)	(77)	(78)	(79)	(80)
Land rented-in	(81)	(82)	(83)	(84)	(85)
Land rented-out	(86)	(87)	(88)	(89)	(90)
Land shared in	(91)	(92)	(93)	(94)	(95)
Land shared out	(96)	(97)	(98)	(99)	(100)
Total					
of which:					
Cultivated	(101)	(102)	(103)	(104)	(105)
Fallow	(106)	(107)	(108)	(109)	(110)

Soil type codes: 1 = sandy, 2 = sandy loam, 3 =loam, 4 = clay
Drainage codes: 1 = well drained, 2 = poorly drained

3.4 Sources of farm labour

Type of labour	Estimated share of all farm labour used in 2003 (%)
Family labour	(111)
Permanent hired labour	(112)
Casual hired labour	(113)

3.5 Access to credit

Source	Amount (Rupees)	Purpose	Duration (months)	Monthly interest rate
Commercial bank	(114)	(115)	(116)	(117)
Co-operative bank	(118)	(119)	(120)	(121)
Money lender or arhtya	(122)	(123)	(124)	(125)
Input dealers	(126)	(127)	(128)	(129)
Relatives /Friends	(130)	(131)	(132)	(133)

Codes for Purpose: 1 = production, 2 = consumption, 3 = social functions, 4 = house construction, 5 = vehicle purchase

3.6 Income sources

Proportion of total household income from farming activities (%)	(134)
Proportion of total household income from non-farming activities (%)	(135)

Sources of farm income (%)		Sources of non-farm income (%)	
Rice production	(136)	Family business	(147)
Wheat production	(137)	Contract machinery rental	(148)
Pulse production	(138)		
Oilseed production	(139)	Employment on other farms	(149)
Vegetable production	(140)	Non-agricultural employment	(150)
Sugar cane production	(141)	Remittances	(151)
Cotton production	(142)	Money lending	(152)
Other crops:	(143)		
Other crops:	(144)	Other:	(153)
Livestock sales (meat)	(145)	Other:	(154)
Livestock sales (milk)	(146)	Other:	(155)
Total farm income	*100 %*	*Total non-farm income*	*100 %*

4. Experience with zero tillage

4.1 Classification of farmer

Have you ever practiced zero tillage? *1 = yes, 2 = no*	(156)

Did you practice zero tillage in 2003? *1 = yes, 2 = no*	(157)

Farmer classified as: *1 = ZT adopter, 2 = ZT non-adopter, 3 = ZT disadopter*	(158)

Do you use ZT drill only for line sowing on conventionally plowed fields?	(i1)

Codes: 1 = yes, 2 = no

4.2 Adoption history (adopters and disadopters only)

What was the first year in which you practiced zero tillage?	(159)

What was your main source of information about zero tillage?	(160)

Codes: 1 = print media (newspaper or magazine), 2 = broadcast media (radio or TV), 3 = agricultural extension agent, 4 = university scientist, 5 = visit to research station, 6 = input dealer, 7 = family member, 8 = other farmer, 9 = N/A, 10 = drill manufacturer, 11= N/A, 12 = Department of Agriculture.

Year	Wheat area cultivated using zero-till	Yield (kg/acre)	Wheat area cultivated using conventional tillage	Yield (kg/acre)
2003	(i2)	(i8)	(i14)	(i20)
2002	(i3)	(i9)	(i15)	(i21)
2001	(i4)	(i10)	(i16)	(i22)
2000	(i5)	(i11)	(i17)	(i23)
1999	(i6)	(i12)	(i18)	(i24)
1998	(i7)	(i13)	(i19)	(i25)

Tubewell technical information

Do you use a tubewell to irrigate rice and/or wheat? *1 = yes, 2 = no*	(i26)
If you use a tubewell, do you own the tubewell? *1 = yes, 2 = no*	(i27)

If you use a tubewell (owned or rented), what is the pump size (in horsepower)?	(i28)
If you use a tubewell, what is the source of power?	(i29)

1 = electricity, 2 = diesel (separate engine), 3 = diesel (attached to tractor engine)

If you use a tubewell (owned or rented), how big is the inlet pipe? *(inches diameter)*	(i30)
If you use a tubewell (owned or rented), how big is the delivery pipe? *(inches diameter)*	(i31)

If you use a tubewell, what is the depth of the water table? *(feet)*	(i32)

If you use a tubewell, what is the position of the pump?	(i33)

1 = at the surface, 2 = submerged

What is average hourly rental rate for tubewells in this village? (Rs/hour)	(i34)

Annex 4 Cont'd...

