Adoption and Impacts of

Zero-Tillage in the Rice-Wheat Zone

of Irrigated Punjab, Pakistan

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Comprehensive Assessment of water management in agriculture

Rice Wheat

CIMMYT

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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 Pakistan's Punjab province primarily drawing on a detailed empirical survey of 458 rice-wheat farmers. Our random stratified sample revealed 19% to be ZT wheat adopters and a similar share of the wheat area in the surveyed communities to be under ZT. The study suggests that diffusion has stagnated and also flags the issue of disadoption (14%). 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 7 tractor hours and 35 liters of diesel per hectare. ZT did not have any significant effect on the mean farmer estimated wheat yield of 3.3 tons per hectare. ZT also had no significant effect on water productivity for wheat or spillover effect on the subsequent rice crop. ZT primarily appears to be a cost-saving technology for wheat in Pakistan's Punjab. Based on these findings, the study provides a number of recommendations for research and development in Pakistan Punjab's rice-wheat systems.

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Table of contents

List of tables

List of figures

List of acronyms

CIMMYT	International Maize and Wheat Improvement Center (www.cimmyt.org)
FMI	Farm Machinery Institute, PARC
IGP	Indo-Gangetic Plains
NA	not applicable
NARC	National Agricultural Research Centre, Islamabad (www.parc.gov.pk/narc.html)
NS	not significant
OFWM	On-Farm Water Management, Punjab Ministry of Agriculture, Lahore
p.a.	per annum (per year)
PARC	Pakistan Agricultural Research Council (www.parc.gov.pk)
PKR	Pakistani rupees
RCT	resource-conserving technology
RWC	Rice-Wheat Consortium for the Indo-Gangetic Plains (www.rwc.cgiar.org)
s.d.	standard deviation (std. dev.)
SSI	Social Sciences Institute
SO	Scientific Officer
SSO	Senior Scientific Officer
t	tons (1,000 kg)
TTI	Technology Transfer Institute
ZT	zero-tillage
ZTD	zero-tillage drill

Acknowledgements

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Executive summary

The recent stagnation of productivity growth in the irrigated plains of the Indo-Gangetic Plains of South Asia has led to a quest for resource-conserving technologies that can save water, reduce production costs and improve production. The present study documents the adoption and impacts of zero-tillage (ZT) wheat in the rice-wheat systems of Pakistan's Punjab province drawing on detailed empirical surveys.

Diffusion of zero-tillage (chapter 3)

Our random stratified sample of 458 rice-wheat farmers revealed 19% to be ZT wheat adopters and a similar share of the wheat area in the surveyed communities to be under ZT in rabi 2003-04. The present study thus confirms empirically the significant levels of adoption of ZT wheat in Punjab's rice-wheat systems. Up until 2002-03, ZT diffusion in many ways seemed to follow the traditional diffusion pattern of technological innovations. After nearly a decade of adaptive research, demonstration and slow initial diffusion, diffusion started to pick up rapidly from 2000. However, adoption rates seem to have abruptly peaked in 2002 (at 24%) and 14% of the sample were found to be disadopters in 2003-04. The ZT manufacturers' survey revealed a similar pattern, with peak sales in 2002. The subsequent years will thus inform us whether ZT adoption levels for wheat may end up significantly lower or higher than at the time of the survey. Disadoption comprises both prolonged and temporary disadoption, whereas 54% of those that have used ZT have done so continuously.

The relatively high disadoption is likely associated with the ongoing institutional ZT controversy in Punjab-Pakistan. ZT diffusion has been hampered by institutional rivalry between On Farm Water Management and agricultural extension with unfortunate implications for the farmers and the technology alike, particularly in view of conflicting information. Otherwise, our findings suggest there is no clear single overarching constraint explaining disadoption, but a combination of factors is at play, including technology performance, technology access and seasonal constraints. Better understanding the rationale for disadoption merits further scrutiny.

Adoption is also far from uniform, with significant variations in terms of penetration and use over districts and villages. ZT penetration (adoption plus disadoption) is geographically concentrated in the rice-wheat heartland (Sheikhupura, Gujranwala and Hafizabad districts), whereas ZT manufacturing capacity is concentrated in Sialkot district of Punjab province. The district level suggests that an increased penetration of ZT is associated with increased ZT adoption but also with increased disadoption levels, although ZT adopters typically outnumber disadopters. The assumed intensity of ZT promotion at the district level did not show a clear linkage to increased adoption rates, an issue likely associated with the technology primarily spreading from farmer to farmer and the ongoing institutional ZT controversy in Punjab.

The village level data also allow for some important inferences. First, it illustrates that ZT penetration to individual villages was widespread but not comprehensive at the time of the survey. Second the considerable gradient in village wise adoption rates from none to saturation suggests that intrinsically there is nothing wrong with the technology itself, but that access and application of the technology may be an issue. Indeed the fact that some villages are saturated and others show no disadoption suggests that ZT has considerable merit and wide applicability once the technology has proven itself within a community. Third, disadoption seems to be concentrated in about half the villages where ZT had penetrated. Access to ZT drills varies over villages and is likely to have contributed to the observed adoption patterns.

Partial adoption of ZT on 75% of the wheat area of the adopting farm seems to be the prevalent practice. Ownership of a ZT drill was reported by 7% of the households. The majority of ZT adopters (74%) therefore relied on contracted ZT drill services at the time of the survey.

Understanding adoption of zero-tillage (chapter 4)

The ZT adopters, non-adopters and disadopters categories differ significantly in terms of their resource base. For the various indicators compiled, adopters typically have 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 their risk bearing capacity and ability to innovate. Second, it highlights that ZT disadopters combine characteristics of both adopters and non-adopters. The favorable characteristics may thereby facilitate the initial adoption of ZT, whereas the unfavorable characteristics undermine its continued use.

Bivariate analysis highlighted that adoption of ZT was positively associated with size of operational holding, possession of farming and household assets, literacy ratio, access to both canal and tubewell irrigation water and the reliance on permanent and casual labor. Heavy soils and drainage problems may have contributed to adopters' interest to continue ZT use.

On average, rice and wheat crops occupied three-fourth of total operational holding, while slightly more than 15% of the farm size was allocated for fodder crops during both seasons. Farming was the main income source across households, contributing 80% of overall household income. The share of farming was significantly higher for adopters and disadopters compared to non-adopters, highlighting that adopters and disadopters 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 and disadopters to innovate and cut production costs.

Technical factors rated highest in terms of constraining ZT adoption, with extension and financial factors playing only a minor role. The most pressing and revealing constraint is the reduced/low yield with ZT, which is the prevailing reason for disadopters' abandonment of ZT. Disadopters also had more problems in controlling weeds. Interestingly, non-adopters scored the lack of technical assistance from extension workers and the high cost of ZT drill highest, suggesting that there is potential to further enhance the access to this technology and thereby its penetration.

Binomial logit models reiterate that ZT adoption is closely associated with farm size and rice-wheat specialization. ZT promotion, having more physical assets and not belonging to the prevailing caste played an important role in trying out ZT, but less so in continuing with its use. Conversely, (sandy) loam soils reduced the likelihood of continued ZT 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 per hectare saving of 7 tractor hours and 35 liters diesel. ZT did not have any significant effect on the mean farmer estimated wheat yield of 3.3 t/ha. The lack of a yield increase largely reflects that the ZT induced time savings in land preparation did not translate into timelier establishment. 'Rauni' (with pre-irrigation prior to land preparation) yields were not significantly different from ZT and yields without pre-irrigation in the survey year 2003-04, but were reportedly higher in 2002-03 and 2001-02. However, in none of the recall years was ZT yielding significantly different from yields without pre-irrigation. The lack of a significant yield effect has undermined widespread ZT acceptance and is a major factor explaining disadoption. Without a yield benefit, the immediate pay-off of ZT is reduced to its cost-saving potential, primarily for land preparation and establishment.

ZT wheat was not observed to have any significant effect on seed rate (117 kg/ha of seed), chemical fertilizer use (177 kg/ha of fertilizer-nutrients, 115:61:1) and weed management (0.9 weedings). ZT reduced the duration of the first tubewell irrigation (8.5 vs 9.5 hours per hectare), but had no significant effect on total number (3.4 per season) and duration of subsequent irrigations. The relatively similar yields in the survey year combined with the relatively modest irrigation savings by ZT imply that water productivity indicators are relatively similar across the various plot categories. Water productivity was estimated to average 1.5 kg wheat per irrigation m^3 and 1.0 kg of wheat per gross m^3. Inqalab-91 is the prevailing variety, reported in 69% of plots.

ZT did not have any significant spillover effect in terms of affecting the crop management, yield and water productivity of the subsequent rice crop. Most significant differences between surveyed rice plots reflect structural differences between adopters and non-adopters. Differences between rice plots after ZT wheat and the rice plots after conventional wheat for adopters were typically not significant. Super Basmati is the prevailing rice variety reported in 88% of plots and being late maturing, it conflicts with optimum wheat sowing. Measured rice crop management indicators included tillage operations (9.1 per season), seed rate (8.8 kg/ha of seed), chemical fertilizer use (132 kg/ha of fertilizer-nutrients, 98:34:0), weed management (0.9 weedings) and irrigation (35 irrigations per season). Pesticide use in rice cultivation is widespread (83% of plots), with an above average use in rice after ZT wheat plots (92% of plots). The average farmer estimated rice yield was 3.5 t/ha. Water productivity was estimated to average 0.28 kg rice per irrigation m^3 and 0.22 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 so as to maintain standing water in the paddies with relatively similar yields. Rice cultivation practices also differ from wheat in terms of the intensity of land preparation (one more tractor pass and wet cultivation), fertilization practices (less inorganic fertilizer use and more organic fertilizer), pesticide use (near universal) and harvesting practices (wider reliance on combine harvesting).

Therefore in the case of Pakistan's Punjab, ZT had insignificant effects on yield and water productivity for the wheat crop and the subsequent rice crop. The study thereby cannot confirm that the generally favorable implications of ZT in terms of enhancing wheat yield and saving water reported in trials are also achieved in farmers' fields. The study only confirms the drastic reduction in tractor time and diesel use in wheat land preparation and establishment.

Financial impact of zero-tillage technology (chapter 6)

On an average hectare basis, wheat production implies a gross revenue of PKR 33,500, total costs of PKR 27,300 and a net revenue of PKR 6,200. This implies an average return of 23% to production costs, with 81% of wheat plots having a positive net revenue. The net revenue based water productivities amount to PKR 4.0 per irrigation m^3 and PKR 2.5 per gross m^3. Gross revenue does not significantly differ between wheat plots, but compared to non-adopters and disadopters, adopters achieve significantly lower total costs and higher net revenue in both their ZT and conventional plots. Compared to the conventional plots of adopters, ZT does imply a significant cost saving effect of PKR 2,600 per hectare, but this is partially annulled by a non-significant negative yield effect of PKR 1,100, resulting in a non-significant advantage of PKR 1,500 for ZT in terms of net revenue. The ZT induced cost saving is substantial, and represents a saving of 9.5% on total costs, or 16.4% on operational costs (excluding land). ZT plots thereby achieve a significantly higher return on production costs (a respectable 37%) and significantly higher net revenue based water productivities (PKR 5.6 per irrigation m^3 and PKR 3.4 per gross m^3). The ZT 'cost-saving effect' seems robust enough to make adoption worthwhile and is the driving force behind the prior spread of ZT amongst adopters in Pakistan Punjab. However, learning costs eat into the cost-saving effect and may undermine the apparent returns to adoption for prospective adopters, particularly in view of the lack of a positive yield effect.

On an average hectare basis, rice production implies a gross revenue of PKR 46,300, total costs of PKR 32,400 and a net revenue of PKR 13,900. This implies an average return of 46% to production costs, with 91% of rice plots having a positive net revenue. The net revenue based water productivities amount to PKR 1.4 per irrigation m^3 and PKR 1.1 per gross m^3. Prior ZT wheat does not significantly affect gross revenue, production cost, net revenue or financial water productivity of the subsequent rice crop.

The relative performance at the aggregate rice-wheat system level primarily mirrors the ZT effects on wheat performance. The significant ZT induced cost saving is maintained, whereas for the other indicators ZT and conventional plots of adopters typically tend to outperform non-adopters and disadopters, but do not differ significantly from each other. We can therefore conclude that financial ZT effects 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 Pakistan's rice-wheat systems (Chapter 8).

1 Introduction[3]

The rice-wheat rotation is one of the largest agricultural production systems in the world, occupying 13.5 million hectares of the most productive land in the Indo-Gangetic Plains (IGP) of South Asia, encompassing Northern India, Pakistan, Nepal and Bangladesh (Gupta et al. 2003; Timsina and Connor 2001). About 1.3 billion or about 20% of the world population is dependent on the produce of this area (Ladha et al. 2000). Rice-wheat systems cover about 32% of the total rice area and 42% of the total wheat area in these four countries and accounted for between one-quarter and one-third of total rice and wheat production (Hobbs and Morris 1996). The Green Revolution generated an impressive increase in supply from 1965 to 1985, but subsequently the increase in production did not keep pace with the population growth. The stagnation of rice-wheat productivity called for new resource- conserving production techniques to meet the challenge of productivity enhancement, ensure environmental safety and conserve natural resources (Ladha et al. 2003).

The irrigated rice-wheat systems consume a large proportion of the region's water resources. In the face of increasing competition for water from industrial, domestic and environmental sectors, concerns are being raised about the productivity of water used in agriculture (Kijne et al. 2003). Increasing water scarcity is also seen as a major contributor to stagnating productivity in the rice–wheat cropping systems in the IGP (Byerlee et al. 2003). 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). Negative environmental effects related to irrigation are increasing as overexploitation of groundwater and poor water management lead to dropping water tables in some areas and increased water logging and salinity in others (Harrington et al. 1993; Pingali and Shah 2001; Qureshi et al. 2003), although over time, the mushrooming of small sized diesel tubewells in the Pakistan-Punjab rice-wheat area may have reduced the water logging problem. In addition, tubewell irrigation has raised production costs in view of the energy expenses incurred (electricity or diesel) (Qureshi et al. 2003). Agricultural technologies that can save water, reduce production costs and improve production are therefore becoming increasingly important (Gupta et al. 2002; Hobbs and Gupta 2003b).

The Rice-Wheat Consortium for the Indo-Gangetic Plains (RWC, www.rwc.cgiar.org), which is made up of international agricultural research centers, national agricultural research organizations from Bangladesh, India, Nepal, and Pakistan, and advanced research institutes, has developed and promoted a number of technologies that increase farm-level productivity, conserve natural resources, and limit negative environmental impacts (Gupta and Sayre 2007; Gupta and Seth 2007; Hobbs and Gupta 2003a). These resource-conserving technologies (RCTs) form the basis for conservation agriculture. "Conservation agriculture" is the term used for a diverse array of crop management practices that involve minimal disturbance of the soil, retention of residue mulch on the soil surface, and use of crop rotations 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 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. 2002; Malik et al. 2005a).

3 This section draws from Morris 2003.

To date, the RCT that has received most attention in Pakistan is zero-tillage (ZT) planting of wheat after rice (Iqbal et al. 2002; Khan et al. 2002; Sheikh et al. 2003). Successful adoption of ZT requires the use of a specialized tractor-drawn implement called ZT seed drill, which allows wheat seed to be planted directly into the unplowed fields with a single pass of the tractor. In contrast, conventional tillage practices for wheat involve multiple passes of the tractor to accomplish plowing, harrowing, planking, and seeding operations. The obvious advantage of ZT drill is the reduction in the energy costs, mainly by reducing the tractor costs associated with conventional tillage methods, but also as water savings reduce the time that tubewells must be operated . The use of ZT drill also allows the wheat crop to be planted sooner than would be possible using conventional tillage methods, hence significantly reducing the turnaround time. This is an important consideration in many parts of the rice-wheat belt, where late planting of wheat is a major cause of reduced yields: terminal heat implies that wheat yield potential drops by 1-1.5% per day if planting occurs after 20 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. With ZT, surface irrigation water spreads more quickly across the surface, whereby irrigation can be stopped once the field is covered. ZT potentially improves 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' self-adopted fields, although now some recent studies have become available (Ahmad et al. 2007; Chandra et al. 2007; Jehangir et al. 2007; Malik et al. 2005b)

A pre-requisite 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 NW 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 also 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 also not known exactly. Field observations and knowledgeable experts estimate that the area under ZT is significant and rapidly increasing, particularly in India (Laxmi et al. 2007). There was thus a need to verify the extent of adoption and its impact through structured empirical surveys. Without such data, the technical and economic benefits actually realized by farmers also remain unknown, since scaling up from plot-level experimental data to arrive at aggregate estimates of impact is problematic. We would also fail to pick up eventual adaptations of 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 the adoption and diffusion. Research has indicated the potential technological benefits, but experience suggests 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 include:

1. Document the diffusion of zero-tillage in the rice-wheat systems of irrigated Punjab, Pakistan.

2. Identify technical, economic, institutional, and policy factors that affect ZT adoption and diffusion in the study area.

3. Evaluate impacts of ZT adoption on productivity and profitability of rice-wheat systems in the study area, including impacts stemming from water-use savings.

4. Identify research and extension needs, policy interventions, and institutional changes needed to accelerate adoption and diffusion of ZT.

The present study is complemented by a similar study that was conducted in Haryana, India (Erenstein et al. 2007b). 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 the report.

2 Study area and research methodology

2.1 Study area

The study focuses on the irrigated rice-wheat zone in Pakistan Punjab, located in the North East of Pakistan close to the Indian border and falling within the Indus plains (Figure 1). The average annual precipitation ranges from 400 mm per year^{-1} (Sheikhupura district) to 800 mm per year^{-1} (Sialkot district) (Byerlee et al. 1984). 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/semi-humid monsoon season during June to October (*kharif* season) (Timsina and Connor 2001). With an annual potential evapotranspiration of at least 1,400 mm (Jehangir et al. 2007), the rice and wheat are dependent on irrigation, which includes the conjunctive use of surface and groundwater. The study area is served by a developed canal irrigation system, although groundwater now provides the major share of total water supply at the farm gate (Jehangir et al. 2007) making up for the inadequate volume, frequency and timing of canal water (Ahmad et al. 2007). The soils in the study areas are predominantly alluvial, calcareous, very low in organic carbon and weakly structured, with light to medium texture (sandy loam to clay loam) (Jehangir et al. 2007).

The rice-wheat system in the study area is highly mechanized, input-intensive, commercial and has relatively large farm holdings, particularly when compared to the Eastern IGP (Erenstein et al. 2007c; 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 time to mature. Wheat has traditionally been, and continues to be the mainstay of food security in the North West IGP, and the introduction and widespread cultivation of rice only occurred in recent decades (Erenstein et al. 2007e). The introduction of rice thereby put increasing pressure on the ability of farmers to plant wheat in a timely manner without incurring yield losses. The delay in planting of the wheat crop is mainly due to the late harvest of the previous crop and/or a long turnaround time. The late harvest of the previous rice crop can be linked to both the late rice establishment and the duration of the rice crop, particularly basmati. The long turnaround time often reflects intensive tillage operations, soil moisture problems (too wet or too dry), unavailability of traction power for plowing, and the urgency to store the rice crop before preparing land for wheat cultivation. Farmers perceive the need for intensive tillage due to the difference in soil management practices for rice and wheat—the former being grown under anaerobic conditions and the latter under aerobic conditions (Laxmi et al. 2007).

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. Punjab province was purposively chosen for this study as the Pakistani province where ZT promotion was initiated and adoption has been

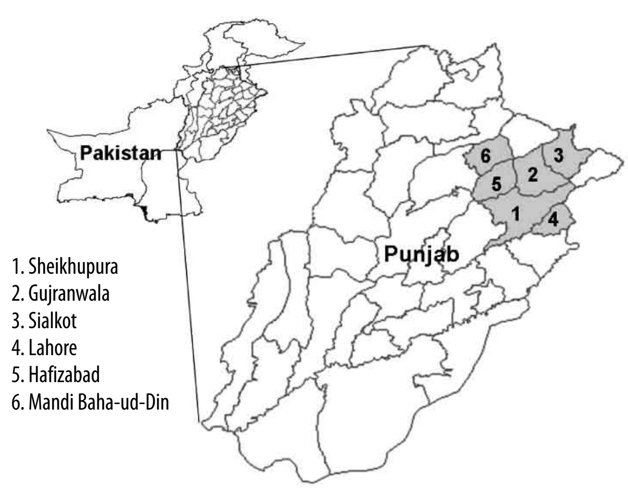

Figure 1. Survey locations within Punjab province, Pakistan.

most significant (Khan et al. 2002). Punjab also comprises nearly three-fifths of Pakistan's 2.1 million hectares of rice-wheat system. The study draws from three primary data sources: a survey of ZT drill manufacturers, a formal adoption survey of rice-wheat farmers and a village survey.

Survey of zero-tillage drill manufacturers

The present study focuses on ZT through the use of the tractor-drawn ZT seed drill, i.e. ZT as a crop management technology that is embodied in unique agricultural machinery. As a result, it is possible to assess the advent of the technology through supply side analysis. For this purpose a survey of local agricultural machinery manufacturers and sellers in Pakistani Punjab was implemented (Anwar et al. 2004).

A list of 31 manufacturers was obtained from the On Farm Water Management (OFWM) department of the Punjab Ministry of Agriculture, Lahore. In December 2003, a two-person team visited and interviewed personally all of the firms on the list using a two- page structured questionnaire. The questionnaire (see Annex 3) covered manufacturer contact details and ZT sales history from 1995 through 2003. The list of manufacturers proved not to be exhaustive. A further 12 manufacturers were subsequently identified in Punjab and 2 in Sindh. For these additional manufacturers only selected indicators were compiled, including contact details, start of ZT manufacturing and range of implements manufactured.

Adoption survey of rice-wheat farmers in Punjab

The main primary data source for this study was a formal survey of the rice-wheat growers from the rice-wheat zone of the Punjab province of Pakistan (Figure 1). The rice-wheat cropping sequence is primarily practiced in the Kalar tract, covering the districts of Gujranwala, Sheikhupura and Sialkot, and to a lesser extent in surrounding districts. The adoption survey used a stratified sampling frame. Within the province, the 4 districts where rice-wheat systems predominate and RCTs have been widely promoted were purposively chosen (Gunjranwala, Sheikiphura, Sialkot and Lahore). Two additional districts were randomly chosen as control from the districts where rice-wheat systems are prominent but RCTs have not been widely promoted (Hafiz Abad and Mandi Baha-ud-din). In the six districts taken together, the rice crop was planted on 854.2 thousand hectares during 2001-02 with an approximate ratio of 80:20 between the first four RCT promoted districts and the two control districts. The same proportion was maintained for the relative sample size.

Within the four RCT promoted districts villages were enlisted where ZT had been promoted. The list is largely based on the villages where the On Farm Water Management (OFWM) department of the Punjab Ministry of Agriculture in Lahore has been promoting the ZT technology. Against each ZT promoted village, one ZT non-promoted village was randomly chosen within a radius of 5-10 kilometers. The list was complemented with some of the villages where the International Water Management Institute (IWMI, Lahore) has been testing zero-tillage. Within the two control districts 5-6 villages each were randomly chosen. In total, 51 villages were selected comprising 24 ZT promoted and 27 non-promoted villages (Table 1). From each selected village typically some 8-10 farmers were interviewed for a total of 458 farmers. The ratio of sample farmers from ZT promoted and non-promoted villages was 47:53 (Table 1). More than half (57%) of the sample farmers belonged to Sheikhupura and Gujranwala districts,

Table 1. Sample distribution by zero-tillage promotion category for village.

District	Tehsil (sub-district)	Sample villages by promotion category (#)			Sample farmers by promotion category (#)		
		Promoted	Non-promoted	Overall	Promoted	Non-promoted	Overall
Gujranwala	Gujranwala	4	3	7	34	27	61
	Nowsshera	4	2	6	36	17	53
Hafizabad*	Hafizabad	0	5	5	0	41	41
Lahore	Lahore	1	1	2	8	9	17
Mandi Bahudin*	Mandi Bahudin	0	3	3	0	18	18
	Phalia	0	3	3	0	26	26
Sheikhupura	Ferozewala	3	3	6	26	31	57
	Nankana Sahib	3	2	5	21	30	51
	Safdar Abad	1	0	1	15	0	15
	Sheikhupura	2	0	2	25	0	25
Sialkot	Daska	6	5	11	51	43	94
Total districts=6	Total tehsils=11	24	27	51	216	242	458

* Districts where ZT promotion has been less intensive

reflecting both the importance of the rice-wheat system and the extent of ZT promotional activities (Table 1). The names of the surveyed villages and sample breakdown are given in Annex 1.

Each selected household was visited twice during 2003-04 by a multidisciplinary team of social scientists comprising statisticians, rural sociologists, anthropologists and agricultural economists from Social Sciences Institute, NARC, Islamabad. Use was made of a structured questionnaire (see Annex 4) to collect detailed information covering various indicators at the farm-level and plot-level. 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 522 wheat plots from 458 farm households. Similarly, depending on the preceding wheat crop, 528 rice plots were surveyed respectively. To put the rabi 2003-04 season into perspective, the study also traced the adoption history of each farmer.

Village survey

A village survey was conducted in March 2005 in 50 villages, basically a revisit of the same villages covered during the adoption survey. The village revisit in the subsequent year to the adoption survey allowed us to ascertain amongst others the extent of ZT area in rabi 2004-05. The survey also compiled village-level information like the size of the village in terms of population and agricultural land holding and the availability of farm machinery at village level (Annex 5). Where applicable, ZT drill owners were contacted specifically to record the wheat area planted with the ZT drill, thereby distinguishing between their own farm and others' farms.

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 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 for wheat in the past, but not in rabi 2003-04 were classified as disadopters. Amongst the 458 households surveyed, 89 were classified as adopters, 305 as non-adopters and 64 as disadopters (Table 2).

We hypothesize that there are a number of differences between the three types of adopters, and 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 amongst 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 522 wheat plots from 457 farm households.[4] We can thus distinguish between 4 categories of wheat plots: ZT wheat plots of adopters (87 plots) and 3 types of conventional

Table 2. Sample distribution across administrative boundaries and adoption category.

District	Tehsil (sub-district)	Villages	Sample farmers by adoption category (#)			Sample size
			Adopters	Non-adopters	Disadopters	
Gujranwala	Gujranwala	7	17	38	6	61
	Nowsshera	6	9	30	14	53
Hafizabad *	Hafizabad	5	8	28	5	41
Lahore	Lahore	2	0	14	3	17
Mandi Bahudin *	Mandi Bahudin	3	2	15	1	18
	Phalia	3	2	24	0	26
Sheikhupura	Ferozewala	6	15	30	12	57
	Nankana Sahib	5	13	29	9	51
	Safdar Abad	1	5	9	1	15
	Sheikhupura	2	7	14	4	25
Sialkot	Daska	11	11	74	9	94
Total districts=6	Total tehsils=11	51	89	305	64	458

* Districts where ZT promotion has been less intensive

4 The wheat plot level data for one household are missing (non-adopter, conventionally sown wheat plot).

wheat plots, distinguishing between adopters (67), non-adopters (304) and disadopters (64) (Table 3). We hypothesize that there are differences between the three types of conventional plots. First, 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 basis.' Second, as adopters and disadopters may have changed their 'conventional' crop management practices after 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 amongst plot types where relevant.

To assess eventual carry-over 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. In the event the farmer had both types of plots, data was compiled for each plot, giving a total of 528 rice plots from 456 farm households.[5] The rice plot data refer to the kharif 2003 season, and hence are influenced by the adoption 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 4). We can thus potentially distinguish 5 categories of plots. However, all plots with data for rice sown after no till wheat were 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, 102 plots), and 3 types of rice plots sown after conventional wheat, distinguishing between adopters (71), non-adopters (303) and disadopters (52) (Table 4). 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 chapter 6) we aggregate the implications of ZT on system productivity—i.e. the combined effect on the wheat and subsequent rice crop. In aggregating we can distinguish two scenarios. The first scenario aggregates *after* averaging by plot type, i.e. it simply adds the previously reported averages for wheat and rice by plot type. The second scenario aggregates *before* averaging, i.e. aggregation is done for each individual plot and subsequently averaged by plot type. The advantage of the first scenario is that it corresponds with the previous section and maintains the maximum number of observations (522 wheat plots and 528 rice plots). The advantage of the second scenario is that it more adequately captures carry-over effects and allows us to test for statistical significance of differences. The second scenario however, loses a number of observations due to incomplete matching.[6] Of the 522 wheat plots,

Table 3. Sample breakdown for wheat plot level data by adoption category (rabi 2003-04).

	Adopters	Non-adopters	Disadopters	Overall
No. of plots with no till wheat data	87	-	-	87
No. of plots with conventional wheat data	67	304	64	435
Total No. of plots with wheat data	154	304	64	522

Table 4. Sample breakdown for rice plot level data by adoption category (kharif 2003).

Nature of the plot	Adopters	Non-adopters	Disadopters	Overall
No. of plots with data for rice sown after no till wheat	60	-	42	102
No. of plots with data for rice sown after conventional wheat	71	303	52	426
Total no. of plots with rice data	131	303	94	528

[5] The rice plot-level data for two households were dropped due to data inconsistencies (non-adopter, rice after conventionally sown wheat plot).

[6] For 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.

only 474 are retained in the second scenario, and 48 plots are dropped for lacking corresponding rice plot data. This particularly reduces the number of ZT plots (by 28 plots out of the original 87 plots). Despite these differences, the two scenarios present a largely similar picture. The second scenario 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 relevant statistical tests (e.g. ANOVA with post-hoc test; t-test). The factors affecting the farm-level decision to adopt ZT were analyzed using the logit regression model, a standard limited-dependent variable approach (CIMMYT 1993). The dependent variable is dichotomous, and takes the value of one when ZT is used and zero if it is not. The independent variables included in the adoption models 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 Haryana-India study (Erenstein et al. 2007b).

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

The water inflow indicators draw from farmer recall plot-level data for number and duration of irrigations by source (canal and tubewell). These were converted into water volumes using average irrigation volumetric rates and seasonal rainfall, as reported by Jehangir et al. (2007) within the same area (102 m^3/hour for tubewell [i.e. 1 cusec] and 117 m^3/hour for canal; seasonal rainfall of 103 mm in rabi [average 2001-03] and 239 mm in kharif 2003).

The financial analysis is done per individual surveyed household using the reported physical input/output levels and local farm prices from the time of the survey. Prices are reported financial market prices, including eventual taxes and subsidies. These market rates are assumed to be a reliable reflection of opportunity costs, irrespective of ownership (e.g. in case of land and tractors) and facilitate comparison. Missing values have been substituted with the corresponding average for the locality. Local currency was converted to US dollars at the average conversion rate at the time (average for July 2003 to June 2004: USD 1 = Pakistan Rupee 57.59,(State Bank of Pakistan 2005).

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

(1) Land preparation (all tillage plus eventual post-sowing pass to cover seed);

(2) Crop establishment (cost of seeding operation only, includes seed, labor and machinery);

(3) Fertilizer cost (includes chemical fertilizer and farm yard manure);

(4) Plant protection cost (includes herbicides, manual weeding, and pesticides/fungicides);

(5) Irrigation cost (flat area-based rate for canal and variable time-based cost for tubewell);

(6) Harvesting expenditures (includes labor and machinery for harvesting and threshing);

(7) Land rent (prevailing seasonal rent); and

(8) Interest on capital invested (9% of all costs).

As performance indicators are included:

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

3 Diffusion of zero-tillage

In Pakistan, promotion and adoption of zero-tillage (ZT) started in Punjab province (Aslam et al. 1993; Iqbal et al. 2002; Khan et al. 2002; Sheikh et al. 1993). 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 (Amir and Aslam 1992; Byerlee et al. 1984; Sharif et al. 1992). ZT was thereby perceived to be a viable option to alleviate the problem of late planting of wheat after rice, the combined result of growing late maturing rice varieties and long turnaround time.

Favorable experimental findings led to a ZT pilot production program in the 1990s to expand the use of this technology in the rice-wheat zone of Punjab (Aslam et al. 1993). ZT was subsequently picked up by farmers with an estimated 0.2 million hectares planted with ZT drills during 2001-02 (Mann and Meisner 2003) and an estimated 0.3 million hectares in 2003-04 (RWC 2004). The present chapter analyzes the extent of diffusion, drawing from both supply and demand side indicators drawn from the surveys of manufacturers, villages, and farmers.

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

3.1 Supply of zero-tillage drills[7]

Promotion and adoption of ZT in Punjab emphasized the use of a tractor-drawn ZT seed drill. This drill typically opens a number (6-11) of narrow slits with inverted-T tines for placement of seed (and sometimes fertilizer) at a depth of 7.5-10 cm into the soil. This specialized agricultural machinery was originally not available in Pakistan. Adaptive research designed to make zero-tillage methods suitable for local conditions started during the mid 1980s, following the importation of a prototype drill by Aitcheson Industries from New Zealand. Thanks to concerted long-term efforts by researchers from the Pakistan Agricultural Research Council (PARC), researchers from the International Maize and Wheat Improvement Center (CIMMYT), and local machinery manufacturers, an effective zero-tillage seed drill was successfully developed for local manufacture. The Farm Machinery Institute (FMI) of PARC adapted the design to make the zero-tillage drill more suitable for local conditions and modified the manufacturing specifications so it could be produced locally at an affordable cost. They then formed a joint venture with local machinery manufacturers in Daska tehsil (Sialkot district),which is the traditional center where farm machinery is made for cultivators and threshers in Punjab. They also jointly worked out methods for manufacturing the drills using relatively inexpensive and locally available materials. The adapted design and local manufacturing processes eventually spread to other manufacturers throughout Pakistan (Anwar et al. 2004).

By 2004, 45 ZTD manufacturers were known to operate in Pakistan, with all but two located in Punjab province. Within Punjab, the manufacturing capacity is again spatially concentrated, with 11 manufacturers located in Daska tehsil of Sialkot district. Other districts with more than two manufacturers include Okara (6), Hafizabad (5), Faisalabad (4), Khanewal (4) and Sheikhupura (3). The first year in which ZTDs were sold by each manufacturer allows us to plot the manufacturing capacity of ZTDs in Punjab over time (Figure 2 - line). The number of ZTD manufacturers increased slowly in the 1990s with a total of 5 manufacturers in 1998. In the subsequent years there

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

has been a steady growth in the ZTD manufacturing capacity, but growth in the number of manufacturers started to stagnate in 2003.

Figure 2 (columns) depicts the aggregate sales history of the 31 surveyed manufacturers in Punjab. This provides further evidence of the significant growth and recent stagnation of annual ZT drill sales. From a combined total of 50 ZTDs sold in 1998, annual sales increased to a total of 532 ZTDs in 2002, but fell to 386 ZTDs in 2003, with 104 ZTDs manufactured in 2003 left unsold. The manufacturers attributed the stagnation in demand to the districts of Hafizabad, Sialkot, Gujranwala, and Lahore and to farmers' perception that wheat yields in zero-tillage plots are lower than yields in conventionally tilled plots.

By the end of 2003 a cumulative total of 1,957 ZTD machines had been sold, out of 2,088 manufactured by the 31 surveyed manufacturers. Nearly 90% of these drills were sold to farmers in the Punjab, with the remaining 10% sold to farmers from other provinces. Eighty-nine percent of the cumulative total number of drills were manufactured in Daska tehsil, accentuating the spatial concentration of ZT manufacturing. Surveyed manufacturers in the other tehsils were reluctant to increase ZT production for various reasons, including having limited production capacity, manufacturing zero-tillage drills only to order, specializing in the production of other farm implements, being primarily ZT traders reselling drills from Daska under their own labels or being in locations with limited demand, such as the cotton-wheat belt.

The manufacturers reported an average sales price of PKR. 32,200 per ZTD in 2003 (USD 559), ranging from PKR 22-40,000. Average retail selling prices have remained relatively constant through time.

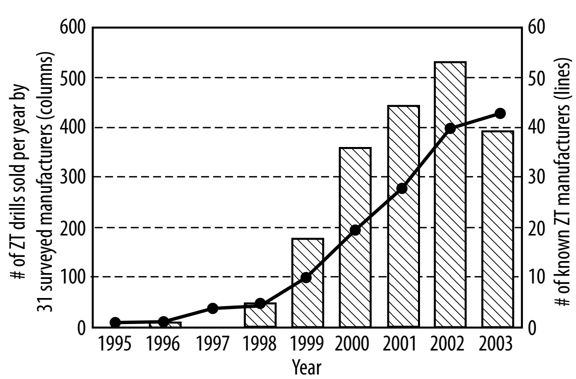

Figure 2. Number of ZT drills sold per year by surveyed manufacturers [columns] and number of ZT drill manufacturers (lines) in Punjab, 1994-2003.

Manufacturers indicated the difference between more expensive and less expensive drills can be attributed mainly to differences in materials and design.

Manufacturers also provide ZT support services, such as providing technical assistance (80%), offering free repair services during the first year (52%), and distributing documentation describing proper operation of the drill as well as maintenance procedures (44%). Most of the ZT manufactures surveyed were not specialized solely in ZTDs, but typically produce a range of agricultural implements. Their diversified product portfolio also implies they can suspend and resume ZT manufacturing based on market demand. Some manufacturers also modify rabi drills into ZTDs.

Manufacturers were divided about the need to enhance the ZTDs currently being produced. Forty-five percent said further design modifications are unnecessary because the drills perform well in farmers' fields and they have received very few complaints from farmers regarding the current design. Fifty-five percent expressed their intentions to make further adjustments to existing designs in order to improve the quality and performance of their drills. Planned improvements included modifications to the straw chopper, the number and/or design of tines and the metering system (Anwar et al. 2004).

3.2 Zero-tillage adoption rates

Our random stratified sample of 458 rice-wheat farmers revealed 19% to be ZT adopters in 2003-04 (Table 5). ZT adopters are defined here as farmers who have used the ZT drill for wheat in untilled fields during rabi 2003-04. The corresponding aggregate ZT wheat area in the sample was 18% of the aggregate wheat area in rabi 2003-04. The present study thus confirms empirically significant levels of adoption of ZT wheat in Punjab's rice-wheat systems, underscoring the appeal of the technology among farmers. Overall, one-third of the sample farmers reported having ever used the ZT drill at their farm.

Table 5. Breakdown of sample by zero-tillage adoption category (rabi 2003-04).

ZT Adoption category	Share sample (n=458)
Adopter	19.4% (89)
Non-adopter	66.6% (305)
Disadopter	14.0% (64)
Total	100%

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

Our random stratified sample of rice-wheat farmers also revealed 14% to be ZT disadopters in 2003-04 (Table 5). Disadopters are defined here as farmers who have used ZT in preceding seasons, but they did not do so in the rabi 2003-04 season for whatever reason. In case 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. Still, 14% disadoption is relatively high and an issue that merits further scrutiny.

The present study and adoption figures refer to the use of the ZTD in untilled fields only. However, the ZTD may also be used in reduced tilled or conventionally tilled fields, but such partial adoption is not included here as ZT.

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

The survey averages mask significant differences in adoption rates amongst the districts surveyed (Table 6).[8] The penetration of ZT was highest in Sheikhupura, followed by Gujranwala and Hafizabad districts. In these districts 32-45% of surveyed farmers have tested the ZT drill, and 20-27% are current adopters. These three districts are contiguous and are located in the rice-wheat heartland (Figure 1). The soils in these districts are relatively heavy. suggesting the need for the ZT drill is relatively more felt in these areas. In the remaining three districts, ZT penetration was modest with 11-21% of surveyed farmers having tested the ZT drill. In Sialkot and Mandi Baha-ud-din this has translated into 9-12% adopters. The concentration of ZTD manufacturing capacity in Daska in Sialkot therefore does not seem to have contributed to higher ZT adoption levels. Lahore is the odd district, with 0% adoption and 18% disadoption for a relatively small sample from two villages. One of the Lahore villages had been subject to ZT promotional activities possibly contributing to the observed ZT penetration. However, the village survey revealed that there are no ZTDs in either of the surveyed Lahore villages, possibly reflecting their previous reliance on promotional ZTDs from OFWM that were subsequently shifted elsewhere.

Clarifying the underlying factors is an issue that merits follow up, and this may show the role of proximity to a major urban centre which may dilute incentives to invest in agricultural machinery. With the exception of Lahore, Table 6 reveals two further issues across districts. First, an increased penetration of ZT is not only associated with increased adoption levels, but also with increased disadoption levels. Second, ZT adopters typically outnumber disadopters. However, the

Table 6. Distribution of zero-tillage adoption category (% farmers, row wise) across sample districts.

Districts	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall (n=458)	Significance
Sheikhupura	27.0	55.4	17.6	100 (n=148)	0.00
Gujranwala	22.8	59.6	17.5	100 (n=114)	
Hafizabad*	19.5	68.3	12.2	100 (n=41)	
Sialkot	11.7	78.7	9.6	100 (n=94)	
Lahore	0.0	82.4	17.6	100 (n=17)	
Mandi Baha-ud-din*	9.1	88.6	2.3	100 (n=44)	
Total	19.4	66.6	14.0	100	

* Districts where ZT promotion has been less intensive

8 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.

assumed intensity of ZT promotion at the district level does not show a clear linkage to increased adoption rates, an issue likely associated with the technology primarily spreading from farmer to farmer and the ongoing institutional ZT controversy in Punjab.

There is also significant variation of ZT adoption and disadoption by village. In part this can be attributed to the recent nature of its diffusion and that it is embodied in lumpy technology. Indeed, village wise adoption rates amongst our sample farmers vary from 100% to 0%, and disadoption rates from 44% to 0%. Table 7 therefore provides some village level adoption indicators. The first indicator classifies the village according to the predominant adoption category. This illustrates that in 6 villages (12%) adopters already predominate, in 2 villages (4%) disadopters predominate, whereas in the remaining 42 villages non-adoption is still prevalent. The second indicator classifies the villages by each adoption category. This illustrates that only in 17 villages (34%) there was no ZT adoption in the survey year, including 6 villages (12%) where there had been no penetration of ZT yet and 11 villages where limited ZT use (9-33% of sampled farmers per village) had been abandoned. There are 2 villages (4%, both in Sheikhupura district) where all sampled farmers had ever used ZT, including 1 village where all sampled farmers used ZT in the survey year whereas in the other 90% continued to do so. We can further categorize the 44 villages where ZT had penetrated into 11 villages with no disadoption amongst sampled farms, 12 villages with some disadoption and 21 villages where disadoption outnumbers adoption.

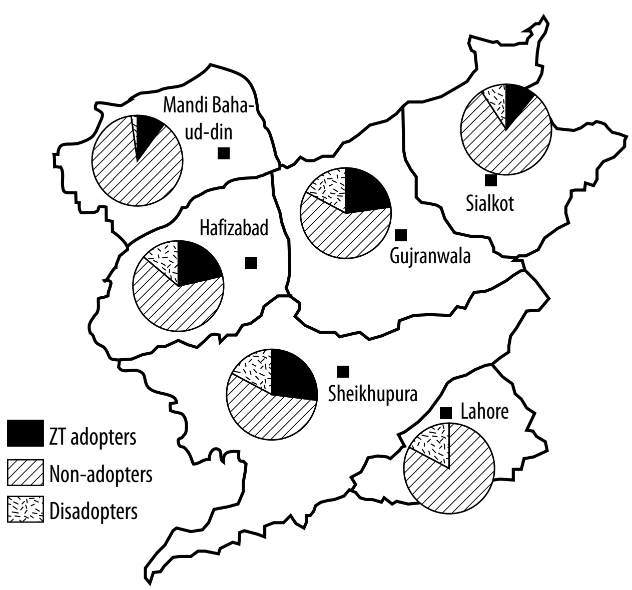

Figure 3. ZT adoption rates by survey locations within Punjab Province, Pakistan.