4.3 Crop and irrigation management practices for zero-till and conventional till plots

		Rice (Kharif 2003)		Wheat (Rabi 2003-4)	
		Sown after zero-till wheat	Sown after conventional wheat	Zero-till	Conventional
General	Plot size (acres)	(161)	(239)	(316)	(365)
	Main soil type	(162)	(240)	(317)	(366)
Dry plowing (tractor / animals)	Number of dry plowings per season (tractor)	(171)	(249)	N / A	(375)
	Number of dry plowings per season (animals)	(172)	(250)	N / A	(376)
	Tractor hours required for each dry plowing (h/acre)	(173)	(251)	N / A	(377)
	Diesel consumed for each dry plowing (l/acre)	(174)	(252)	N / A	(378)
	Tractor rental rate for dry plowings (Rs/acre)	(175)	(253)	N / A	(379)
	Animal rental rate for dry plowings (Rs/acre)	(176)	(254)	N / A	(380)
Dry planking (tractor / animals)	Number of dry plankings per season (tractor)	(177)	(255)	N / A	(381)
	Number of dry plankings per season (animals)	(178)	(256)	N / A	(382)
	Tractor hours required for each dry planking (h/acre)	(179)	(257)	N / A	(383)
	Diesel consumed for each dry planking (l/acre)	(180)	(258)	N / A	(384)
	Tractor rental rate for dry plankings (Rs/acre)	(181)	(259)	N / A	(385)
	Animal rental rate for dry plankings (Rs/acre)	(182)	(260)	N / A	(386)
Wet plowing (tractor / animals)	Number of wet plowings per season (tractor)	(183)	(261)	N / A	N / A
	Number of wet plowings per season (animals)	(184)	(262)	N / A	N / A
	Tractor hours required for each wet plowing (h/acre)	(185)	(263)	N / A	N / A
	Diesel consumed for each wet plowing (l/acre)	(186)	(264)	N / A	N / A
	Tractor rental rate for wet plowings (Rs/acre)	(187)	(265)	N / A	N / A
	Animal rental rate for wet plowings (Rs/acre)	(188)	(266)	N / A	N / A
Wet planking (tractor / animals)	Number of wet plankings per season (tractor)	(189)	(267)	N / A	N / A
	Number of wet plankings per season (animals)	(190)	(268)	N / A	N / A
	Tractor hours required for each wet planking (h/acre)	(191)	(269)	N / A	N / A
	Diesel consumed for each wet planking (l/acre)	(192)	(270)	N / A	N / A
	Tractor rental rate for wet plankings (Rs/acre)	(193)	(271)	N / A	N / A
	Animal rental rate for wet plankings (Rs/acre)	(194)	(272)	N / A	N / A
Planting	Tractor hours required for planting (h/acre)	(195)	(273)	(318)	(387)
	Diesel required for planting (l/acre)	(196)	(274)	(319)	(388)
	If ZT drill hired, what was the hiring rate? (Rs/??)	(197)	(275)	(320)	(389)
	Human labour required for planting (h/acre)	(198)	(276)	(321)	(390)
	Planting date (dd/mm)	(199)	(277)	(322)	(391)
Variety / Seed	Name of variety	(200)	(278)	(323)	(392)
	Seed rate (kg/acre)	(201)	(279)	(324)	(393)
	Seed source *(1 = own , 2 = neighbor , 3 = purchased)*	(202)	(280)	(325)	(394)
	If seed purchased, what was the cost? (Rs/kg)	(203)	(281)	(326)	(395)
Fertilization	Amount of urea applied (kg/acre)	(204)	(282)	(327)	(396)
	Cost of urea (Rs/kg)	(205)	(283)	(328)	(397)
	Amount of 2nd fertilizer applied (kg/acre)	(206)	(284)	(329)	(398)
	Cost of 2nd fertilizers (Rs/kg)	(207)	(285)	(330)	(399)
	Amount of 3rd fertilizer applied (kg/acre)	(i35)	(i37)	(i39)	(i41)
	Cost of 3rd fertilizers (Rs/kg)	(i36)	(i38)	(i40)	(i42)
	Amount of manure applied (trolleys/acre)	(208)	(286)	(331)	(400)
	Cost of manure (Rs/kg)	(209)	(287)	(332)	(401)