Some important conclusions can be drawn from the village-level data. First, it illustrates that ZT penetration to individual villages was widespread but not comprehensive at the time of the survey. Second the considerable gradient in village wise adoption rates from none to saturation suggests that intrinsically there is nothing wrong with the technology itself, but access and application of the technology may be an issue. Indeed the fact some villages are saturated and others show no disadoption suggests ZT has considerable merit and wide applicability once the technology has proven itself within a community. Third, disadoption seems to be concentrated in about half the villages where ZT had penetrated.

3.3 Zero-tillage adoption history

The surveyed farmers were questioned when they first used ZT and their use of ZT since. The plotted responses (Figure 4) distinguish between ZT adoption (i.e. those that actually used ZT in the corresponding year, dash) and ZT penetration (i.e. those that have ever used ZT by that year, adopters and disadopters combined, line). The lines show the typically slow initial diffusion during the 1990s followed by the rapid acceleration of ZT adoption from 2000 onwards.[9] The ZT penetration line thus far follows the typical sigmoid curve, and suggests to be leveling off. The ZT adoption line seems to have peaked in 2002-03 at 24.4% adoption. The 19.4% adoption rate in the survey year 2003-04 is thus 5.0%

Table 7. Distribution of villages by zero-tillage adoption category (# of villages).

	Adopters	Non-adopters	Disadopters
# of villages where adoption category dominates (n=50)[1]	6	42	2
# of villages by adoption category:			
with 100% of adoption category	1	6	0
intermediate	32	42	33
with 0%	17	2	17
Total	**50**	**50**	**50**

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

[9] 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

down on the year earlier. The difference between the two lines reflects disadoption, showing a significant increase in disadoption rates during the survey year (11.1%). There was still a significant increase in new adopters in the survey year (6.1%), but these were outnumbered by disadopters. It remains an open question if the recent adoption and disadoption rates reflect a structural trend or a temporary adjustment. For instance, a separate study in Pakistan-Punjab reports a considerable increase in the adoption of ZT between 2000 and 2003, but does not show signs of peaking (Ahmad et al. 2007). The subsequent years will thus inform us whether ZT adoption levels for wheat may end up significantly lower or higher than the observed one-fifth of the surveyed rice-wheat farmers at the time of the survey.

The 14% disadoption is higher than originally expected. Disadoption is occurring across the various start years, although it was found to be particularly high amongst those farmers that started with ZT in 2002-03. It also raises the question whether the disadoption is temporary or prolonged. Temporary disadoption of ZT may occur when the farmer reverts back to conventional tillage in a given year for whatever reason and resumes ZT in a subsequent season. For instance, untimely availability of the ZT drill 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 lead combiners to cause ruts in the fields that need to be evened out through tillage. Alternatively, untimely rain can cause a flush of weeds that a farmer prefers to control through reduced tillage. However, in

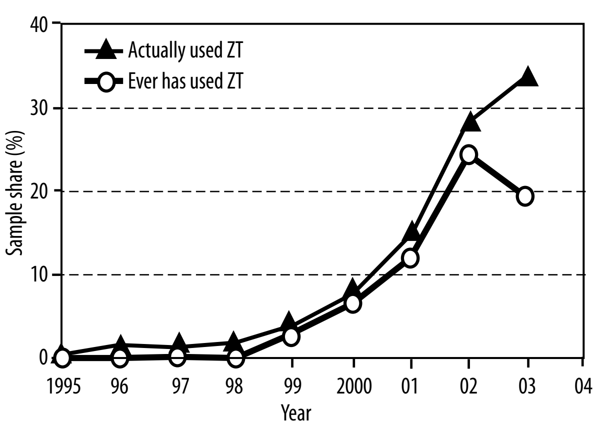

Figure 4. Diffusion of ZT based on first year of use.

the survey year 2003-04 rainfall during the critical months of October and November suggest about normal aggregate rainfall, albeit somewhat late.[10] Prolonged disadoption may result from a farmer structurally losing access to a functional ZTD or being disillusioned with ZT for whatever reason. For instance, disadopters in particular reported the lack of yield enhancement with ZT as an issue (see subsequent chapters). In the extreme case there may be permanent disadoption where a farmer abandons it for good, but otherwise disadopters could still revert to ZT under changed circumstances. The subsequent chapter will look further into the factors and constraints affecting the adoption and disadoption of ZT. Our findings suggest there is no clear single overarching constraint, but a combination of factors is at play, including technology performance, technology access, seasonal constraints and the institutional ZT controversy. 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 scrutiny.

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 the survey and the preceding year.
- *Undefined disadopters:* Farmers who stopped using ZT in the survey year but used ZT in the 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=151), reveals that 54% used ZT continuously (continuous adopters, 82 cases), 3% used ZT intermittently (intermittent adopters, 5 cases) and 9% dropped ZT for at least the last two consecutive seasons (prolonged disadopters, 14 cases). The remaining 33% (50 cases) stopped using ZT in the survey year and we cannot say whether ZT disadoption is temporary or prolonged (undefined disadopters). However, based on the

[10] October-November rainfall in nearby Lahore was 16 mm in 2003 (0 mm Oct. and 16 mm Nov.) as against a 30 year average of 16.6 mm (12.4 mm Oct and 4.2 mm Nov., Lahore meteorological station, unpublished data).

observed prolonged disadoption and intermittent adoption levels we may assume the undefined disadopters to be similarly split. This implies that the observed 14% disadopters for the sample as a whole (64 cases) would likely comprise 11% prolonged disadopters (14 known + 37 assumed cases) and 3% temporary disadopters (13 assumed cases).

Table 8 lists 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 nature of ZT adoption. Intermittent disadopters by definition have used ZT for more than one year, typically two. Prolonged and undefined disadopters have typically used ZT for a single year, suggesting an unsuccessful experience and/or limited perseverance.

3.4 Zero-tillage adoption intensity

Surveyed ZT adopters apply ZT to approximately three-quarters of their total wheat area. 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 for 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. A separate study in the area indeed revealed half the ZT users were not allocating the whole of their wheat area to ZT because they were still experimenting with the technology (Tahir and Younas 2004). Other reasons for partial area adoption in that study included the availability of enough time for conventional tillage (11% of cases), land not suitable for ZT (10%), unavailability of ZTD at sowing time (8%), lack of proper knowledge (6%) and a range of perceived negative carry-over effects in relation to ZT use (e.g. in terms of yield, soil compaction, and tillage for subsequent rice).

There is no significant trend in the aggregate ZT area share over time in our survey. This may reflect the combined effect of the arrival of new adopters and lower area shares for disadopters. The ZT area share for disadopters was indeed found to be significantly lower in 2002-03 (Table 9). This is in line with expectations, the more so as prolonged disadopters tend to drop ZT after only one year of trying. To control for new arrivals and disadopters, Figure 5 plots the ZT share of total wheat area per ZT farm over time for different subsets of ZT adopters. The area shares fluctuate over time, but no significant trend was observed for any group. A word of caution remains as the sample size for subsets is small and the data were collected retrospectively. Still, partial adoption of ZT on three-quarters of the wheat area of the adopting farm seems to be the prevalent practice.

Table 8. Categorization of zero-tillage users based on adoption history (% of farmers, adopters and disadopters only, n=151).

# of years with ZT plot data	Adoption history over time: Prolonged dis-adopters	Undefined dis-adopters	Inter-mittent adopters	Continuous adopters	Overall
1	7.9%	23.8%	0.7%	13.9%	46.4%
2	1.3%	6.6%	2.0%	17.9%	27.8%
3		1.3%	0.7%	12.6%	14.6%
4		1.3%		6.6%	7.9%
5				3.3%	3.3%
Total	**9.3%**	**33.1%**	**3.3%**	**54.3%**	**100.0%**

Table 9. Evolution of wheat area share with zero-tillage drill by adoption category.

Years	Current adopters	Current disadopters	Overall	Significance
2003-04	74% (80)	-	74% (s.d.=35, n=80)	-
2002-03	76% (56)	59% (45)	69% (s.d.=32, n=101)	.01
2001-02	64% (26)	67% (16)	65% (s.d.=33, n=42)	NS
2000-01	76% (12)	74% (7)	76% (s.d.=26, n=19)	NS
1999-00	72% (4)	78% (2)	74% (s.d.=31, n=6)	NS

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.

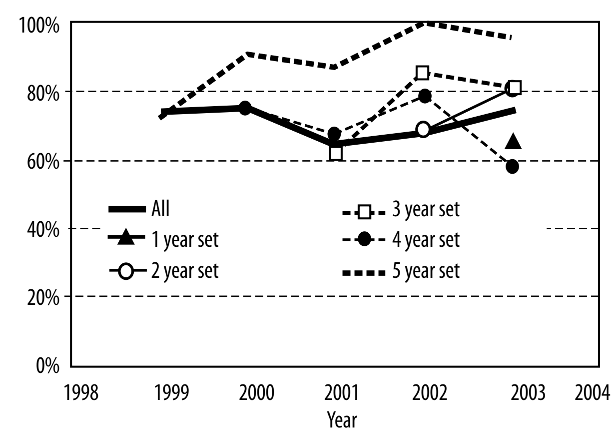

Figure 5. ZT share of total wheat area per ZT farm over time for different subsets of ZT adopters.
(non-zero values only, subsets refer to farmers grouped by the number of consecutive years of using ZT prior to 2004. For 1, 2, 3, 4 and 5-year set, n=25, 32, 12, 7 and 4 farms respectively)

The adoption intensity could reflect differential access to a ZT drill. In this respect, one might expect ZT drill owners to have higher adoption intensities than those reliant on ZT service providers. Earlier research for the 2000-01 season in Punjab province has indeed reported ZT drill owners plant 75% of their wheat area against only 47% for those relying on service providers (Iqbal et al. 2002:669). A similar tendency is found here in the preceding years, although only statistically significant in the 2002-03 season. However, in the survey year, there is no discernable difference in ZT area share between these two categories of ZT drill access. This suggests ZT access categories did not constrain the extent of ZT adoption in the survey year, provided they had access to a ZT drill in the first place. This possibly reflects an easing of ZTD demand with respect to supply. The adoption intensity could also vary between tractor owners and those reliant on tractor service providers. But there was no significant difference in terms of ZT area share between tractor owners and those reliant on tractor service providers in the five years for which (retrospective) data is available (Table 10).

The adoption intensity discussion 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 also presents two aggregate ZT wheat adoption indicators. For the first aggregate indicator, we have summed ZT wheat and overall wheat area (ZT plus conventional) across all 458 surveyed farm households. The aggregate ZT wheat area share of aggregate wheat area is an indicator of the area wise adoption intensity. The figure shows a rapid increase from 2000 to 2002, from 6% to 21% of the aggregate wheat area in 2002. However, in 2003 the aggregate ZT wheat area share decreased with 2.8% to 18%. The decrease is significantly lower than the 5% decrease in farm-level adoption, primarily reflecting the relatively lower ZT wheat area shares of disadopters.

As a second aggregate indicator, key informants were requested to estimate the aggregate ZT wheat area at the village level for the last couple of years. The aggregate ZT wheat village area reportedly increased from 350 hectares for the 50 villages (i.e. on average 7.0 hectares per village) in 2000 to approximately 2500 hectares (i.e. 49.5 hectares per village) in 2002, but decreased thereafter to 1400 hectares (i.e. 27.6 hectares per village) in 2004 (Figure 6). The two aggregate indicators were derived from two different sources (farm and village survey respectively) albeit from primarily the same set of villages. The fact that they largely reflect a similar pattern therefore provides further credence to each individual source. The village-level survey also allowed for one additional season to be covered. The village-level data thereby once more flag the disadoption issue, as aggregate ZT wheat area continued to decline in 2004 to a level similar to 2001.

Table 10. Evolution of wheat area share with zero-tillage drill (%) by zero-tillage drill 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	77 (23)	74 (57)	74 (s.d.=35, n=80, NS)	73 (50)	77 (30)	74 (s.d.=35, n=80, NS)
2002-03	85 (28)	63 (74)	69 (s.d.=32, n=102, p=0.00)	68 (64)	70 (38)	69 (s.d.=32, n=101, NS)
2001-02	76 (14)	59 (28)	65 (s.d.=33, n=42, p=0.12)	64 (27)	66 (15)	65 (s.d.=33, n=42, NS)
2000-01	81 (9)	70 (10)	76 (s.d.=26, n=19, NS)	77 (16)	67 (3)	76 (s.d.=26, n=19, NS)
1999-00	78 (5)	56 (1)	74 (s.d.=31, n=6, NS)	78 (5)	56 (1)	74 (s.d.=31, n=6, 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.

3.5 Zero-tillage drill ownership and use

Ownership of a zero-tillage drill was reported by 7% of the surveyed households. As expected, drill ownership was significantly higher for adopters (26%), less common for disadopters (14%) and

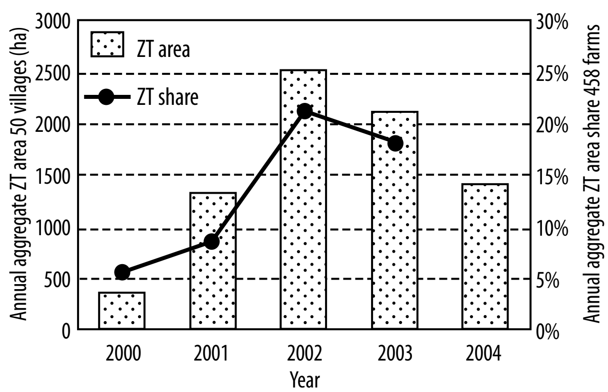

Figure 6. Aggregate ZT wheat area for 50 survey villages and ZT wheat area share of aggregate wheat area for 458 surveyed farms over time.

virtually absent amongst non-adopters (1%,) (Table 11)[11]. On aggregate, there are 0.16 ZTD per tractor. ZTD-owning farmers also contract their service to farmers who do not own a drill. This is in line with the common tillage practices in these areas, whereby many farmers do not own a tractor and thereby rely on tillage contract services to get their fields prepared. Contracted ZT drill services have thereby made the technology divisible and accessible to smallholders without tractors, whereas tractor owners can put off the investment decision. It merits highlighting that the current ownership of ZTDs implies that the majority of ZT adopters (74%) relied on contracted ZT drill services at the time of the survey. These current service contractors are divided into those that have their own tractor (32%) and those that do not (42%). Whereas, the latter group is likely to remain ZT service contractors unless they acquire a tractor, the former may well acquire their own ZT drill if they continue with the technology. A separate study in the area revealed that the reasons for ZT users not purchasing a ZTD included having easy access to drills on rent or free of cost from relatives/friends, drill still in experimental phase and high drill cost (Tahir and Younas 2004). The same study also reported that the majority of ZT users considered ZTD to be easily available within the village, although 40% claimed available drills were insufficient. Another earlier study reported that out of 35 surveyed ZTD owners in 2001, only 40% were providing the drills on rental basis (Khan et al. 2002:63).

The village-level survey reported a total of 55 ZT drills for the 50 villages in 2003-04. The ZTDs are not evenly spread, with 22 villages having no ZTD (including all surveyed villages in Lahore and Mandi Baha-ud-din). Those villages that had a ZTD, typically had one (15 villages), whereas 7 villages had two ZTDs and 6 villages had more (3 to 7 ZTDs). The number of ZTDs and their spread over villages was relatively constant over the last three years, increasing slightly from 52 in 2002-03 to 56 in 2004-05, but doubled relative to 2001-02. On average over the 50 villages, there are 0.8 ZTD per 100 farm households, 0.23 ZTD per 100 hectares and 0.071 ZTD per tractor. These village-level indicators of ZTD accessibility are thereby somewhat less favorable than the aforementioned farm-level indicators from the household survey.

The presence of village-level ZTDs contributes to the differential ZT adoption rates at the village level. Indeed, of the 11 villages that had reportedly abandoned ZT, 7 villages had no ZTD compared to 3 that had (1 village missing). Conversely, of the 11 villages that had no disadoption of ZT, 7 villages had a ZTD compared to 4 that had none. Timely access to a ZTD is critical to its success and a village-level ZTD contributes to this. Some villages had access to promotional ZTDs from OFWM that were located within the vicinity. The recent relocation of these machines to other regions likely has contributed to the observed disadoption of ZT in at least some localities. Still, if ZT is sufficiently appealing one would expect private entrepreneurs and/or tractor owning farmers to invest in a ZTD in such localities.

During the village survey, ZTD owners were contacted to enquire about the extent of ZTD use during the last five seasons. This revealed each operational ZTD was used to establish 36 hectares on average in 2003-04, although actual figures ranged from only 2 to 91 hectares (Table 12 – first rows). Average use rates peaked at 46 hectares in 2001-02, and slipped further to 30 hectares in 2004-05. The maximum use reported for a single ZTD amounted to 176 hectares in the peak year 2002-03. In addition to the operational ZTDs, there were several non-operational ZTDs in the villages (Table 12 – last

Table 11. Zero-tillage drill (ZTD) and tractor ownership by adoption category.

	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Sample mean (std.dev., n=458)	Significance
% household reporting					
Tractor	58%	37%	61%	45%	0.00
Zero-tillage drill	26%	1%	14%	7%	0.00
# per household					
Tractor	0.65b	0.39a	0.66b	0.48(±0.57)	0.00
Zero-tillage drill	0.27c	0.01a	0.14b	0.08(±0.27)	0.00

11 The ownership of a ZTD by a non-adopter likely reflects the use of the ZTD in combination with reduced tillage. Only zero-tillage as such was considered here as adoption. It remains an open question what the disadopters will do with their ZTD. In case of temporary disadoption, they may continue its use in the subsequent season. The survey also 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.

column). These non-operational units probably reflect the combined effect of being in disrepair and / or limited demand. Anecdotal evidence indeed suggests ZTD breakdown and its deterioration over time may occasionally be an issue. Some ZTDs are more liable to the breaking of tines, particularly when tractor operators keep the drill running when turning a field corner instead of the recommended lifting, backing up and reinsertion. Some ZTDs were reportedly liable to operational problems like raking of loose stubbles during drilling or the clogging of pipes. A separate study in the area reported 68% of ZT users to be satisfied with the operation of the ZTD (Tahir and Younas 2004). The same study reports the main reason for farmers not being satisfied with the ZTD operation was the straw choking the seed nuzzles (84% of cases), with lesser reasons including frequent breakage of drill parts (9%), problems with the seed / fertilizer gauge (6%), equipment with discs (5%) and inadequate knowledge of the drill operator (5%).

Reported ZTD use of the operational drills was broken down into drill use on the owners' farm and use on other farms, typically as contract service. For the last three years, the own farm area share of operational ZTDs averages some 50% (Table 12– second set of rows). The area share varies greatly by ZTD owner. Indeed, about a third of the operational ZTDs were reportedly only used on the owners' farm during the last 3 years, a share which was even higher in the preceding years. The sole owner use of ZTDs could reflect a combination of both limited demand and the owners' preference. Indeed, anecdotal evidence suggests that farmers who own tractors and large holdings are often reluctant to contract out their machinery in the area – an issue also reported for the 2000-01 season (Iqbal et al. 2002:677). The fact that the 'own-farm only' ratio remains relatively high over the whole period further supports this. The apparent availability of ZTD at the village level may thus overestimate actual accessibility to the larger village population and thereby constrain ZT use. Anecdotal evidence suggests this may indeed be an issue, particularly in villages that previously enjoyed access to demonstrational ZTDs from OFWM that were recently transferred to new regions. Conversely, a limited number of drills are purely used for service provision.

We have reported the aggregate ZT area at the village level for the last couple of years (Figure 6). To this we can now superimpose the reported ZTD use by own farm and other farm (Figure 7). We thereby assume that all other farms where village ZTDs were used are located in the village and that the difference between reported ZTD use and ZT area in each village was met by non-village ZTDs. Two issues merit highlighting. First, for the last three years, relative shares of drill-use categories remained relatively constant. Typically, 80% of the aggregate ZT area in the surveyed villages was sown with the village-based ZTD, comprising 36% owner area and 44% other farm area. This reiterates that the lion's share of the ZT area (64%) is sown through service providers, comprising at most 44% village-based service providers and at least 20% non-village based service providers. Second, the three drill- use categories show a similar pattern of increase up to 2002-03 and decrease thereafter, thereby diminishing the importance of the ZTD category in explaining adoption and disadoption.

Table 12. Zero-tillage drill use indicators for 50 surveyed villages in Punjab, 2000-2004.

	Year	Mean[b]	Std. Deviation	Minimum (n)[c]	Maximum (n)[c]	N	Unused/ total ZTD
ZTD use	2004	30.4	25.4	1.6	109.3	36	19/55
(ha)[a]	2003	35.7	22.5	2.0	91.1	48	8/56
	2002	43.1	34.1	1.6	176.4	46	8/54
	2001	46.0	30.0	2.4	121.4	25	
	2000	36.1	25.7	0.8	80.9	9	
Own farm	2004	48%	41%	0% (6)	100% (12)	36	
share of	2003	47%	38%	0% (3)	100% (13)	48	
ZTD use[a]	2002	52%	39%	0% (1)	100% (16)	46	
	2001	60%	41%	7%	100% (12)	25	
	2000	83%	34%	16%	100% (7)	9	
ZTD rental	2004	1069 a	144	865	1236	26	
charge	2003	993 b	160	741	1236	29	
(PKR/ha)	2002	976 b	206	741	1236	24	

[a] Operational ZTD's only (i.e. ZTD that were used in the corresponding year).
[b] Rental charges followed by different letters differ significantly – paired T-test (.10).
[c] Number between brackets refers to number of observations with 0 or 100%.

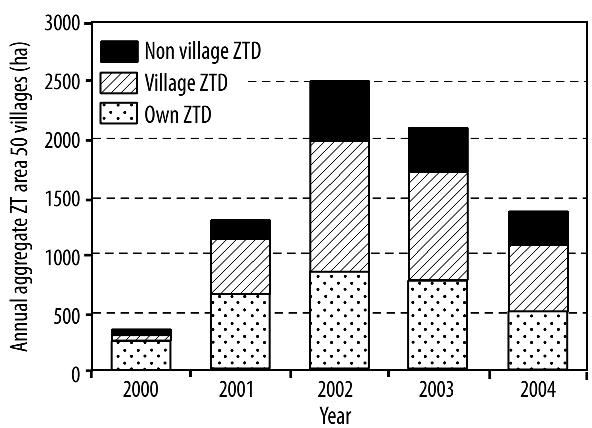

Figure 7. Annual aggregate ZT area for 50 surveyed villages (ha) by ZTD ownership.

The question arises whether the rental price of the ZT drill might be linked to the changes in ZT use. For this purpose the prevailing ZTD rental charges for the last three years were obtained from the ZTD owners and key informants. The average rental charges of ZTDs were relatively constant for 2002-03 (PKR 976/ha) and 2003-04 (PKR 993/ha), but increased to PKR 1070/ha in 2004-05, varying from PKR 865 to 1236 (Table 12 – last set of rows). The decline in demand over the last two years therefore did not translate into lower nominal prices. Instead, the increase in nominal price may have contributed to erode the attractiveness of ZT use. The number of observations is too limited to allow for a detailed analysis. Still, it is worth noting that each of the two districts where the bulk of the ZT area is located (Sheikhupura and Gujranwala) reported a significant increase in rental charges. Although not significant, rental rates at the village level show a tendency to be associated with prevailing adoption levels, being relatively high in villages lacking disadoption and relatively low in villages with complete disadoption.

3.6 Zero-tillage information sources

After adapting and making a local ZT drill, PARC researchers and the private manufacturers with whom they were working initially promoted the technology on a limited scale. Beginning in the mid 1990s, the technology was taken up by OFWM, which thereafter played a major role in its promotion. During the past 10 years, OFWM introduced ZT to thousands of farmers through practical training programs, demonstration plots, farmer field days (Table 13) and the distribution of printed material (including 4,800 fact sheets and 15,000 production guides up to 2003) (Anwar et al. 2004).

Table 13. Zero-tillage promotional activities by OFWM over time.

	ZT trained farmers	ZT demos	ZT farmer field days
1997	856	78	6
1998	1,789	189	13
1999	2,721	356	26
2000	3,322	778	47
2001	5,089	1,120	64
2002	7,500	0	78
2003	9,500	0	49
Total	30,777	2,521	283

Source: OFWM, Lahore as cited in Anwar et al. 2004.

ZT adopters and disadopters were asked for their main source of information about this technology. With 73.7% of the 153 responses, fellow farmers clearly emerged as the main source of information for both adopters and disadopters alike. OFWM and agricultural extension were reported by 17% of the respondents (10.5% and 6.5% respectively), particularly amongst adopters. Other infrequent listed sources of information included mass media (4.0%), drill manufacturers (3.3%), family members (2.6%), NARC (2.0%) and input dealers (0.7%). The prevalence of farmer to farmer diffusion of ZT knowledge in the rice-wheat area was similarly reported in another study (Tahir and Younas 2004).

The machinery manufacturers were also queried as to their initial source of information about zero-tillage methods. OFWM (39% manufacturers reporting) again played an important role, followed by other manufacturers (31%), PARC (27%) and farmers (15%).[12] In terms of their initial source of information about ZT drill design, manufacturers primarily reported other manufacturers (67%) and PARC (47%) (Anwar et al. 2004).

[12] Sums to more than 100% as multiple responses were recorded.

4 Understanding adoption of zero-tillage

The previous chapter showed there is significant adoption and disadoption of ZT in Punjab province. The literature reports on numerous factors that affect the adoption of new agricultural technologies, including personal, physical, institutional and socioeconomic factors (Ervin and Ervin 1982; Feder et al. 1985; Napier et al. 1991). One indeed expects a relationship between the nature of the technology itself and farm characteristics. In scale neutral and divisible technologies like seed, fertilizer and pesticides, both small and large sized farms might be expected to have equal access. ZT is embodied in bulky machinery and therefore possibly not scale neutral. Zero-tillage technology is indeed dependent on tractor availability, although tractor and ZTD custom hiring services still enable access to small holders. The present chapter analyzes the empirical differences at the household level that may help explain the ZT (dis)adoption decision.

This chapter is divided into four main sections, The first section deals with assessing the factors affecting the adoption of ZT in order to examine the contrasts and similarities among users and non-users of the ZT drill. The constraints in the adoption of ZT are discussed in the second section. The third section comprises the multivariate analysis of the factors affecting the adoption of ZT in the rice-wheat tract of Pakistan's Punjab.

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 subsequently 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, (vii) income sources, and (viii) cropping pattern. For the various factors we present tables with 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

Location of the farm is linked to the exposure to various factors that drive and modify farm dynamics, including technology adoption. In the previous chapter mention was already made of differential adoption rates between districts. 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 at 28 km from the district head quarters, 67 km from agricultural research stations, more than 9 km from an agricultural extension's office, and 6-7 km from grain and inputs markets. ZT adoption categories only differ significantly in terms of the distance to agricultural research station and district headquarters, typically the main and nearest town. Relative proximity to an agricultural research station has favored penetration of ZT, but this may be a somewhat spurious relation in view of the absolute distance (60 km for adopters and disadopters) and the relatively limited role research stations have played in the promotion of ZT. Remoteness from district headquarters has favored disadoption of ZT.

The village survey compiled selected village characteristics. The farm households are typically located in nuclear villages with on average 453

Table 14. Distance of sample villages (km) from different locations of agricultural importance.

Location type	Adoption Category: Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall (std.dev., n=458)	Significance
District headquarters	26.6[a]	27.8[a]	31.4[b]	28.1 (±14.3)	0.10
Agri. research station	60.5[a]	70.6[b]	58.7[a]	66.9 (±39.6)	0.02
Agri. extension office	9.5	9.4	9.1	9.4 (±5.2)	NS
Grain market	8.1	7.4	7.7	7.5 (±5.4)	NS
Inputs market	7.2	6.3	6.2	6.4 (±4.8)	NS

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

households per village (±449, ranging from 50-2500), with an average of 57% of the households per village engaged in farming. Village land ranged from 80 to 2200 hectares, with an average of 720 hectares per village (±506). The population pressure on village land was estimated as 6.2 persons/ha (±4.6, ranging from 1.4-20), whereas available land per farm household averaged 3.7 hectares (±2.2, ranging 1.3–11.0).[13]

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 social farmer and household characteristics are important in two respects. First, they comprise elements of the household's human and social capital base. Second, they in turn can modify access to other assets. For each household we enlisted a number of farmer and household characteristics that were assumed to potentially influence ZT adoption.

Overall, the sample farmers were aged about 44 years with a farming experience of nearly 22 years and had a family size of 11—comprising in decreasing order children, male adults, female adults (Table 15). There were few noteworthy differences between adoption categories. ZT adopter households had significantly more children, and there is a tendency for non-adopters to have more farming experience and somewhat smaller family sizes.

Most commonly, the farmer had attended secondary school (34%) or was illiterate (30%). The remainder included those that had attended primary school (22%) and had received higher education (14%). Education status was associated with the adoption categories (Table 16). Non-adopters had a significantly lower education status compared to adopters and disadopters, primarily comprising more illiterates and less with higher education.

About half the farmers belonged to the Jat (46%) caste, with 20% being Rajput. The remainder was split over a number of other castes with 6% or less of the sample. There is no significant association of caste with the adoption categories (Table 17), although the proportion of Jats was highest amongst non-adopter families.

A very low proportion of sample farmers (12%) were found to be member of an organization/association, with in decreasing order the Zakat Committee, Village Organization, Water Users Association, Market Committee and Youth Club. On average there are only 0.13 memberships per farmer. The poor membership to these organizations in the study area suggests they provide limited scope for their use in the promotion of new agricultural technologies. There is an apparent tendency for membership to increase moving from non-adopters, to disadopters, to adopters of ZT – but for none of the variables is the association significant (Table 18). This suggests ZT adopters may have more social capital.

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

Characteristics	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall (std.dev., n=458)	Significance
Age (yrs.)	41.5	44.8	43.7	44.0 (±14.5)	0.18
Farming experience (yrs.)	19.8	22.8	19.7	21.8 (±14.3)	0.09
Family size (#)	11.6	10.3	11.6	10.7 (±6.09)	0.10
Adult men (#)	3.4	3.4	4.1	3.5 (±2.8)	0.17
Adult women (#)	2.9	2.8	3.2	2.8 (±1.6)	0.13
Children (#)	5.3[b]	4.2[a]	4.3[a]	4.4 (±3.5)	0.03

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

Table 16. Educational status of the household head by adoption category.

Educational groups	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall (n=458)	Significance
Illiterate (%)	20.2	34.1	23.4	29.9	0.03
Primary school (%)	20.2	21.6	26.6	22.1	
Secondary school (%)	39.3	33.8	29.7	34.3	
Higher (%)	20.2	10.5	20.3	13.8	
Total (%)	100.0	100.0	100.0	100.0	
Education index*	1.6[a]	1.2[b]	1.5[a]	1.3 (±1.0)	0.00

* Education index values the education groups as 0, 1, 2, and 3 respectively.
Data followed by different letters differ significantly – Duncan (.10), within row comparison.
Some column sums may not exactly add up due to rounding.

Table 17. Distribution of castes in the study area by adoption category.

Castes	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall (n=458)	Significance
Jat (%)	39.8	50.2	32.8	45.7	0.36
Rajput (%)	21.6	18.4	23.4	19.7	
Arain (%)	8.0	5.2	9.4	6.3	
Gujar (%)	3.4	3.9	4.7	3.9	
Other (%)	27.3	22.3	29.7	24.3	
Total (%)	100.0	100.0	100.0	100.0	

[13] Village land per village household (farm + non-farm) averaged 2.1 hectares (±1.5, ranging 0.2–7.3).

4.1.3 Household and farm assets

Farm assets are an indicator of the physical capital a farm household commands and thereby 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 were well endowed, both in terms of farm and household assets (Table 19 and Table 21).

In terms of farm assets, the possession of a tubewell was near universal (93%), with an average of 1.4 tubewells per household. Tractor ownership was relatively widespread (45%), with an average of 0.5 tractors and 0.2 disc/rotavators per household. Besides timely and efficient execution of different farm operations, the ownership or custom-hiring of farm machinery reflects progressiveness in farming in the area. Generally, the ownership of farm machinery is positively associated with farm size (Farooq 1997). Bullock ownership was reported by 5% of the households, in part a reflection of the prevailing tractorisation levels. Ownership of milk animals is very widespread however, with an average of 3.7 milk animals per household. Ownership of insecticide hand pumps is relatively common (44%). Other less frequently reported physical farm assets included motorized threshers (18%) and combine harvesters (4%).

On average, each household reported 3.3 farm asset categories (excluding ZT drill), this average being significantly higher for adopters and disadopters as compared to non-adopters (Table 19). Most individual asset categories show a similar pattern, with prevalence and possession rates being significantly less widespread amongst non-adopters.

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

	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall (n=458)	Significance
Member of:					
Zakat Committee	7.9%	3.3%	4.7%	4.4%	NS
Village Organization	3.4%	3.6%	3.1%	3.5%	NS
Water Users Association	3.4%	1.6%	3.1%	2.2%	NS
Market Committee	3.4%	2.0%	0.0%	2.0%	NS
Youth Club	1.1%	1.0%	1.6%	1.1%	NS
Any of the above	18.0%	10.2%	12.5%	12.0%	.14
Total number of memberships	0.19	0.11	0.13	0.13 (±.39)	NS

Combine harvesters are concentrated amongst the adopters and absent amongst disadopters. This suggests adopters are relatively larger in terms of farm size and more capitalized, with combine harvesters being the largest and most expensive of the farm asset categories.

Further characteristics of the livestock herd are presented in Table 20. On average, 93% of households reported some livestock, typically buffalo (89% of households reporting), whereas cows (42%) and sheep/goats (12%) were less common. The average livestock herd of sample farm households consisted of 9.3 animal heads (or 9.2 animal units) with a composition of 4.5 buffaloes, 1.3 cattle, 3.1 buffalo/cattle young stock, and 0.3 sheep/goats. This illustrates that buffalo are the main dairy animal in the area. The average herd size of non-adopters was relatively small as compared to adopters and disadopters (Table 20) – particularly because of having less buffalo.

The household assets reiterate the relative wealth of the households. In terms of domestic appliances sewing machines are the widest spread (86%), followed by ownership of televisions (56%), refrigerators (47%), tape recorders (34%), telephones (32%) and radios (32%). Transport assets are still primarily two-wheel (bicycle 59%, motorcycle 28%), with car/motor vehicle ownership being

Table 19. Possession of farm assets by adoption category.

	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall (n=458)	Significance
Assets (% reporting): [1]					
Tractor	58.4	37.0	60.9	44.5 (204)	0.00
Disc / Rotavator	28.1	18.4	31.3	22.1 (101)	0.02
Tubewell	96.6	92.1	90.6	92.8 (421)	NS
Combine Harvester	9.0	2.6	0.0	3.5 (16)	0.00
Thresher	25.8	12.8	31.3	17.9 (82)	0.00
Spray pumps	50.6	38.4	57.8	43.4 (199)	0.01
Bullocks	3.4	5.6	1.6	4.6 (21)	NS
Milk animals	94.4	89.5	90.6	90.6 (415)	NS
# of the above farm asset categories	3.7[b]	3.0[a]	3.6[b]	3.2 (±1.5)	0.00
Assets (# per household):					
Tractor	0.65[b]	0.39[a]	0.66[b]	0.48(±0.57)	0.00
Disc / Rotavator	0.30[b]	0.19[a]	0.33[b]	0.23(±0.45)	0.02
Tubewell	1.84[b]	1.26[a]	1.73[b]	1.44(±1.03)	0.00
Combine Harvester	0.09[b]	0.03[a]	0.00[a]	0.03(±0.18)	0.00
Thresher	0.27[b]	0.13[a]	0.31[b]	0.18(±0.39)	0.00
Spray pumps	0.65[b]	0.42[a]	0.73[b]	0.51(±0.70)	0.00
Bullocks	0.07	0.09	0.03	0.08(±0.38)	NS
Milk animals	4.37[b]	3.27[a]	4.44[b]	3.65(±3.85)	0.01

[1] Note: Figures in parentheses are number of cases (n).
Data followed by different letters differ significantly – Duncan (.10), within row comparison.

reported by 11%. In addition, farm assets such as tractors and bullock carts are also widely used for transportation purposes. On average, each household reported 3.8 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 non-adopters (Table 21). Interestingly, motor vehicles are concentrated amongst the adopters. Motor vehicles are the largest and most expensive of the household asset categories and thereby reiterate a similar difference between adopters and disadopters observed earlier for combine harvesters.

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

The rice-wheat cropping system in Punjab is primarily located in irrigated areas with tubewell irrigation, sometimes with the joint use of 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, but tubewells can also be rented at PKR 89 per hour, a practice which is relatively uncommon for wheat and rice cultivation. Farmers rely primarily on diesel tubewells (92%) and to a lesser extent electric tubewells (9%). The reliance on diesel tubewells is even more pronounced for non-adopters, likely again a reflection of the relatively larger asset base of adopters and disadopters and the corresponding ability to electrify their tubewell. The diesel tubewells primarily rely on a 'Peter' engine (97% cases) and to a lesser extent on tractor engines (3%). Diesel tubewells consume 2.1 liters of diesel per hour. The pump tends to be 16 HP and located at the surface. The inlet tube typically is 10.2-12.7 cm and the outlet tube 12.7 cm or less. The groundwater table depth averages 14 meters, whereas the average depth of tubewell hole was estimated to be 33.5 meters. Groundwater quality is generally adequate, with only 5% of the plots reporting poor quality water. Overall though, there is no clear association between the tubewell characteristics and adoption categories (Table 22).

Table 20. Livestock characteristics by adoption category.

Animal types	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall (n=458)	Significance
Possession (% reporting):					
Buffalo	92%	89%	88%	89%	NS
Cow	44%	40%	50%	42%	NS
Young buffalo/cow stock	81%	73%	75%	75%	NS
Sheep/goats	10%	13%	11%	12%	NS
Any of above	97%	92%	92%	93%	NS
# of animals:					
Buffalo milking	3.60b	2.48a	3.36b	2.82 (±2.70)	0.00
Buffalo dry	2.22b	1.41a	2.45b	1.72 (±2.58)	0.00
Cow milking	0.91	0.74	1.05	0.82 (±1.93)	NS
Cow dry	0.44	0.50	0.77	0.53 (±1.55)	NS
Young buffalo/cow stock	3.64	2.95	3.31	3.14 (±3.73)	NS
Sheep/goats	0.28	0.28	0.28	0.28 (±0.94)	NS
Total animal heads	11.09b	8.36a	11.22b	9.29 (±8.78)	0.01
Total animal units[1]	11.20b	8.08a	11.35b	9.15 (±8.37)	0.00

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

[1] The animal units were computed using conversion factors from Bashir *et al.* (1993) as milking and dry buffaloes equal to 1.5 and 1.2 respectively; milking and dry cow as 1 and 0.8 respectively; young stock of large ruminants as 0.5; and sheep/goat as 0.2.

4.1.4 Land characteristics

Land is a key natural capital for a farm household and access to land thereby an influential determinant of adoption decisions and the overall livelihood

Table 21. Possession of household assets by adoption category.

Asset type	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall (n=458)	Significance
Assets (% reporting):[1]					
Sewing machine	87.6	84.9	87.5	85.8 (393)	NS
Television	74.2	48.5	67.2	56.1 (257)	0.00
Refrigerator	61.8	39.0	60.9	46.5 (213)	0.00
Tape recorder	40.4	30.8	39.1	33.8 (155)	0.15
Radio	36.0	30.5	32.8	31.9 (146)	NS
Telephone	48.3	24.6	42.2	31.7 (145)	0.00
Bicycle	67.4	58.7	48.4	59.0 (270)	0.06
Motorcycle/scooter	37.1	23.3	40.6	28.4 (130)	0.00
Car/motor vehicle	22.5	7.2	15.6	11.4 (52)	0.00
# of the above household asset categories	4.8[b]	3.5[a]	4.3[b]	3.8 (±2.2)	0.00
Assets (# per household):					
Sewing machine	0.99	0.89	0.89	0.91(±0.63)	NS
Television	0.79[b]	0.49[a]	0.67[b]	0.57(±0.52)	0.00
Refrigerator	0.70[b]	0.39[a]	0.61[b]	0.48(±0.54)	0.00
Tape recorder	0.43	0.31	0.39	0.34(±0.49)	0.11
Radio	0.37	0.31	0.33	0.33(±0.48)	NS
Telephone	0.54[b]	0.25[a]	0.42[b]	0.33(±0.52)	0.00
Bicycle	0.80[b]	0.63[a]	0.48[a]	0.64(±0.64)	0.01
Motorcycle/scooter	0.45[b]	0.24[a]	0.41[b]	0.31(±0.53)	0.00
Car/motor vehicle	0.33[b]	0.07[a]	0.16[a]	0.13(±0.44)	0.00

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

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

strategy. For each household, we inventoried land access by season and selected indicators of land use and land quality.

The average land holding size for the surveyed farmers in the study area was 8.8 hectares (rabi 2003-04), well above the average farm size in Punjab province (2.9 hectares) (ACO 2003). There is a very significant association of operational holding size and zero-tillage adoption (Table 24). ZT adopters have the largest holdings (16.3 hectares) and non-adopters the smallest (6.3 hectares), with disadopters taking an intermediate position (10.7 hectares). The size of operational holding did not vary much by season.

Owner operators are predominant (60%) followed by owner-cum-tenants (33%), with pure tenancy being relatively uncommon (7%). The operational land holding (8.8 hectares) comprises primarily owned self-cultivated land (6.4 hectares) and to a lesser extent rented-in land (2.0 hectares) and shared-in land (0.4 hectares). Land tenure reveals two major differences amongst adoption categories (Table 24). Differences in land ownership are the main contributor to the observed differences in operational area, with land owned by adopters being significantly larger than dis-adopters and this in turn being lowest for non-adopters – reiterating the significant differences in resource bases. Adopters rent-out and share-out significantly more land than non-adopters, largely a reflection of their larger land ownership. In proportional terms, 76% of the land holding is owned—a proportion which is relatively constant over adoption classes (Table 24).

Rice-wheat systems in Punjab rely on irrigation, with tubewells being the predominant irrigation source for the surveyed farmers, either as their sole irrigation source or supplemented with canal water. There is a change in relative emphasis over irrigation sources between the two seasons due to the availability of canal water. In rabi, 55% of the operational area relies on tubewells only and 44% on tubewells in combination with canal irrigation (Table 25). In kharif, 64% of the operational area is served by a combination of sources, and 34% relies on tubewells

Table 22. Characteristics of tubewells by adoption category.