4.3 Crop and irrigation management practices for zero-till and conventional till plots

		Rice (Kharif 2003)		Wheat (Rabi 2003-4)	
		Sown after zero-till wheat	Sown after conventional wheat	Zero-till	Conventional
Weed control	Number of hand weedings per season	(210)	(288)	(333)	(402)
	Human labour required per hand weeding (h/acre)	(211)	(289)	(334)	(403)
	Hand weeding labour cost (Rs/acre)	(212)	(290)	(335)	(404)
	Number of herbicide applications per season	(213)	(291)	(336)	(405)
	Herbicide cost (Rs/acre)	(214)	(292)	(337)	(406)
Pesticides/ fungicides	Cost of pesticide used (Rs/acre)	(215)	(293)	(338)	(407)
	Cost of fungicide (Rs/acre)	(216)	(294)	(339)	(408)
Irrigation	Irrigation source *(1 = canal, 2 = tubewell, 3 = both)*	(217)	(295)	(340)	(409)
	Number of irrigations, canal water	(218)	(296)	(341)	(410)
	Time required for 1st irrigation (hrs), canal water	(219)	(297)	(342)	(411)
	Time required for later irrigation (hrs), canal water	(220)	(298)	(343)	(412)
	If you own tubewell, what is its depth (m)?	(221)	(299)	(344)	(413)
	Number of irrigations, tubewell	(222)	(300)	(345)	(414)
	Time required for 1st irrigation (hrs), tubewell	(223)	(301)	(346)	(415)
	Time required for later irrigation (hrs), tubewell	(224)	(302)	(347)	(416)
	How much tubewell water did you buy? (hours)	(225)	(303)	(348)	(417)
	How much tubewell water did you sell? (hours)	(226)	(304)	(349)	(418)
	Quality of tubewell water *(1 = good, 2 = poor)*	(227)	(305)	(350)	(419)
	Did you face water scarcity in 2003? *(1= yes, 2 = no)*	(228)	(306)	(351)	(420)
Harvesting	Date of harvesting (mm/dd)	(229)	(307)	(352)	(421)
	Manual harvesting labour use (mandays/acre)	(230)	(308)	(353)	(422)
	Labour cost (Rs/manday)	(231)	(309)	(354)	(423)
	Combine harvesting time (hrs)	(232)	(310)	(355)	(424)
	Cost of combine (Rs/acre)	(233)	(311)	(356)	(425)
	Grain yield (kg/acre)	(234)	(312)	(357)	(426)
	Residue management *(1 = burn, 2 = remove, 3 = plow)*	(235)	(313)	(358)	(427)
	Value of by-products (straw) (Rs/acre)	(236)	(314)	(359)	(428)
Threshing	Manual rice threshing labour use (mandays/acre)	(237)	(315)	N / A	N / A
	If wheat hand threshed, threshing cost (Rs/acre)	N / A	N / A	(360)	(429)
	If wheat hand threshed, threshing cost (% crop)	N / A	N / A	(361)	(430)
	If wheat machine harvested, threshing cost (Rs/acre)	N / A	N / A	(362)	(431)
	If wheat machine harvested, threshing cost (% crop)	N / A	N / A	(363)	(432)

Annex 4 Cont'd...

4.4 Constraints to adoption of zero tillage technology

If a farmer decides to practice ZT, what could prevent him or her from doing so?

Assign each factor a score on a scale of 1-3, where:

1 = very serious constraint to adoption of zero tillage technology
2 = moderate constraint to adoption of zero tillage technology
3 = not a constraint at all to adoption of zero tillage technology.