	Adopters (n≤77)	Non-adopters (n≤268)	Disadopters (n≤55)	Sample mean (std. dev., n≤400)	Significance
Power source tubewell (n=395)a					
Electric	14%	6%	16%	9%	.01
Diesel	86%	95%	84%	92%	.01
Position pump (n=396)					
Surface	77%	74%	73%	75%	NS
Submerged	23%	26%	27%	26%	NS
Depth (m)					
water table	12.5	14	12	14 (±17, n=400)	NS
tubewell	33 a	33 a	36 b	33.5 (±11, n=528)	0.03
Rental rate tubewell (PKR/hr)	75	90	91	89 (±42, n=34)	NS
Diesel consumption tubewell (l/hr)	2.1	2.1	2.0	2.1 (±.8, n=358)	NS
Pump size (HP, n=397)					
< 16 HP	16%	16%	22%	17%	
16 HP	49%	51%	44%	50%	
>16 HP	35%	32%	35%	33%	
Diameter of tubewell inlet tube (n=402)					
< 10.2 cm (4")	4%	6%	5%	5%	
10.2 cm (4")	41%	47%	45%	45%	
12.7 cm (5")	51%	45%	50%	47%	
>12.7 cm (5")	4%	2%	0%	2%	
Diameter of tubewell outlet tube (n=403)					
<12.7 cm (5")	32%	42%	39%	40%	
12.7 cm (5")	53%	39%	39%	42%	
>12.7 cm (5")	15%	19%	23%	19%	

[a] Column sum over response categories ≥ 100% as multiple responses possible.
Data followed by different letters differ significantly – Duncan (.10), within row comparison.

Table 23. Land holding and tenure status (ha) by adoption category (rabi 2003-04).

Land tenure category	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall (std.dev., n=458)	Significance
A. Owner cultivated	14.53[c]	4.68[a]	9.99[b]	7.33 (±11.32)	0.00
B. Net rented/shared in	1.77	1.61	0.72	1.51 (±8.02)	NS
Of which:					
B1. Area rented-in	2.76	1.79	1.70	1.97 (±5.36)	NS
B2. Area rented-out	-1.14[b]	-0.34[a]	-0.91[ab]	-0.57 (±2.82)	0.04
B3. Area shared-in	0.83	0.29	0.08	0.36 (±2.72)	0.17
B4. Area shared-out	-0.68[b]	-0.13[a]	-0.17[a]	-0.24 (±1.98)	0.07
C. Total operational holding (A+B)	16.29[c]	6.28[a]	10.69[b]	8.84 (±12.01)	0.00

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

Table 24. Share of land owned and land tenure status by adoption category.

	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Sample mean (std.dev., n=458)	Significance
Share operational area owned	75%	75%	83%	76% (±35)	NS
Tenancy status					NS
Owner operator	57%	60%	64%	60%	
Owner-cum-tenant	36%	32%	33%	33%	
Tenant	7%	8%	3%	7%	
	100%	**100%**	**100%**	**100%**	

only. Non-adopters tended to rely more heavily on tubewells only and adopters and disadopters on the combination, particularly in kharif, suggesting a less developed irrigation infrastructure for the former. The prevalence of irrigation implies an annual land-use intensity of 192%, reflecting a seasonal land-use intensity of 95% and 97% for kharif and rabi seasons respectively. Despite the high land use intensity, some fallow was still reported by a quarter of the households, with about a fifth of households reporting some fallow in each season (Table 25). ZT adoption was positively associated with farms having some fallow land in rabi season. This is partly due to the strong association of ZT with farm size, but also reflects the potential of ZT to increase the area cultivated as compared to conventional tillage. The average fallow area amounted to 0.49 hectares per household in kharif and 0.35 hectares in rabi. ZT adopters thereby reported the highest average rabi fallow area and disadopters the highest kharif fallow area (Table 25).

The kharif season begins in May/June and ends in October. The rabi season begins in November and terminates in April. The cropping pattern indicates the relative share of each crop in the total cropped area in a cropping season per farm. The farmers' response to changes in agricultural price policy is also reflected in changes over time in the cropping patterns. All things being equal, a farmer's decision about area allocation to a crop is generally affected by its profitability and resources at his disposal. On sample farms, rice and wheat crops were planted at almost three-quarters of the operational holding during kharif 2003 and rabi 2003-04. A little more than 15% of operational holding was allocated to fodder crops during both seasons, with the remaining area under a range of other crops and fallow. The prevalence of rice during the kharif season and wheat during the rabi reasons reiterates why the study area is known as the rice-wheat cropping zone.

Table 25. Land use intensity, fallowing and irrigation source by season and by adoption category.

	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Sample mean (std.dev., n=458)	Significance
Land use intensity (LUI)[1]					
Kharif 2003	96%	96%	93%	95% (±12)	NS
Rabi 2003-04	96%	97%	97%	97% (±10)	NS
Annual	192%	193%	190%	192% (±17)	NS
Fallow (% reporting)					
Kharif 2003	22.5	18.4	20.3	19.4	NS
Rabi 2003-04	27.0[b]	15.4[a]	20.3[ab]	18.3	0.04
Annual	32.6	23.0	29.7	25.8	0.14
Fallow area (ha)					
Kharif 2003	0.60[ab]	0.37[a]	0.88[c]	0.49 (±1.55)	0.05
Rabi 2003-04	0.60[b]	0.26[a]	0.44[ab]	0.35 (±1.34)	0.10
Share operational area by irrigation source – kharif 2003					
Canal only	3%	3%	0%	3% (±15)	NS
Tubewell only	25%[a]	38%[b]	24%[a]	34% (±46)	0.01
Both canal & tubewell	71%[b]	59%[a]	75%[b]	64% (±47)	0.01
Share operational area by irrigation source – rabi 2003-04					
Canal only	1%	2%	0%	2% (±11)	NS
Tubewell only	51%[ab]	58%[b]	42%[a]	55% (±49)	0.03
Both canal & tubewell	48%[ab]	39%[a]	58%[b]	44% (±49)	0.02

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

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

There are a couple of noteworthy differences between adoption categories. The share of the area devoted to rice and wheat crops was relatively higher for adopters than non-adopters, with disadopters taking an intermediate position—reiterating the importance of rice-wheat to adopters. Non-adopters devoted a significantly larger share to fodder crops in both seasons, a reflection of their significantly smaller operational areas with a still significant dairy herd. The significantly lower rice area for non-adopters is associated with a lower area share under Super Basmati. The lower rice area for disadopters is associated with a significantly higher kharif fallow share (Table 26).

For each household we inventoried the main soil type and drainage class. The main soil types on the sample farms were sandy loam (39%) and saline/hard (32%). Loam and sandy loam soil types together were reported on about half of the sample farms, with nearly 57% of the sample farms reportedly having good drainage. Interestingly, both (sandy) loam soil types and good drainage were significantly less common amongst adopters (Table 27), suggesting that non-(sandy) loam soils and drainage problems may have contributed to their interest in ZT. These soils would be more difficult to plow and so ZT would have more potential to reduce turnaround time. A separate study in the area indeed revealed that ZT users generally perceive heavier soils to be more suitable for ZT, with in decreasing order of suitability clayee ('*rohi,*' 44% of cases), clayee low lying ('*chamb,*' 26%), clay loam ('*bhari mera,*' 22%), sandy loam ('*raith,*' 16%) and hard/saline ('*kalrathi,*' 4%) (Tahir and Younas 2004).

4.1.5 Sources of farm labor

For each household we inventoried the contribution of labor sources to overall farm labor use. Overall, nearly two-thirds of the total demand for farm labor was provided by family sources, whereas 21% was contributed by casual hired labor and 15% by permanent hired labor. There are three marked differences amongst adoption categories (Table 28). First, there is a gradient in reliance on family labor: adopters relying the least, non-adopters the most and disadopters taking an intermediate position. Second, the contribution of permanent labor sources is significantly lower for non-adopters compared to relatively similar levels for adopters and disadopters. Third, the contribution of casual labor is the highest for adopters. Labor use patterns are likely associated with family labor availability relative to land. Earlier we had seen 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 hired labor sources is a reflection of this. The adopters also are economically better off and thereby can more easily opt for hiring in labor to substitute for family labor. It also reiterates that adopters are likely more commercially oriented.

Table 26. The cropping pattern (% area) on sample farms by adoption category.

Seasons / Crop name	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall (std.dev., n=458)	Significance
Kharif 2002-03:					
Rice	82.3[b]	70.8[a]	74.8[a]	73.6 (±23.5)	0.00
Super Basmati	67.1[b]	55.5[a]	63.7[b]	58.9 (±28.0)	0.00
Basmati-386	10.8	11.0	7.7	10.5 (±17.3)	NS
Other basmati	4.1	4.1	2.8	3.9 (±10.9)	NS
Coarse varieties	0.3	0.3	0.6	0.3 (±2.7)	NS
Sunflower	0.0	0.6	0.3	0.4 (±3.9)	NS
Fodder	9.1[a]	17.8[b]	10.5[a]	15.1 (±15.0)	0.00
Pulses	1.5	1.6	1.7	1.6 (±7.3)	NS
Vegetables	1.6	2.5	0.8	2.1 (±8.4)	NS
Other kharif crops	0.6	0.5	1.5	0.7 (±5.0)	NS
Fallow	5.0[a]	6.2[a]	10.5[b]	6.5 (±14.0)	0.04
Total season	100	100	100	100	
Rabi 2003-04:					
Wheat	79.8[b]	71.5[a]	75.9[ab]	73.7 (±20.3)	0.00
Berseem	10.9[a]	16.9[b]	12.9[a]	15.2 (±13.5)	0.00
Potato	0.7	0.7	1.4	0.8 (±4.7)	NS
Pulses	0.2	0.1	0.4	0.2 (±1.8)	NS
Vegetables	0.9	1.0	0.4	0.9 (±4.8)	NS
Oats	0.4	1.0	1.3	0.9 (±4.4)	NS
Melon	1.4	0.8	0.6	0.9 (±4.8)	NS
Other	3.3	4.4	3.3	4.0 (±11.4)	NS
Fallow	2.4	3.6	3.9	3.4 (±9.2)	NS
Total season	100	100	100	100	

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

Table 27. Soil type and drainage categories by adoption category.

	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Sample mean (std.dev., n=458)	Significance
Main soil type (multiple response)[a]					NA
Sandy loam	28%	43%	36%	39%	
Loam	22%	16%	17%	17%	
Clay	10%	7%	9%	8%	
Clayee low lying (*'chamb'*)	4%	4%	2%	3%	
Hard/saline (*'kalrathi'*)	37%	32%	23%	32%	
Clayee (*'rohi'/'pacci'*)	11%	8%	17%	10%	
Only (sandy) loam soil type	37%	51%	50%	48%	0.07
Well-drained land	46%	59%	58%	57%	0.08

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

4.1.6 Access to credit

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

Access to credit sources was reported by half of the sample households (47%), comprising both formal (22%) and informal (31%) credit sources. Zari Taraqiati Bank Limited (ZTBL) was the main formal credit source and money lenders the main informal source. Except for the ZTBL which was more frequented by the disadopters, there was no significant association between the source of credit and adoption classes (Table 29).

The total credit amounted to PKR 43,000 per household, with formal sources contributing PKR 24,000 and informal sources PKR 19,000 (Table 30).

Table 28. Relative contribution of labor sources to overall farm labor use (% share) by adoption category.

Labor type	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall (std.dev., n=458)	Significance
Family	48[a]	72[c]	55[b]	65 (±31)	0.00
Permanent hired	26[b]	10[a]	23[b]	15 (±24)	0.00
Casual hired	26[b]	19[a]	22[a]	21 (±20)	0.01
Sum	100	101	100	101	

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

ZTBL charged 13% per annum and commercial banks 10% (Table 31). Rates charged by moneylenders were often not reported, and where reported highly variable with an average of 13%. Credit was primarily used for production purposes, irrespective of credit source. Duration of credit from the moneylender averaged six months, suggesting its use primarily for working capital, whereas from formal sources it averaged a year, possibly contributing to investment purposes (Table 31).

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, first in terms of farming and non-farming, and second, in terms of contributing activities.

Farming was the main income source across households, contributing 80% of overall household income. The share of farming was significantly higher for adopters and disadopters compared to non-adopters (Table 32), highlighting that adopters and disadopters 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 and disadopters to innovate and cut production costs.

Rice and wheat provide the bulk of the farm income (83% farm income share). Other significant contributors are milk (9%), livestock sales (3%) and sugarcane (2%), with a range of other crops as minor contributors. The dominance of rice and wheat income reflects the underlying cropping system. The contribution of rice is the only significant difference amongst adopter categories, being significantly higher for adopters and disadopters (Table 33). Having taken the rice-wheat specialization furthest,

Table 29. Sources of credit by adoption category (% household reporting).

	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall (n=458)	Signifi-cance
Credit source:					
Commercial bank	3.4%	3.0%	3.1%	3.1%	NS
Zari Taraqiati Bank Ltd (ZTBL)	20.2%	16.1%	31.3%	19.0%	.02
Arthya or Commission Agent	29.2%	29.5%	26.6%	29.0%	NS
Input Dealers	0.0%	0.7%	0.0%	0.4%	NS
Friends / Relatives	0.0%	1.3%	1.6%	1.1%	NS
Any credit source	49%	45%	55%	47%	NS
Any formal credit source	22%	19%	34%	22%	0.03
Any informal credit source	29%	31%	28%	31%	NS

Table 30. Amount of credit from different sources by adoption category (000 PKR).

	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall n=458)	Signifi-cance
Formal credit	31	23	23	24 (±89)	NS
Informal credit	22	19	12	19 (±47)	NS
Total credit	53	42	35	43 (±111)	NS

Table 31. Selected credit indicators by adoption category (non-zero values only).

	Adopters	Non-adopters	Disadopters	Sample mean (std.dev.n)	Signifi-cance
Duration credit (months)					
Commercial bank	28	8	9	12 (±18, 14)	NS
Zari taraqiati bank	20	11	11	13 (±21, 83)	NS
Money lender	5.8	6.4	6.2	6.3 (±2.8, 129)	NS
Interest rate (% p.a.)					
Commercial bank	10.7%	9.8%	9.0%	9.9% (±1.8, 14)	NS
Zari taraqiati bank	12.8%	13.4%	13.3%	13.2% (±1.7, 80)	NS
Money lender	6.2%	15.1%	10.1%	12.9% (±12, 33)	NS

Table 32. Percent share of farm and non-farm sources in household income by adoption category.

Income source	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall (std.dev., n=458)	Signifi-cance
Farm income	85.3^{b}	77.3^{a}	84.4^{b}	79.9 (±25.3)	0.01
Non-farm income	14.7^{a}	22.6^{b}	15.6^{a}	20.1 (±25.3)	0.01
Sum	100.0	100.0	100.0	100.0	

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

Table 33. Relative contribution of farm sources to farm income (% share) by adoption category.

Farm income sources	Adopters (n=89)	Non-adopters (n=305)	Disadopters (n=64)	Overall (std.dev., n=458)	Signifi-cance
Rice production	53.9^{b}	49.6^{a}	54.1^{b}	51.1(±15.4)	0.02
Wheat production	32.2	32.1	31.8	32.1(±11.2)	NS
Pulses production	0.0	0.1	0.0	0.1(±1.6)	NS
Vegetable production	0.4	0.6	0.2	0.5(±3.2)	NS
Sugarcane production	0.8	2.2	0.8	1.7(±8.1)	NS
Other crops	1.9	2.5	2.0	2.3(±8.5)	NS
Sale of live animals	2.6	3.2	3.8	3.2(±6.0)	NS
Sale of milk	8.1	9.7	7.2	9.1(±13.6)	NS
Total farm	100.0	100.0	100.0	100.0	

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

this also strengthens farmers' incentives to adopt new time and cost-saving technologies like zero-tillage for wheat.

The income from livestock sector is composed of two sources, i.e. income from the sale of live animals and income from the sale of milk. On average, almost one animal head was sold per household per annum, primarily buffalo young stock and adults. On average, 7.3 liters of milk were sold per household per day. The total annual household income from livestock farming was estimated as PKR 43,000, comprising 22% from the sale of animals and the remaining 78% from the sale of milk. The relative magnitude of the livestock income source was relatively similar across adoption categories.

Non-farm income contributed 20% of overall income across households. Non-agricultural employment was the main contributor (33% non-farm income share), followed by family business (18%), remittances (12%), farm machinery rental (9%) and other sources (24%). Although non-farm income as a category is more important for non-adopters, there is no clear association between the different sources of non-farm income and ZT adopter categories (Table 34).

Table 34. Relative contribution of non-farm sources to non-farm income (% share) by adoption category.

Non-farm income source	Adopters (n=39)	Non-adopters (n=140)	Disadopters (n=22)	Sample mean (std.dev., n=221)	Significance
Family business	17%	18%	18%	18% (±36)	NS
Farm machinery	11%	9%	7%	9% (±27)	NS
Employment on other farms	8%	4%	5%	4% (±20)	NS
Non-agricultural employment	29%	34%	39%	33% (±46)	NS
Remittances	8%	12%	14%	12% (±31)	NS
Other	28%	24%	18%	24% (±42)	NS
Total non-farm	100%	100%	100%	100%	

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 of the ranking analysis conducted are presented in Table 35.

As a group, technical factors rated highest in terms of constraining adoption. The most pressing and revealing constraint is the reduced / low yield with ZT. For the sample as a whole, this was rated at a

Table 35. Constraint index for zero-tillage adoption by adoption category (0: no constraint; 1: very serious constraint).

Factor groups /factors	Adopters	Non-adopters	Disadopters	Overall (std.dev., n)	Significance
Technical factors					
Reduced yield	0.12[a]	0.35[b]	0.50[c]	0.32 (±0.46,458)	0.00
Hardening of upper soil	0.02[a]	0.10[b]	0.14[b]	0.09 (±0.28,458)	0.01
Non-availability of high-quality ZT drills	0.02[a]	0.11[b]	0.04[a]	0.08 (±0.27,458)	0.01
Standing stubbles/crop residues at time of planting	0.12	0.07	0.07	0.08 (±0.25,458)	NS
Dense population of weeds at the time of planting	0.04[a]	0.04[a]	0.10[b]	0.05 (±0.19,458)	0.04
Lack of appropriate soil moisture at time of planting	0.02	0.03	0.05	0.03 (±0.15,458)	NS
Lack of local manufacturing/repair facility for ZT drills	0.01	0.02	0.01	0.02 (±0.12,458)	NS
Risk of increased problem with insect pests and diseases	0.00	0.01	0.01	0.01 (±0.06,458)	NS
Other	0.04[a]	0.18[b]	0.03[a]	0.13 (±0.33,458)	0.00
ZT not available on rented basis	0.00	0.09	-	0.07 (±0.25,394)	0.00
Early harvesting of rice	0.01	0.02	-	0.02 (±0.10,394)	NS
Straw burning	0.00	0.02	-	0.01 (±0.11,394)	0.18
No significant difference in yield	-	-	0.09 (±0.27,64)	-	NA
Increased weed problem following adoption of ZT	-	-	0.08 (±0.26,64)	-	NA
No significant cost savings	-	-	0.07 (±0.22,64)	-	NA
Increased irrigation water requirement	-	-	0.05 (±0.19,64)	-	NA
Extension factors					
Lack of technical assistance from extension worker	0.04[a]	0.10b	0.02[a]	0.08 (±0.25,458)	0.01
Non-availability of extension literature on ZT methods	0.02	0.05	0.02	0.04 (±0.17,458)	NS
Lack of coverage of ZT method by mass media	0.03	0.04	0.02	0.04 (±0.16,458)	NS
Financial factors					
High cost of ZT drill	0.02[a]	0.09[b]	0.03[a]	0.07 (±0.25,458)	0.02
Farmer lacks resources to purchase ZT drill	0.02	0.05	0.04	0.04 (±0.18,458)	NS
No credit available for purchasing ZT drill	0.02	0.02	0.01	0.02 (±0.12,458)	NS
No credit available for purchasing other inputs	0.00	0.02	0.00	0.01 (±0.10,458)	NS
Other	0.00	0.01	0.03	0.01 (±0.11,458)	NS

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

constraint index of 0.3, basically implying it is a slight to moderate constraint. Although it was rated as the most pressing constraint across each of the adopter categories, the index differs significantly amongst the three adopter categories (Table 35). The constraint was scored highest by disadopters, suggesting this is the most pressing reason for their abandonment of ZT. The constraint also scored relatively high for non-adopters, thereby adding to their reluctance to try to the technology.

There is a range of other less pressing technical constraints. These include hardening of upper soil, non-availability of high-quality ZT drills, the presence of crop residues and weeds in the field at time of planting. Although the scores for these were relatively low, they still highlight significant differences between adoption categories (Table 35). The soil hardening was particularly reported by non-adopters and disadopters, but not really by adopters, suggesting this may either be a perceived issue or something related to the differences in soil type reported earlier. On the other hand, the weed problem at the time of planting was particularly mentioned by disadopters, possibly contributing to the disadoption decision perceiving tillage as a more economical means for controlling the problem. Interestingly, the non-availability of high-quality ZTDs was raised primarily by non-adopters, suggesting there still is some unmet demand for experimenting with the technology and that further penetration is possible. Similarly, the non-availability of ZTD on rental basis was solely reported by some of the non-adopters.

The non-adopters also reported other constraints, most prominent amongst which was their reluctance to take risk with a new technology. Relatively minor constraints specific for disadopters related to the lack of significant yield differences and cost savings, the increased weed problem following adoption of ZT and an increased irrigation water requirement. The extension services in Punjab have discredited ZT for the perceived danger for pest carryover in the rice stubble (particularly rice stem borer). Interestingly, the risk of increased insect and disease problems was rated insignificant by the farmers across adoption categories.

As a group, extension factors were rated relatively low in terms of constraining adoption (Table 35). Amongst these, the lack of technical assistance from extension worker rated highest. Interestingly, non-adopters scored this constraint significantly higher. This implies that technical assistance from extension services may be effective in furthering the penetration of this technology.

As a group, financial factors also rated relatively low in terms of constraining adoption (Table 35). Amongst these, the high cost of ZT drill rated highest. Non-adopters again scored this constraint significantly higher. This likely reflects a combination of factors, including the more limited resource base of the non-adopters, the perception that a ZTD is relatively expensive in view of its limited annual use (primarily wheat establishment only) and/or the real cost of the ZTD in Pakistan. The fact that it is primarily raised by non-adopters again suggests that there is potential to further enhance the access to this technology and thereby its penetration. Possibilities to do so may include enhancing access to ZTD rental services and reducing the cost of the ZT drill.

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

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 moves into multivariate analysis, whereby various indicators are grouped into a single adoption model to analyze their joint effect on the likelihood of adoption of ZT. 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 if it is not (Table 36). 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 the previously hypothesized factors that may 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 for a number of reasons. Some variables proved to be highly correlated. Some originally postulated variables were not unambiguously measured or proved non-discriminating. For consistency reasons, we retained the same explanatory variables as in the other country study (Erenstein et al. 2007b). The descriptive statistics of the independent variables included in the empirical models are given in Table 36.

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 for ZT is ambiguous though, as remoteness likely reduces both exposure and the incentives to diversify. ZT promotion in the district enhances the relative exposure of farm households to the technology and is expected to be positively associated with ZT adoption.

Three land resource-related indicators include farm size, the prevalence of (sandy) loam soil types 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 for 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 would be easier to plow and so the potential time saving of ZT is less important since turnaround would already be fast (P.R. Hobbs, personal communication 2007). The relative area with canal irrigation is expected to be variously associated with adoption. With the prevalence of tubewell irrigation, canal irrigation reflects a higher asset base, and cheaper and more diverse irrigation sources. The latter however 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 by 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 which are as follows: farmer age, farmer education, family size, whether farmer belongs to the prevailing caste and 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 could be more entrepreneurial and willing to take on new technologies. Organizational membership is expected to be positively associated with adoption

Table 36. Descriptive statistics for variables used in empirical models.

Var.	Description	Mean	Std.dev.	Min.	Max.	Cases
	Independent variables					
NDISDTHQ	Distance to district headquarters (km)	28.1	14.1	1	80	458
DDZTPROM	ZT Promotion in district (1:yes, 0:no)	0.81	0.39	0	1	458
NRAOPER	Farm size (total operational holding, rabi 2003-04, ha)	8.85	12.01	0.20	121.4	458
DRLISOIL	Only (sandy) loam soils (1:yes, 0:no)	0.48	0.50	0	1	458
NRPCANAL	Share operational area with canal irrigation	0.45	0.49	0	1	458
ICASSET	Asset index (number of assets owned by household/16)	0.44	0.20	0	1	458
DCREDFOR	Any formal credit source (1:yes, 0:no)	0.22	0.41	0	1	458
NAGE	Age of household head	44.0	14.5	17	85	457
CEDUCATN	Education index for household head	1.3	1.0	0	3	458
NFAMILY	Family size	10.7	6.1	1	59	458
DJAT	Household head belongs to prevailing caste (Jat (Sikh), 1:yes, 0:no)	0.46	0.50	0	1	458
NMEMBER	Number of organizational memberships	0.13	0.39	0	4	458
NIRW	Rice-wheat specialization index (fraction of household income from rice-wheat)	0.66	0.26	.010	1.00	458
	Dependent variables					
ZTEVER	Ever used ZT (1:yes, 0:no)	0.334	0.472	0	1	458
ZT2003	Used ZT in 2003-04 (1:yes, 0:no)	0.194	0.396	0	1	458

by enhancing social capital and enabling access to resources and information.

The final independent variable is the rice-wheat specialization index and reflects the livelihood strategy of the household. Specialization in rice-wheat reflects 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 37. The models predict 73-82% 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 five independent variables. In decreasing order of significance: farm size and rice-wheat specialization (1%-level), assets (5%-level), main caste [negative] and ZT promotion (10%-level). The ZT current use model highlights three significant independent variables: farm size (1%-level), (sandy) loam soils [negative] (5%-level) and rice-wheat specialization (10%-level). The models thereby reiterate that ZT adoption is closely associated with a more favorable resource base and rice-wheat specialization. The importance of rice-wheat specialization is intuitive, and refutes the findings reported by Sheikh et al. (2003) in relation to the early ZT adoption phase (1995-96 season). This likely reflects the specification of their model, whereby their rice-wheat area variable "almost certainly represents a contrast to the combinable area variable" (ibid.:91).

The contrast between our two models also generates some insights into current adopters and disadopters. Farm size is equally important in both models, suggesting its imperative role for adopters and disadopters alike. Rice-wheat specialization is however markedly more pronounced in the penetration model. This suggests rice-wheat specialization played an important role in trying out the technology, but less so in continuing with its use. The other significant variables are specific to a single model. In this regard, ZT promotion at the district level contributed to farmers trying out the technology but not to its continued use. This likely reflects that for whatever reason the ZT technology performed less well in disadopters' fields than alluded to by the ZT promoters. Not belonging to the prevailing caste and having more physical assets helped explain trying out the technology but not its continued use. Conversely, predominantly (sandy) loam soils did not affect the likelihood of trying out the technology but did reduce the likelihood of its continued use. This suggests that the technology likely performed better on heavier soils.

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. Our models for instance, do not adequately capture some features of the ZT innovation process, such as local ZT champions and the functioning (or absence) of ZT service providers. In the end though, adoption and disadoption can be expected to reflect the underlying performance of the technology in the farmers' fields, an issue we explore in the next chapter.

Table 37. Factors affecting zero-tillage use (2 binomial logit models, normalized on non-use of technology)

Independent variable	Model 1: ZT use ever	Model 2: ZT use 2003-04
Constant	-2.77 (0.74)***	-2.17 (0.84)**
Distance to district headquarters (km)	-0.0039 (0.0083)	-0.016 (0.010)
ZT Promotion in district (dummy)	0.63 (0.34)*	0.46 (0.39)
Farm size (ha)	0.040 (0.015) ***	0.041 (0.014)***
Only (sandy) loam soils (dummy)	-0.37 (0.22)	-0.65 (0.27)**
Share operational area with canal irrigation	0.35 (0.23)	0.086 (0.273)
Asset index	1.53 (0.72)**	0.92 (0.81)
Any formal credit source (dummy)	0.40 (0.26)	0.0067 (0.3096)
Age of household head	-0.011 (0.008)	-0.015 (0.010)
Education index for household head	0.16 (0.12)	0.16 (0.14)
Family size	0.015 (0.020)	0.0052 (0.021)
Household belongs to main caste (dummy)	-0.48 (0.24)*	-0.29 (0.29)
Number of organizational memberships	0.051 (0.296)	0.18 (0.30)
Rice-wheat specialization index	1.21 (0.46)***	0.93 (0.55)*
Model parameters		
Cases predicted correctly	73%	82%
Log-likelihood	-248	-224
Chi-squared	85	58
Degrees of freedom	13	13
Significance level	.000	.000
Valid cases	457	457

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

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. 2002; Malik et al. 2005a). On-farm experiments of wheat sowing with ZT were initiated in Pakistan during 1984-89 (Aslam et al. 1989). The results showed that ZT improved the crop stand and yielded 10-40% higher under different soil types and wheat sowing regimes as compared with planting under conventional system. Significantly higher grain yields were obtained with ZT when wheat was planted at the recommended time, i.e. early to mid-November. For the late planted sites, there was no significant yield difference between ZT and conventional tillage planted wheat. This mainly reflects reduced terminal heat stress for wheat with a correspondingly longer growing period when wheat is timely planted. At the same time no major carry-over effects on the subsequent rice were 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 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, thereby 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 'conventional' data with earlier diagnostic studies (Byerlee et al. 1984) suggests this is not the case. Furthermore, in the absence of a baseline, we cannot always 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. We therefore prefer to err on the safe side and assume that the comparison between the ZT plots and 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.

Table 38. Selected characteristics of wheat survey plots reported by adoption category.

Items	Adopters – ZT plot (n=87)	Wheat sown by conventional method			Overall (n=64)	Significance
		Adopters – non ZT plot (n=522)	Non-adopters (n=67)	Disadopters (n=304)		
Plot size (ha)	8.28[b]	7.54[b]	4.06[a]	7.16[b]	5.59 (±8.67)	0.00
(Sandy) Loam soil type (% reporting)[1]	43%	45%	52%	50%	49%	NS

[1] '*Mera*', includes sandy, sandy loam, loam soil types. Excludes clay, clayee, hard/saline and mixed soil types.
Data followed by different letters differ significantly – Duncan (.10), within row comparison.

5.1 Wheat crop

The 522 surveyed wheat plots were equally split between having predominantly (sandy) loam and other soil types (Table 39), without a significant difference between ZT plot types (Table 38). The average wheat plot size was 5.6 hectares. There is a highly significant difference in size amongst plot types, with non-adopter plots averaging 4 hectares against 7-8 hectares for the three other types of plots (Table 38). These differences mirror the underlying farm size differences.

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 in sample plots is entirely mechanized using 4-wheel tractors, with no use of animal traction being reported. Conventional land preparation practices are very intensive, with 8-8.5 tractor operations (with a reported maximum of 16), comprising on average per plot (Table 40):

- 1-3 disc plowings (with a maximum of 4),
- 3-4 cultivator plowings (with a maximum of 7) and
- 2-3 tractor plankings (with a maximum of 6).

Wheat is subsequently sown manually by broadcasting. ZT wheat implies the use of a tractor drawn ZT drill and is achieved in a single pass.

The results thereby confirm that ZT drastically reduces tractor operations in farmers' ZT fields. An earlier diagnostic study reported an average of 6 tillage operations in Punjab-Pakistan (ranging from 2 to 10, Byerlee et al. 1984), followed by another tractor cultivation after broadcasting the seed. Our study highlights that the current conventional tillage practices do not deviate much from the earlier study, whereas broadcasting of seed still prevails. The total number of tillage operations in conventionally tilled wheat plots (8.1 including any cultivation to cover broadcast seed) also did not vary between the soil types or adopter categories. Therefore, contrary to expectations, there is no significant spill-over effect in terms of reducing tillage intensity in 'conventional' plots of adopters and disadopters. Although there is no significant difference between total number of tractor operations, there is some variation in type of tillage operations: disadopters applied the highest number disc plowings and conventional plots of adopters had the highest number cultivator plowings and plankings, with non-adopters taking intermediate positions (Table 40). The reported intensity of tillage is such that only 11 cases (2.1%, comprising 3 conventional plots of adopters and 8 non-adopters) could be classified as using reduced tillage (i.e. maximum of two plowings).

The number of tractor operations translates into equally pronounced differences in number of tractor hours and diesel use (Table 41). Conventional tillage implies a per hectare use of 9.3-10.6 tractor hours and 42-48 liters of diesel. This contrasts with the 2.4

Table 39. Soil categories of wheat survey plots reported by farmers.

Soil category	% of fields (n=522)	
(Sandy) Loam soil types	*49.4%*	
Sandy loam ('medium *mera*')		33.0%
Loam ('*mera*')		15.7%
Sandy ('light *mera*')		0.8%
Other soil types	*50.6%*	
Hard/saline ('*kalrathi*')		28.9%
Clayee ('*rohi*'/'*pacci*')		8.0%
Clay		6.7%
Clayee low lying ('*chamb*')		2.9%
Mixed		4.0%

Table 40. Wheat establishment operations reported by plot category.

Tillage operation	Adopters – ZT plot (n=87)	Wheat sown by conventional method: Adopters – non ZT plot (n=67)	Non-adopters (n=304)	Disadopters (n=64)	Overall (n=522)	Significance
# of tillage operations with tractor (#/season)						
Disc plowing	0.00[a]	1.36[b]	1.72[c]	2.33[d]	1.46 (±1.53)	0.00
Cultivator plowing	0.00[a]	3.82[c]	3.78[c]	3.39[b]	3.10 (±1.91)	0.00
Planking	0.00[a]	2.81[c]	2.62[bc]	2.55[b]	2.20 (±1.37)	0.00
Mechanized planting	1.00	0.00	0.00	0.00	0.17 (±0.37)	0.00
Total number with tractor	1.00[a]	7.99[b]	8.11[b]	8.27[b]	6.93 (±3.29)	0.00

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

tractor hours and 7 liters of diesel reported for ZT, implying a saving of 7 tractor hours and 35 liters diesel (compared to adopters' conventional plots). The diesel savings are increasingly attractive in view of the hike in oil prices. The time saving enhances the farmers' opportunity to complete the wheat establishment operation well in time. The optimum period for wheat establishment is short and tractor availability often constrained during this window. This is due to the combined effect of peak tractor demand for wheat land preparation/establishment, transportation of rice from farm to market and tractor owner preferences to first complete their own wheat establishment.

Overall, the mean sowing date of wheat on sample plots was 26 November, with a standard deviation of more than 2 weeks across plots. Contrary to expectations, there was no significant difference in establishment date between ZT and conventional plots (Table 42). A similar finding was reported in another study (Tahir and Younas 2004). The time savings induced by ZT in land preparation have therefore not translated into timelier establishment. Farmers thereby forfeit one of the potential advantages of the technology, as earlier establishment is one of the main contributors to the enhanced wheat yields observed under trial conditions. One possible explanation is untimely availability of the ZTD, particularly for those reliant on service providers. Ownership of a ZTD did indeed significantly advance the sowing date for ZT plots by 8 days (23 November vs 01 December, p = 0.05), suggesting that reliance on ZT service providers did significantly delay wheat establishment.

Table 41. Duration and diesel use of mechanized wheat establishment operation reported by plot category.

Tillage operation	Adopters – ZT plot (n=87)	Wheat sown by conventional method: Adopters – non ZT plot (n=67)	Non-adopters (n=304)	Disadopters (n=64)	Overall (n=522)	Significance
Duration of tillage operations (tractor hrs/ha)						
Plowing	0.00[a]	7.30[b]	8.43[c]	8.83[c]	6.93 (±2.38)	0.00
Planking	0.00[a]	2.02[c]	1.74[b]	1.75[b]	1.49 (±1.01)	0.00
Mechanized Planting	2.39[b]	0.00[a]	0.00[a]	0.00[a]	0.40 (±0.91)	0.00
Total duration	2.39[a]	9.32[b]	10.18[c]	10.58[c]	8.80 (±4.43)	0.00
Diesel consumption (l/ha)						
Plowing	0.0[a]	34.3[b]	37.8[c]	41.3[d]	31.5 (±11.5)	0.00
Planking	0.0[a]	7.7[c]	6.8[b]	7.1[bc]	5.8 (±4.1)	0.00
Mechanized Planting	7.2[b]	0.0[a]	0.0[a]	0.0[a]	1.2 (±2.7)	0.00
Total diesel consumption	7.2[a]	42.0[b]	44.6[b]	48.4[c]	38.5 (±20.2)	0.00

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

Table 42. Wheat seed and planting practices reported by adopter plot category.

Items	Adopters – ZT plot (n=87)	Wheat sown by conventional method: Adopters – non ZT plot (n=67)	Non-adopters (n=304)	Disadopters (n=64)	Overall (n=522)	Significance
Planting date	Nov. 27th	Nov. 24th	Nov. 27th	Nov. 26th	Nov. 26th (±14.7)	NS
Labor time for planting (hrs/ha)	2.37[b]	1.55[a]	1.55[a]	1.53[a]	1.68 (±0.61)	0.00
Seed rate (kg / ha)	119	119	117	116	117 (±14)	NS
Main variety (% reporting)						0.11
Inqalab-91	62.1%	58.2%	73.0%	71.9%	69.2%	
Watan	37.9%	40.3%	24.3%	25.0%	28.7%	
Auqab-2000	0.0%	0.0%	0.7%	0.0%	0.4%	
Other	0.0%	1.5%	2.0%	3.1%	1.7%	
Seed source (% reporting)						NS
Own	81.6%	83.6%	83.6%	81.3%	83.0%	
Purchased	16.1%	13.4%	13.8%	17.2%	14.6%	
Own + purchased	2.3%	1.5%	0.7%	1.6%	1.1%	
Neighbor	0.0%	0.0%	1.6%	0.0%	1.0%	
Research Institute	0.0%	0.3%	0.0%	0.0%	0.2%	

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

The reported wheat planting date is also relatively late and did not markedly change over time: in 1984 60% of wheat was estimated to have been planted after 01 December (Byerlee et al. 1984:20). Late maturing basmati rice varieties originally contributed to delayed wheat establishment. The availability of shorter duration basmati rice varieties (see 5.2.1) should potentially have diminished the time conflict, but this does not seem to have had a significant effect on more timely wheat planting. Similarly, the now widespread tractor ownership (45% of sample) could have reduced turnaround time. Ownership of a tractor did indeed significantly advance the wheat sowing date, albeit with only 2 days (27 November vs 29 November, prob = 0.04). This suggests farmers have generally been reluctant to significantly advance their wheat planting date despite apparently increased opportunities to do so.

Farmers reported an average seed rate of 117 kg/ha. The use of the ZTD is potentially seed saving as compared to broadcasting without any yield loss. However, no significant difference in reported seed rates was observed between plots (Table 42). This may reflect farmers' reluctance to reduce seed rates. The results show that labor needs for the sowing operation are higher for ZT plots (2.4 hours) as compared to conventional plots (1.5-1.6 hours – Table 42).

Inqalab-91 and Watan were the major wheat varieties planted in the area, reported in 69% and 29% of sample plots, respectively. Inqalab-91 became the dominant variety during the 1990s, largely displacing Pak-81 which was popular in the 1980s (Amir and Aslam 1992). The prevalence of a few varieties over large areas is worrying in view of the underlying risk from any resistance breakdown. This has become even more pressing in view of their susceptibility to Ug99, the virulent new stem rust for wheat (Mackenzie 2007; Raloff 2005). On most of the sample plots farmers' own seed was used while 15% of plots reported the use of purchased seed (Table 42).

A separate study in the area requested ZT users give their perception of ZT effects on wheat establishment and crop stand (Tahir and Younas 2004). Based on the study, farmers concur that seed germination with ZT is early and good (95%), crop stand uniform (84%) and that ZT enhanced tillering (64%) without any effect on the incidence of lodging.

Nutrient management

All wheat plots received applications of chemical fertilizers, with a universal use of urea and widespread use of diammonium phosphate (DAP, 90%) and only sporadic use of other fertilizers including NP, NPK, Single Super Phosphate and potash. Overall, 177 kg of NPK per hectare were applied to wheat, comprising 115 kg of nitrogen, 61 kg of phosphorous and only 1 kg of potash. The use of ZT potentially saves fertilizer, particularly by placing basal fertilizer in the row, but no significant differences in chemical fertilizer use were noted between ZT and conventional plots (Table 43). Only 2.5% of the sample wheat plots received Farm Yard Manure (FYM) with an average quantity of 0.97 t/ha. FYM use for wheat was confined to non-adopter and disadopter plots (Table 43).

Table 43. Wheat fertilization practices reported by plot category.

		Wheat sown by conventional method				
Items	Adopters – ZT plot (n=87)	Adopters – non ZT plot (n=67)	Non-adopters (n=304)	Disadopters (n=64)	Overall (n=522)	Significance
Chemical nutrient application rates (kg nutrient/ha)						
Nitrogen (kg N/ha)	112	118	115	119	115 (±34)	NS
Phosphorous (kg P_2O_5/ha)	60.5	60.4	60.5	60.8	60.5 (±22.3)	NS
Potash (kg K_2O/ha)	1.3	0.6	1.3	0.8	1.1 (±7.8)	NS
Sulphur (Kg S/ha)	1.19	1.11	0.34	0.93	0.65 (±4.59)	NS
Total nutrients (kg NPK/ha)	174	179	177	181	177 (±45)	NS
Main types of chemical fertilizer (% reporting)						
Urea	100%	100%	100%	100%	100%	NS
DAP	92.0%	89.6%	90.1%	85.9%	89.8%	NS
NP	2.3%	3.0%	4.6%	4.7%	4.0%	NS
NPK	2.3%	4.5%	1.3%	3.1%	2.1%	NS
Single Super Phosphate	3.4%	3.0%	1.3%	3.1%	2.1%	NS
Potash	1.1%	0.0%	1.3%	0.0%	1.0%	NS
FYM (% reporting)	0.0%	0.0%	2.6%	7.8%	2.5%	0.01
Qty. of FYM applied (t/ha)	0	0	1.1	2.5	1.0 (±7.0)	0.11

Weed, pest and disease management

Four-fifths of the sample wheat plots were weeded, whereas none received any pesticide or fungicide application. Chemical weed control is the dominant method in the area (79% of plots), with only sporadic use of manual weed control (4%) being reported. Typically only one weed control application is applied, resulting in an overall average of 0.9 weedings per plot.

There is no significant difference between plots in terms of manual weeding. There is a significant difference in terms of herbicide use, with disadopters applying more frequently (Table 44). This corresponds with the more widespread weed problems reported earlier by disadopters (see section 4.2). Herbicide use could reflect inherently weedier fields or a stronger preoccupation with weeds amongst disadopters. It could also possibly signal a carryover from previous ZT use. However, a combination of two factors makes this unlikely. First, previous use of ZT by disadopters was often short-lived (see section 3.3), thereby not allowing a significant buildup in weed pressure. Second, weed carryover would be more plausible if particularly found in fields with ZT in the previous year, but no such association was apparent. Although we cannot unambiguously establish causality, the weed problem does not seem to be caused by prior use of ZT, but inherent weed pressure may have contributed to the decision to discontinue ZT.

A separate study in the area requested ZT users for their perception of ZT effects on weed, pest and disease incidence in the wheat crop (Tahir and Younas 2004). This revealed that farmers concur on ZT not having any effect on diseases (96%) or insect population (93%). However, farmers were split in terms of the perceived effect on weeds, with 37% reporting no effect, 39% an increase and 24% a decrease.

Water management

Wheat cultivation in sample plots is irrigated. The prevailing conventional wheat establishment practice ('wadwatter') relies on residual moisture, and tillage and sowing are completed before the first irrigation is applied. An alterative wheat establishment practice ('rauni') irrigates the field prior to tillage and sowing. *Rauni* was reported in 14-15% of the conventional plots, irrespective of adoption category.