Technical factors	
Non-availability of high-quality ZT drills	(433)
Lack of local manufacturing / repair facility for ZT drills	(434)
Standing stubbles / crop residues at time of planting	(435)
Dense population of weeds at the time of planting	(436)
Lack of appropriate soil moisture at time of planting	(437)
Risk of increased problem with insect pests and diseases	(438)
Hardening of upper soil	(439)
Early harvesting of rice	(440)
Straw burning	(441)
Lack of good quality irrigation water	(442)
Other (specify):	(443)
Extension factors	
Lack of technical assistance from extension workers	(444)
Non-availability of extension literature on ZT methods	(445)
Lack of coverage of ZT methods by mass media	(446)
Other (specify):	(447)
Other (specify):	(448)
Financial factors	
High cost of ZT drill	(449)
Farmer lacks resources to purchase ZT drill	(450)
No credit available for financing purchase of ZT drill	(451)
No credit available to finance purchasing of other inputs	(452)
High labour cost at time of planting	(453)
Other (specify):	(454)
Other (specify):	(455)

4.5 Reasons for discontinuation of zero tillage (disadopters only)

What factors caused you to stop practicing ZT?

Assign each factor a score on a scale of 1-3, where:

1 = major factor
2 = moderate factor
3 = not important at all

Technical factors	**Rating**
Non-availability of high-quality ZT drills	(456)
Lack of local manufacturing / repair facility for ZT drills	(457)
Standing stubbles / crop residues at time of planting	(458)
Lack of appropriate soil moisture at time of planting	(459)
Dense population of weeds at the time of planting	(460)
Increased weed problem following adoption of ZT	(461)
Increased problems with insect pests and diseases	(462)
Hardening of upper soil	(463)
Surplus machine power	(464)
Increased irrigation water requirement	(465)
No significant difference in yield	(466)
No significant cost savings	(467)
Lack of good quality irrigation water	(468)
Extension factors	
Lack of technical assistance from extension workers	(469)
Non-availability of extension literature on ZT methods	(470)
Lack of coverage of ZT methods by mass media	(471)
Other (specify):	(472)
Other (specify):	(473)
Financial factors	
High cost of ZT drills	(474)
Farmer lacks resources to purchase ZT drill	(475)
No credit available for financing purchase of ZT drill	(476)
No credit available to finance purchasing of other inputs	(477)
High labour cost at time of planting	(478)
Other (specify)	(479)
Other (specify)	(480)

Annex 4 Cont'd...

5. Impact of zero tillage on farmer's livelihood (adopters and disadopters only)

After adopting zero tillage, do you spend less time cultivating wheat? *1 = yes, 2 = no*	(481)

If you spend less time cultivating wheat, how do you spend the extra time?
(Tick all relevant responses)

Other agricultural activities	(482)	More leisure time	(484)
Other non-agricultural activities	(483)	Other:	(485)

After adopting zero tillage, do you spend less time cultivating rice? *1 = yes, 2 = no*	(486)

If you spend less time cultivating rice, how do you spend the extra time?
(Tick all relevant responses)

Other agricultural activities	(487)	More leisure time	(489)
Other non-agricultural activities	(488)	Other:	(490)

What are the three main changes that zero tillage has brought to your farming activities?

1.

2.

3.

What are the three main changes that zero tillage has brought to your family?

1.

2.

3.

After adopting zero tillage, has your family's income increased? *1 = yes, 2 = no*	(491)
After adopting zero tillage, has your family's food consumption increased? *1 = yes, 2 = no*	(492)

If you earn more income after adopting ZT, how do you spend the extra income?
(Tick all relevant responses)

Purchase of appliances (TV, fridge)	(493)	Debt repayment	(499)
Investment in housing	(494)	Expenditure on social activities	(500)
Investment in children's schooling	(495)	Expenditure on food	(501)
Investment in farming activities	(496)	Other:	(502)
Investment in non-farming business	(497)	Other:	(503)
Investment in vehicle for transport	(498)	Other:	(504)

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