Tubewells are the major source of irrigation for sample wheat plots, with nearly three-quarters of sample plots relying solely on tubewell irrigation and 24% of plots on combined application of canal and tubewell water. Despite the prevalence of irrigation, 16.5% of wheat fields were reported to have experienced water shortage during the season. Actual evapotranspiration of wheat is generally lower than the potential requirement in these rice-wheat systems (Ahmad et al. 2002; Jehangir et al. 2007).

On average, a wheat plot received 3.4 irrigations per season, comprising 2.9 tubewell irrigations and 0.5 canal irrigations. ZT reportedly saves water and it has been suggested that it could save an irrigation. However, there is no significant difference in the reported number of irrigations per plot between adoption categories (Table 45). 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 highlights significant

Table 44. Wheat weed, pest, and disease management practices reported by plot category.

Items	Adopters – ZT plot (n=87)	Wheat sown by conventional method: Adopters – non ZT plot (n=67)	Non-adopters (n=304)	Disadopters (n=64)	Overall (n=522)	Significance
Use of weed control (% reporting)						
Hand weeding	2.3%	4.5%	3.9%	3.1%	3.6%	NS
Herbicide application	71.3%	76.1%	79.3%	92.2%	79.1%	0.02
Hand or herbicide	71.3%	76.1%	80.6%	92.2%	79.9%	0.01
Number of weed controls (# applications/season)						
Hand weeding	0.02	0.04	0.04	0.03	0.04 (±0.19)	NS
Herbicide application	0.74[a]	0.79[a]	0.84[a]	1.06[b]	0.84 (±0.49)	0.00
Hand or herbicide	0.76[a]	0.84[a]	0.88[a]	1.09[b]	0.88 (±0.53)	0.00
Labor use for manual weeding (man-days/ha)	0.03	0.04	0.02	0.04	0.03(±0.30)	NS
Pesticide/fungicide application (% report)	0.0%	0.0%	0.0%	0.0%	0.0%	NS

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

differences that support this (Table 45). In the ZT plots, the first irrigation averaged 8.5 hours per hectare, as against 9.5 in the conventional plots of adopters and 9.8 in non-adopter plots. Consequently, generally less irrigation water is applied to ZT during the first irrigation. This is generally beneficial as in tilled fields often too much water is applied to parts of the field, resulting in waterlogging and yellowing of wheat plants. For subsequent tubewell irrigations, the differences are not significant – nor are they for first or subsequent canal irrigations. The total irrigation time (tubewell and canal combined) is the lowest for ZT plots and highest for non-adopters, with disadopters and conventional plots of adopters taking intermediate positions. Average water use per hectare was estimated at 2,700 irrigation m^3 and 3,800 gross m^3, with an insignificant variation over plot types.

The results therefore provide some support to the postulated water saving nature of ZT. Still one should realize that the results presented here relate to survey findings, which implies we cannot 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 Table 22). 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 the ZT technology effects, if any. A separate water-use survey conducted within the context of the parallel study in Haryana, India indeed showed more significant water savings attributable to ZT than those observed in the adoption survey (Erenstein et al. 2007b). A separate survey in the area amongst ZT users reported water use to amount to 1,800 m^3/ha under ZT and 2,300 m^3/ha under conventional tillage (Tahir and Younas 2004), although not providing the statistical significance of the 22.5% saving.

Harvest practices

The mean wheat harvesting date was 30th April, implying a crop duration of 153 days, with no significant variation across plot types. About half of the wheat plots were manually-harvested, with 38% combine-harvested and 15% reaper-harvested. Combiner use was significantly more widespread on adopter and disadopters plots, with only 28% of non-adopters reporting its use (Table 46). Reaper use was relatively more popular amongst non-adopters

Table 45. Wheat irrigation practices reported by plot category (adoption survey).

Items	Adopters – ZT plot (n=87)	Wheat sown by conventional method: Adopters – non ZT plot (n=67)	Non-adopters (n=304)	Disadopters (n=64)	Overall (n=522)	Significance
Use of rauni method (% reporting)	0%	14.9%	14.1%	14.1%	11.9%	0.00
Irrigation source (% reporting)						NS
Canal	2.3%	3.0%	3.6%	1.6%	3.1%	
Tubewell	72.4%	74.6%	74.3%	68.8%	73.4%	
Both canal and tubewell	25.3%	22.4%	22.0%	29.7%	23.6%	
Number of irrigations (# / season)						
Canal	0.46	0.46	0.53	0.52	0.51 (±0.94)	NS
Tubewell	2.79	2.87	2.87	2.97	2.87 (±0.99)	NS
Total	3.25	3.33	3.40	3.48	3.38 (±0.94)	NS
Duration of irrigations (hrs/ha)[1]						
1st canal (hrs/ha)	7.9	8.6	8.4	7.8	8.3(±3.8, n=128)	NS
Subsequent canal (hrs/ha/irrig.)	6.3	7.8	6.2	5.7	6.3 (±3.1, n=95)	NS
Total canal (hrs/ha/season)	11.6	13.9	15.9	11.4	14.3 (±9.6, n=128)	0.15
1st Tubewell (hrs/ha)	8.5[a]	9.5[b]	9.8[b]	9.1[ab]	9.4 (±3.4, n=501)	0.01
Subsequent tubewell (hrs/ha/irrig.)	6.6	7.1	7.1	6.3	6.9 (±2.6, n=487)	0.13
Total tubewell (hrs/ha/season)	21.0	23.8	24.1	22.1	23.3 (±11.2, n=501)	0.12
Total canal + tubewell (hrs/ha/season)	23.4[a]	26.6[ab]	27.2[b]	25.3[ab]	26.3 (±12.4, n=507)	0.09
Estimated water use (m^3/ha)						
Irrigation water[2]	2480	2760	2830	2630	2740 (±1310)	0.15
Gross water (rain + irrigation)[3]	3510	3790	3860	3660	3770 (±1310)	0.15
Water scarcity (% reporting)	11.5%	11.9%	17.8%	21.9%	16.5%	NS

[1] Non-zero values only.

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

[2] Assumes 102 m^3/hour for tubewell (i.e. 1 cusec) and 117 m^3/hour for canal (Jehangir et al. 2007).

[3] Assumes seasonal rainfall of 103 mm (average 2001-03, Jehangir et al. 2007).

and disadopters. Manual harvesting is laborious needing 12 labor days per hectare, as compared to 1.2 hours per hectare for the combine harvester and 2.5 hours for the reaper. The choice of harvesting method thereby seems associated with the underlying resource base of adopter categories.

Compared to rice, wheat harvesting is less reliant on the use of combiners. The prevalence of manual and reaper harvesting in wheat reflects the widespread use of wheat straw as animal feed. Indeed, wheat residues were removed from 74% of the plots, irrespective of adopter category. Furthermore, the relatively longer turnaround time between wheat harvesting and rice transplanting, allows for a more widespread use of manual labor in the harvesting/threshing process. With most of the wheat residues removed, leftover wheat residues were burned in situ in 45% of the plots whereas they were left in the field and/or incorporated in 19% of the plots. The crop residue management of non-adopters stood out in terms of being least reliant on burning, whereas residues were more commonly left in the field and/or incorporated. This likely reflects two issues. First, the association of residue burning with combine harvesting, as combine harvesting implies loose residues which are more problematic to collect for feed purposes. Second, the significantly smaller farm sizes of non-adopters which imply a higher pressure on the wheat residues for feed purposes.

5.1.2 Impact of zero-tillage on wheat productivity

The mean farmer estimated wheat yield was 3.3 t/ha, with no statistically significant difference between plot types (Table 47). Our results can therefore not settle the dispute between those that claim that ZT raises wheat yields in farmers' fields and those that claim that ZT reduces wheat yields in Pakistan's Punjab. The lack of a significant yield effect is however still an important finding. Indeed, it goes some way in explaining the disillusionment of some of the disadopters (also see 4.2) and their subsequent disadoption. Without a yield benefit, the immediate payoff to ZT is reduced to its cost-saving potential.

A positive yield effect of ZT is closely associated with more timely wheat establishment. Indeed, there is a significant negative correlation between wheat yield and sowing date (Julian day number, -0.15, prob. 0.00). Wheat plots that were established before November 16 yielded significantly more (3.4 t/ha, n = 78) compared to plots established thereafter (3.2 t/ha, n = 444, prob.:0.02). However, as mentioned above, although ZT reduces turnaround time, there was no significant difference in terms of time of wheat establishment between ZT and conventional plots. Wheat grown on (sandy) loam soils also yielded significantly more (3.4 t/ha) compared to heavier soils (3.2 t/ha, prob.:0.00), but no significant interaction with ZT was apparent. A separate study

Table 46. Wheat harvesting practices reported by plot category.

Items	Adopters – ZT plot (n=87)	Wheat sown by conventional method			Overall (n=522)	Significance
		Adopters – non ZT plot (n=67)	Non-adopters (n=304)	Disadopters (n=64)		
Harvesting date	April 30th	April 29th	April 30th	April 30th	April 30th (±8)	NS
Crop duration (days)	153	155	153	154	153 (±16)	NS
Harvesting method (% report)[1]						
Manual	33.3%	52.2%	57.9%	46.9%	51.7%	0.00
Combine	59.8%	47.8%	28.3%	46.9%	38.3%	0.00
Reaper	10.3%	6.0%	18.1%	17.2%	15.1%	0.04
% Area harvested by method						
Manual	33.9[a]	48.2[bc]	55.3[c]	42.5[ab]	49.2 (±49.2)	0.00
Combine	58.3[c]	45.9[b]	26.7[a]	42.4[b]	36.4 (±47.0)	0.00
Reaper	7.9[ab]	6.0[a]	18.0[c]	15.1[bc]	14.4 (±34.8)	0.02
Harvesting time						
Manual (days/ha)	12.4	12.1	12.1	13.1	12.2 (±2.6, n=270)	NS
Combine (hrs/ha)	1.21	1.18	1.28	1.16	1.23(±0.47, n=183)	NS
Reaper (hrs/ha)	2.68	2.32	2.53	2.47	2.53 (±0.43, n=79)	NS
Residue management (% reporting)[1]						
Remove	77.6%	73.0%	74.0%	71.2%	74.2%	NS
Burn	58.8%	50.8%	36.5%	55.9%	44.6%	0.00
Left in field/incorporate	14.1%	15.9%	23.1%	11.9%	19.2%	0.09

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

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

in Pakistan-Punjab also reports a mixed wheat yield effect of ZT, with 54 percent of farmers reporting a yield increase, 30 percent a decrease and 16 percent no change (Ahmad et al. 2007).

Irrigation water productivity averages 1.0 ton of wheat per irrigation and 1.5 kg wheat per m^3. Gross water productivity amounts to a kg of wheat per m^3. The relatively similar yields in the survey year combined with the relatively modest irrigation savings by ZT imply that water productivity indicators are relatively similar across the various plot categories (Table 47). Only irrigation water productivity per hour of irrigation differs significantly across plots, with ZT having the highest levels.

To further explore yield effects, farmers were asked to recall the wheat yields they achieved with either ZT or conventional tillage over the last couple of years. For conventional tillage a distinction was made between 'rauni' (with pre-irrigation prior to land preparation) and 'wadwatter,' as rauni has been reported to significantly increase wheat yields in the area (Iqbal et al. 2002). Rauni yields were not significantly different from ZT and wadwatter in the survey year, but were reportedly higher in 2002 and 2001 (Table 48 – row wise comparison). However, in none of the recall years was ZT yielding significantly different from wadwatter. ZT yields averaged 3.2 ton per hectare over the 4 year period and were not significantly different over the last 3 years, but reportedly higher in 2000 (Table 48 – column wise comparison). Rauni yields averaged 3.5 t/ha over the 4 year period, without significant year to year differences. Wadwatter yields also averaged 3.2 t/ha over the 4 year period, with the lowest yields being reported in 2002. This suggests wheat yields have been relatively low and stagnant for the last couple of years. In part at least, this seems to be associated with the structurally late establishment of wheat after rice in these intensive systems.

A separate survey in the area amongst ZT users reported yields to amount to 3.05 t/ha under ZT and 3.27 t/ha under conventional tillage (Tahir and Younas 2004), although not providing the statistical significance of the 6.8% decrease. The observed yield disadvantage can to some extent be explained by half the conventional tillage cases having used pre-irrigation (rauni). In fact, this irrigation practice is likely to have contributed to some of the confusion over the yield response of ZT vis-à-vis conventional tillage wheat in Pakistan. In any event, the water saving induced by ZT reported in the same study (22.5%) was such that water productivity amounted to 1.72 kg/m^3 under ZT and 1.43 kg/m^3 under conventional tillage (Tahir and Younas 2004), although again not providing the statistical significance of the 20.3% increase.

Table 47. Wheat productivity indicators by plot category (adoption survey).

	Adopters – ZT plot (n=87)	Wheat sown by conventional method: Adopters – non ZT plot (n=67)	Non-adopters (n=304)	Disadopters (n=64)	Overall (n=522)	Significance
Grain yield						
(ton / ha)	3.24	3.36	3.23	3.34	3.26 (±.71)	NS
Irrigation water productivity indicators						
ton / irrigation	1.07	1.07	1.02	1.07	1.04 (±.38)	NS
kg / m^3	1.67	1.47	1.44	1.55	1.50 (±84)	0.16
Gross water productivity (kg / m^3)	1.02	0.97	0.94	1.00	0.96 (±37)	NS

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

Table 48. Reported wheat yields (t/ha) under different tillage systems over time (adoption survey, farmer recall).

	Zero-tillage	Rauni - Conventional tillage	Wadwater - Conventional tillage	Across technologies	Significance
2003	3.24 (87) x	3.38 (72)	3.26 (379) y	3.27 (±.71, n=538)	NS
2002	3.1 (66) a,x	3.6 (31) b	3.0 (131) a,x	3.1 (±.9, n=228)	.00
2001	3.3 (37) a,x	3.9 (19) b	3.2 (75) a,xy	3.3 (±.9, n=131)	.01
2000	3.7 (18) y	3.3 (8)	3.4 (30) y	3.5 (±.9, n=56)	NS
Across years	3.2 (±.8, n=208)	3.5 (±.8, n=130)	3.2 (±.8, n=615)	3.2 (±.8, n=953)	
Significance	.09	0.12	.00		

Figures in parentheses are number of non-zero cases (n). ±: standard deviation. Data followed by a or b differ significantly – Duncan (.10), within row comparison. Data followed by x or y differ significantly – Duncan (.10), within column comparison.

5.2 Rice crop

The 528 surveyed rice plots for kharif 2003 are largely similar to the 522 wheat plots for rabi 2003-04 (see methodology).[14] Therefore, the rice plots are similarly split between having predominantly (sandy) loam and other soil types (Table 49), although other soil types are relatively more common in rice fields sown after ZT wheat and the ZT adopters' conventional plots (Table 50). Similarly, the average rice plot size was 5.6 hectares, with non-adopters having the smallest plots (4 hectares) mirroring the underlying farm size differences (Table 50).

Table 49. Soil categories of rice survey plots reported by farmers.

Soil category	% of fields (n=528)	
(Sandy) Loam soil types	*48.1%*	
Sandy loam ('medium *mera*')		32.2%
Loam ('*mera*')		15.2%
Sandy ('light *mera*')		0.8%
Other soil types	*51.9%*	
Hard/saline ('*kalrathi*')		29.0%
Clayee ('*rohi*'/'*pacci*')		8.7%
Clay		6.8%
Clayee low lying ('*chamb*')		2.8%
Mixed		4.5%

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

Land preparation & establishment

The prevailing practice is to transplant rice into puddled fields and keep the fields ponded. Land preparation for rice in sample plots is entirely mechanized using 4-wheel tractors, with no use of animal traction being reported. Land preparation practices for rice are very intensive, with an average of 9.1 tractor operations, comprising on average 0.3 disc plowings, 6.4 cultivator plowings (under dry and wet conditions) and 2.4 plankings (primarily under wet conditions - Table 51). Compared to conventional wheat (Table 40), land preparation for rice implies an extra tractor pass, uses more cultivator plowings and less disc plowings and includes tillage under wet conditions. Tillage for rice implied a per hectare use of 16 tractor hours and 67 liters of diesel (Table 52). These figures contrast with the approximately 10 tractor hours and 45 liters of diesel reported earlier for conventional wheat land preparation (Table 41).

Prior use of ZT wheat in the plot had no significant effect on the total number of operations for rice as compared to rice after conventional wheat (Table

Table 50. Selected characteristics of rice plots reported by adoption category.

Items	Rice sown after ZT wheat (n=102)	Rice sown after conventional wheat: Adopters -non ZT plot (n=71)	Rice sown after conventional wheat: Non-adopters (n=303)	Rice sown after conventional wheat: Disadopters (n=52)	Overall (n=528)	Significance
Plot size (ha)	7.85[b]	7.34[b]	4.30[a]	6.33[ab]	5.60 (±8.25)	0.00
(Sandy) Loam soil type (% reporting)[1]	41%	39%	52%	54%	48%	.10

[1] '*Mera*', includes sandy, sandy loam, loam soil types. Excludes clay, *chamb*, saline/*kalrathi*, *pacci*/hard and mixed soil types.
Data followed by different letters differ significantly – Duncan (.10), within row comparison.

Table 51. Number of rice establishment operations reported by adoption category.

Items	Rice sown after ZT wheat (n=102)	Rice sown after conventional wheat: Adopters -non ZT plot (n=71)	Rice sown after conventional wheat: Non-adopters (n=303)	Rice sown after conventional wheat: Disadopters (n=52)	Overall (n=528)	Significance
Tillage with tractor (#/season)						
Disc plowing	0.47[b]	0.38[ab]	0.19[a]	0.60[b]	0.31 (±0.83)	0.00
Dry cultivator plowing	2.83	2.44	2.68	2.38	2.65 (±1.86)	NS
Dry planking	0.16	0.14	0.31	0.21	0.25 (±0.70)	0.10
Wet cultivator plowing	3.81	3.90	3.62	3.96	3.73 (±1.24)	0.10
Wet planking	2.09	2.18	2.11	2.23	2.13 (±0.77)	NS
Total number with tractor	9.36	9.04	8.92	9.38	9.07 (±2.50)	NS

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

[14] The main exception is the rice sown after ZT wheat plot category, which now comprises 42 such plots for disadopters in addition to the 60 such plots for adopters.

53). Also, the composition of tillage operations showed no ZT induced variation (Table 53). The only significant difference was the low number of disc plowings in non-adopter plots, but this did not translate into a significant variation in total tillage operations and most likely reflects structural differences between adoption categories. There is also no significant difference in terms of total tractor hours and total diesel use between rice plots (Table 52).

The results thereby confirm that so far ZT has had no significant spillover effect in terms of affecting tillage intensity for subsequent rice crops. The results thereby refute any fear of a negative spillover in terms of tillage intensity being increased in rice to compensate for prior ZT use. At the same time, the results show no positive spillover either, whereby farmers would start to reduce the intensity of their rice land preparation.

Rice is raised in nurseries and subsequently transplanted to the main field, using 9 kg/ha of rice seed. Farmers' own seed was used on three-quarters of sample plots, while purchased seed was planted on 21% of plots. The mean transplanting date in the study area was 06 July with a standard deviation of nearly 2 weeks across plots. Transplanting is labor intensive and implies an average of 12 labor days per hectare. Rice establishment did not differ significantly across field types, except for a surprisingly lower labor use reported in ZT plots. Ownership of a tractor significantly advanced the rice transplanting date, albeit with only 2 days (05 July vs 07 July, p = 0.05).

The use of Basmati rice varieties was found to be universal in the surveyed plots. Super Basmati was the predominant variety reported in 88% of plots followed at a distance by Basmati-386 (7.2% plots - Table 53). The prevalence of Basmati varieties implies

Table 52. Duration and diesel use of mechanized rice establishment operations reported by plot category.

		Rice sown after conventional wheat				
Tillage operation	Rice sown after ZT wheat (n=102)	Adopters -non ZT plot (n=71)	Non-adopters (n=303)	Disadopters (n=52)	Overall (n=528)	Significance
Duration of tillage operations (hrs/ha)						
Plowing	13.7	12.6	12.7	13.2	12.9 (±4.5)	0.19
Planking	2.7	2.9	2.9	2.7	2.9 (±1.4)	NS
Total duration (hrs/ha)	16.5	15.5	15.6	15.9	15.8 (±5.1)	NS
Diesel consumption for tillage operations (l/ha)						
Plowing	57.7 [ab]	54.5 [ab]	53.4 [a]	58.1 [b]	54.9 (±16.5)	0.06
Planking	11.4	12.1	12.1	12.3	12.0 (±4.9)	NS
Total diesel consumption	69.0	66.7	65.5	70.4	66.8 (±19.0)	0.19

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

Table 53. Rice seed and planting practices reported by plot category.

		Rice sown after conventional wheat				
Items	Rice sown after ZT wheat (n=102)	Adopters -non ZT plot (n=71)	Non-adopters (n=303)	Disadopters (n=52)	Overall (n=528)	Significance
Transplanting date	July 6th	July 7th	July 6th	July 6th	July 6th (±14)	NS
Labor time for transplanting (days/ha)	10.7 [a]	11.7 [b]	12.2 [b]	11.7 [b]	11.8 (±2.6)	0.00
Seed rate (kg / ha)	8.96	8.86	8.75	9.00	8.83 (±2.57)	NS
Main variety (% reporting)						NS
Super basmati	92.2%	93.0%	84.8%	88.5%	87.7%	
Basmati-386	3.9%	5.6%	8.9%	5.8%	7.2%	
Basmati-2000	1.0%	1.4%	2.6%	1.9%	2.1%	
Basmati-385	1.0%	0.0%	2.0%	3.8%	1.7%	
Super Basmati plus other (Bas386, Bas2000, IR9)	2.0%	0.0%	1.6%	0.0%	1.3%	
Seed source (% reporting)						NA
Own	75.5%	78.9%	75.6%	71.2%	75.6%	
Purchased	20.6%	19.7%	21.5%	23.1%	21.2%	
Research station/institute	2.0%	1.4%	1.0%	5.8%	1.7%	
Neighbor	0.0%	0.0%	2.0%	0.0%	1.1%	
Own + purchased	2.0%	0.0%	0.0%	0.0%	0.4%	

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

limited turnaround time between the rice and wheat crop and generally delays wheat establishment as the harvesting of the relatively long duration Basmati rice varieties overlaps with optimal sowing time of wheat. Short duration Basmati rice varieties potentially allow for more timely wheat establishment. Basmati-385 is a relatively early-maturing variety, released in 1985 and which subsequently spread rapidly (Sharif et al. 1992), but its potential yield level has now deteriorated. Shaheen Basmati is another early-maturing variety but it has relatively low yield potential and hence not widely acceptable to the farmers. Super Basmati has excellent grain quality and good yield potential, explaining why it is widely accepted by the farmers. However, Super Basmati is particularly late maturing (130 days after transplanting vs 123 days for the other reported varieties) and is transplanted late, thereby vacating the field nearly two weeks later than the other varieties, and thus highly conflicting with optimum wheat sowing. ZT potentially reduces the turnaround time between rice and wheat. One might thus expect a positive association between rice varieties that vacate the field late and the use of ZT wheat. However, no significant association was found.

Nutrient management

Application of chemical fertilizers to rice plots was near universal. Urea was predominant (97% of plots), with diammonium phosphate (DAP) reported in 53% of plots and only sporadic use of other fertilizers including Single Super Phosphate, nitrophos (NP), potash and NPK. Overall, 132 kg of NPK per hectare were applied to rice, comprising 98 kg of nitrogen, 34 kg of phosphorous and only 0.3 kg of potash. Chemical fertilizer rates for rice are somewhat lower than those reported for wheat.

Total NPK application rates did not differ significantly between rice plot types. However, some variation in fertilizer types was observed over the sample rice plots and this contributed to significant differences in individual nutrient application rates (Table 54). Rice established after ZT wheat received the highest N rates and the lowest phosphorous rates, but the implications of this are not clear.

About a fifth of the sample rice plots received Farm Yard Manure (FYM) with an average quantity of 10 t/ha. Compared to wheat, FYM is markedly more widespread for rice. FYM use for rice prevailed in non-adopter and disadopter plots (Table 54). This most likely reflects structural differences between adoption categories as a similar preference was reported earlier for wheat.

Weed, pest and disease management

Eighty-five percent of the sample rice plots were weeded. Chemical weed control is the dominant method in the area (84% of plots), with only sporadic use of manual weed control (4%) being reported.

Table 54. Rice fertilization practices reported by plot category.

Items	Rice sown after ZT wheat (n=102)	Rice sown after conventional wheat: Adopters -non ZT plot (n=71)	Rice sown after conventional wheat: Non-adopters (n=303)	Rice sown after conventional wheat: Disadopters (n=52)	Overall (n=528)	Significance
Chemical nutrient application rates (kg nutrient/ha)						
Nitrogen (kg N/ha)	108[b]	100[ab]	94[a]	103[ab]	98 (±39)	0.01
Phosphorous (kg P_2O_5/ha)	25.9[a]	36.7[b]	36.8[b]	27.2[a]	33.7 (±32.4)	0.01
Potash (kg K_2O /ha)	0.85[ab]	0.00[a]	0.00[a]	1.43[b]	0.30 (±4.59)	0.10
Zinc (Kg Zn/ha)	0.26	0.0	0.06	0.0	0.09 (±0.87)	0.12
Sulphur (Kg S/ha)	0.86	0.84	0.91	0.29	0.83 (±4.71)	NS
Total nutrients (kg NPK/ha)	135	137	130	131	132 (±57)	NS
Main fertilizer types reported (% reporting)						
Urea	100.0%	94.4%	95.7%	100.0%	96.8%	0.06
DAP	37.3%	59.2%	58.1%	46.2%	53.0%	0.00
Single Super Phosphate	2.9%	4.2%	3.6%	1.9%	3.4%	NS
NP	9.8%	0.0%	1.3%	1.9%	2.8%	0.00
Potash	1.0%	0.0%	0.0%	1.9%	0.4%	0.13
NPK	1.0%	0.0%	0.0%	0.0%	0.2%	NS
Other/Zinc Sulphate	2.9%	0.0%	1.0%	0.0%	1.1%	NS
FYM use (% reporting)	13.7%	8.5%	26.7%	23.1%	21.4%	0.00
Qty. of FYM applied (ton/ha)	6.5[a]	4.5[a]	12.5[b]	13.1b	10.3 (±23.6)	0.02

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

Typically only one weed control application is applied, resulting in an overall average of 0.9 weedings per plot. Rice weeding practices thereby resemble wheat weeding practices reported earlier. Rice weeding practices did not differ significantly across field types thereby showing no spillover from ZT wheat on subsequent rice (Table 55).

Eighty-three percent of the sample rice plots received pesticide and/or fungicide application. Application was most commonly reported for rice plots sown after ZT wheat (92%) which may reflect the perceived need to control pests that might have hibernated throughout the wheat season due to non-disturbance of the soil at wheat planting time (Table 55). Effects of ZT on weed, pest and disease incidence in rice, if any, did not seem significant, and at least did not stop the ZT plots from reporting the highest rice yields (see below).

This concurs with a separate study in the area which requested ZT users for their perception of ZT wheat effects on weed, pest and disease incidence in the rice crop (Tahir and Younas 2004). This revealed that farmers concur on ZT not having any effect on diseases (96% of cases), insect population (87%) or weeds (82%).

Water management

Rice cultivation in sample plots is irrigated. Compared to the rabi season, the kharif season implies a greater contribution from rainfall and an increased reliance on canal irrigation water. Notwithstanding, tubewells are still the major source of irrigation for sample rice plots, with 45% of sample plots relying solely on tubewells as their source of irrigation and 54% of plots on combined application of canal and tubewell water. Despite the prevalence of irrigation and rains, 33% of rice fields were reported to have experienced water shortage during the season.

On average, a rice plot received 34.7 irrigations per season, comprising 29.5 tubewell irrigations and 5.2 canal irrigations. This corresponds with a total of 155 hours of irrigation per season and an estimated per hectare use of 16,000 irrigation m^3 and 19,000 gross m^3. Rice irrigation practices did not differ significantly across field types thereby showing no spillover from ZT wheat on subsequent rice (Table 56).

Harvest practices

The mean rice harvesting date was 11 November, implying a crop duration of 129 days, with no significant variation across plot types. The rice harvest date approaches the optimum wheat planting date in the area and goes a long way in explaining why wheat plots were only established on 26 November on average, implying an average turnaround time of two weeks. The mean harvesting date in Pakistan Punjab is 3 weeks later than the mean harvesting date reported in Haryana India (Erenstein et al. 2007b), the combined effect of later rice transplanting (12 days: 06 July versus 24 June in Punjab-Pakistan and Haryana-India respectively) and longer duration of the rice crop (9 days: 129 versus 120 days in Punjab-Pakistan and Haryana-India respectively).

Four-fifth of rice plots were combine harvested and the remaining fifth were harvested manually. Super basmati is typically combine harvested (81%) whereas this is less common for the other basmati varieties (55%). Non-availability of combine harvesters has been reported as a major factor undermining timely wheat planting (Tahir and Younas 2004). Combiner use was again significantly more widespread on

Table 55. Rice weed, pest and disease management practices reported by plot category.

Items	Rice sown after ZT wheat (n=102)	Rice sown after conventional wheat: Adopters -non ZT plot (n=71)	Rice sown after conventional wheat: Non-adopters (n=303)	Rice sown after conventional wheat: Disadopters (n=52)	Overall (n=528)	Significance
Use of weed control (% reporting)						
Hand weeding	3.9%	5.6%	3.6%	1.9%	3.8%	NS
Herbicide application	85.3%	78.9%	84.2%	82.7%	83.5%	NS
Hand or herbicide	86.3%	80.3%	85.1%	82.7%	84.5%	NS
Number of weed controls (# applications/season)						
Hand weeding	0.04	0.06	0.04	0.02	0.04 (±0.21)	NS
Herbicide application	0.87	0.82	0.88	0.83	0.86 (±0.43)	NS
Hand or herbicide	0.91	0.87	0.92	0.85	0.90 (±0.47)	NS
Labor use for manual weeding (man-days/ha)	0.27	0.59	0.26	0.14	0.29 (±1.56)	NS
Pesticide/fungicide use (% reporting)	92.2%	83.1%	78.5%	88.5%	82.8%	0.01

adopter and disadopters plots, approaching 90% as compared to the 75% of non-adopters reporting its use (Table 57). Manual harvesting is laborious, needing 12 labor days per hectare for harvesting alone as compared to 1.7 hours per hectare for the combine harvester. The choice of harvesting method thereby again seems associated with the underlying resource base of adopter categories.

Combine harvesting leaves both loose rice residues and anchored stubbles in the field. Rice residues provide an additional animal feed source and were

Table 56. Rice irrigation practices reported by plot category (adoption survey).

Items	Rice sown after ZT wheat (n=102)	Rice sown after conventional wheat: Adopters -non ZT plot (n=71)	Rice sown after conventional wheat: Non-adopters (n=303)	Rice sown after conventional wheat: Disadopters (n=52)	Overall (n=528)	Significance
Irrigation source (% reporting)						NS
Canal	1.0%	2.8%	1.3%	1.9%	1.5%	
Tubewell	36.3%	43.7%	48.5%	42.3%	44.9%	
Both canal and tubewell	62.7%	53.5%	50.2%	55.8%	53.6%	
Number of irrigations (#/season)						
Canal	6.0	6.1	4.6	5.4	5.2 (±6.8)	NS
Tubewell	28.0	28.2	30.3	29.2	29.5 (±12.3)	NS
Total	34.0	34.3	35.0	34.6	34.7 (±11.1)	NS
Duration of irrigations (hrs/ha)[1]						
1st canal (hrs/ha)	7.4	7.5	8.7	7.4	8.1(±4.4, n=263)	0.16
Subsequent canal (hrs/ha/irrig.)	3.8	3.4	4.0	3.2	3.8 (±2.2, n=259	0.20
Total canal (hrs/ha/season)	33.9	36.0	37.9	32.9	36.2 (±27.8, n=263)	NS
1st Tubewell (hrs/ha)	9.6	9.2	9.9	9.4	9.8 (±2.8, n=519)	0.12
Subsequent tubewell (hrs/ha/irrig.)	4.5	4.2	4.5	4.1	4.4 (±1.6, n=519)	NS
Total tubewell (hrs/ha/season)	134	127	142	129	137 (±72, n=519)	NS
Total canal + tubewell (hrs/ha/season)	157	142	159	148	155 (±74, n=499)	NS
Estimated water use (m^3/ha)						
Irrigation water [a]	16,200	15,100	16,600	15,200	16,200 (±7,700)	NS
Gross water (rain + irrigation) [b]	18,600	17,500	19,000	17,500	18,600 (±7,700)	NS
Water scarcity (% reporting)	32.4%	29.6%	33.7%	30.8%	32.6%	NS

[1] Non-zero values only.

[a] Assumes 102 m^3/hour for tubewell (i.e. 1 cusec) and 117 m^3/hour for canal (Jehangir et al. 2007).

[b] Assumes seasonal rainfall of 239 mm (2003, Jehangir et al. 2007).

Table 57. Rice harvesting practices reported by plot category.

Items	Rice sown after ZT wheat (n=102)	Rice sown after conventional wheat: Adopters -non ZT plot (n=71)	Rice sown after conventional wheat: Non-adopters (n=303)	Rice sown after conventional wheat: Disadopters (n=52)	Overall (n=528)	Significance
Harvesting date	Nov. 11th	Nov. 10th	Nov. 10th	Nov. 13th	Nov.11 (±16)	NS
Crop duration after transplanting (days)	130	128	129	132	129 (±20)	NS
Harvesting method (% report)1						
Manual	10.8%	16.9%	27.7%	11.5%	21.4%	0.00
Combine	89.2%	87.3%	74.9%	90.4%	80.9%	0.00
Area harvested by method (%)						
Manual	10.8^a	13.9^a	25.9^b	10.6^a	19.9 (±39.4)	0.00
Combine	89.2^b	86.1^b	74.1^a	89.4^b	80.1 (±39.4)	0.00
Operation time[2]						
Manual harvesting (days/ha)	13.3^b	10.8a	11.4a	13.6^b	11.6 (±2.6,n=114)	0.02
Manual threshing (days/ha)	14.8	13.1	13.9	9.9	13.7 (±4.1,n=47)	NS
Combine (hrs/ha)	1.71^{ab}	1.54^a	1.80^b	1.62^a	1.72 (±0.63,n=434)	0.02
Residue management (% reporting)[1]						
Remove[3]	84.2%	81.7%	83.0%	90.2%	83.8%	NS
Burn	67.6%	63.4%	50.2%	59.6%	56.3%	0.00
Left in field/incorporate	31.4%	32.4%	44.9%	34.6%	39.6%	0.04

[1] Column sum ≥ 100% as multiple responses possible. [2] Non-zero values only. [3] Includes cases where residues had a non-zero value.

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

(partially) removed in an estimated four-fifth of rice plots.[15] Rice residues were burned in situ in 56% of the fields whereas they were left in the field and/or incorporated in 40% of the plots. Partial application and combination of these crop residue management practices was widespread. The crop residue management of non-adopters again stood out in terms of being least reliant on burning, whereas residues were more commonly left in the field and/or incorporated. As in the case of wheat reported earlier, this likely reflects the combined effect of a lesser reliance on combine harvesting and a higher pressure on the rice residues for feed purposes.

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

The mean farmer estimated rice yield was 3.5 t/ha. Irrigation water productivity averages 112 tons of rice per irrigation, 29 kg of rice per hour of irrigation and 0.28 kg of rice per m^3. Gross water productivity amounts to 0.22 kg of 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 so as to maintain standing water in the paddies during the hot monsoon season. Rice yields on (sandy) loam soils did not differ significantly from heavier soils.

There is a significant difference in rice yields between rice plots favoring rice planted after ZT wheat (Table 58). However, these observed differences are again likely a reflection of structural differences between plots/farms between adopters and non/disadopters. There is no significant yield difference between rice plots after ZT wheat and the rice plots after conventional wheat for adopters. The differences in yield also do not translate into significant differences in water productivity indicators between plot types. These results lead us to the conclusion that so far ZT has had no significant spillover effect in terms of affecting the yield and water productivity of subsequent rice crops.

We can therefore conclude that in the case of Pakistan's Punjab, ZT had insignificant effects on yield and water productivity of both the wheat crop and the subsequent rice crop. The study thereby cannot confirm that the generally favorable implications of ZT in terms of enhancing wheat yield and saving water reported in trials are also achieved in farmers' fields. The study does confirm the drastic reduction in tractor time and diesel use in wheat land preparation and establishment, which imply substantial cost savings.

Table 58. Rice productivity indicators by plot category.

	Rice sown after ZT wheat (n=102)	Rice sown after conventional wheat: Adopters -non ZT plot (n=71)	Rice sown after conventional wheat: Non-adopters (n=303)	Rice sown after conventional wheat: Disadopters (n=52)	Overall (n=528)	Significance
Grain yield (ton / ha)	3.67^{b}	3.59^{ab}	3.47^{a}	3.46^{a}	3.52 (±.37)	0.08
Irrigation water productivity indicators						
kg / irrigation	121	113	109	113	112 (±.37)	0.16
kg / m^3	0.29	0.32	0.26	0.28	0.28 (±.19)	0.16
Gross water productivity (kg / m^3)	0.24	0.24	0.21	0.23	0.22 (±.12)	0.14

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

[15] Originally directly reported rice residue removal rates were lower. However, these often did not match the significant value attributed to the rice residues by the farmer. This revised estimate also considers rice residue to be (partially) removed whenever residues reportedly had a non-zero value.

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. 2002; Malik et al. 2005a). But in those where such analysis was included, results are generally very favorable for ZT due to the combined 'yield-enhancement effect' and 'cost-saving effect' (e.g. Laxmi et al. 2007; Malik et al. 2005a). Most financial analyses are based on partial budgets, and typically limited to the wheat crop.

The previous chapter reviewed the technical impact of ZT in terms of crop management and productivity for both the wheat crop and the subsequent rice crop. The present chapter puts a monetary value on the observed changes and thereby allows us to aggregate the observed technical impacts and assess the financial impact of ZT at the individual crop and the plot level. The first section of this chapter will review the ZT effects on the wheat crop budget. The second section reviews the carry-over 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. Revenue from the wheat grain is estimated as the product of the farmer reported wheat yield and the prevailing wheat price at the time (PKR 9 per kg), averaging PKR 29,400 per hectare. Wheat straw ('*bhusa*') is an important livestock feed in the study area. During the adoption survey farmers were requested to estimate the value of the wheat straw/residue per area basis, averaging PKR 4,100 per hectare. The gross revenue from wheat grain plus straw thus averages PKR 33,500 per hectare. Wheat straw thereby contributes a significant 12.2%. There is no significant variation in gross revenue indicators in relation to the use of ZT (Table 59 – section A).

6.1.2 Production costs

Total wheat production costs average PKR 27,300 per hectare and include the variable costs, land and 9% interest. 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 the 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 village survey revealed the average seasonal cost of land to be PKR 10,500 per hectare, making it the single most important production cost and 38.5% of the average production costs. After land, the three most important cost factors are harvesting expenditures (16.1%), fertilizer cost (15.6%) and land preparation & crop establishment (14.8%). Other costs include irrigation cost (4.5%), plant protection (including weeding, 2.2%) and interest on capital (8.3%).

The production costs in ZT plots are significantly lower than in conventional plots (Table 59 – section B). Two factors are at play. First, adopters have inherently lower production costs than non-adopters and disadopters (PKR 27,900 per hectare), irrespective of whether they use ZT. This largely reflects their crop management practices and higher efficiency. Second, adopters achieve significantly lower production costs in their ZT plots (PKR 24,600 per hectare) as compared to their conventional plots (PKR 27,200 per hectare). The ZT induced savings are primarily a reflection of the approximate halving of land preparation and crop establishment costs, being PKR 4,200-4,600 per hectare for conventional tillage and only PKR 2,500 for ZT. Compared to the conventional plots of adopters, ZT represents a significant cost saving of 9.5% on total costs, or 16.4% on operational costs (excluding land).

6.1.3 Performance indicators

The net revenue (or gross margin) of wheat production averages PKR 6,200 per hectare with a standard deviation of PKR 6,600 per ha. The average net revenue thereby highlights that average gross revenue (PKR 33,500 per hectare) easily surpasses average total costs (PKR 27,300 per hectare), implying an average return of 23% to production costs. However, only 81% of wheat plots had a positive net revenue (i.e. 19% were below breakeven). Production costs thereby amount to PKR 8.8 per kg wheat grain on average, close to the prevailing market rate and highlighting the importance of the additional revenue from wheat straw as byproduct.

Some 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 76% 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 nearly a fifth of the households would have been better off renting out their land and using their resources for other more remunerative activities.

The net revenue from ZT plots (PKR 8,700) is significantly higher than that achieved in conventional plots of non-adopters and disadopters (PKR 5,300-6,000), but not statistically superior to the conventional plots of adopters (PKR 7,200, Table 59 – section C). In view of other than purely ZT related differences between the types of wheat plots, the most objective comparison is between the ZT and conventional plots of adopters. Although often not significantly different in our sample, these consistently suggest ZT indicators to be typically superior to conventional till. ZT does imply a significant cost saving effect of PKR 2,600 in adopters' fields, but this is partially annulled by a non-significant negative yield effect of PKR 1,100 in the same, resulting in a non-significant advantage of PKR 1,500 for ZT in terms of net revenue. The ZT plots of adopters do achieve a significantly higher return on production costs (a respectable 37%) than conventional tillage (27%). Production costs, though lowest for ZT plots (PKR 8.1 per kg), are again not significantly different from adopters' conventional plots.

The survey results clearly challenge the traditional farmer view that frequent tillage is necessary for a successful wheat crop. However, in the absence of a significant positive 'yield effect,' profitability of

Table 59. Crop budget (000 PKR/ha) for wheat crop by plot category.

Items	Adopters – ZT plot (n=87)	Wheat sown by conventional method			Overall (n=522)	Significance
		Adopters–non ZT plot (n=67)	Non-adopters (n=304)	Disadopters (n=64)		
A. Gross value of output	33.3	34.4	33.2	33.9	33.5 (±6.8)	NS
Grain	29.2	30.3	29.1	30.1	29.4	NS
Straw	4.1	4.2	4.1	3.8	4.1	NS
B. Total cost	24.6[a]	27.2[b]	27.9[c]	27.9[c]	27.3 (±2.6)	*0.00*
B1. Land preparation	0.0	2.8	3.0	3.2	2.5	0.00
Plowing	0.0	2.3	2.5	2.7	2.1	0.00
Planking	0.0	0.5	0.5	0.5	0.4	0.00
B2. Crop establishment	2.5	1.4	1.3	1.4	1.5	0.00
Seed drill	1.0	0.0	0.0	0.0	0.2	0.00
Labor for planting	0.2	0.2	0.2	0.2	0.2	0.00
Seed for planting	1.2	1.2	1.2	1.2	1.2	0.08
Subtotal B1+B2	2.5[a]	4.2[b]	4.3[b]	4.6[c]	4.0 (±1.1)	*0.00*
B3. Fertilizer cost	4.2	4.3	4.3	4.5	4.3	NS
B4. Plant protection cost	0.6	0.6	0.6	0.8	0.6	0.01
B5. Irrigation cost	1.1	1.2	1.3	1.2	1.2	NS
B6. Harvesting expenditures	3.7	4.2	4.7	4.1	4.4	0.00
B7. Land rent	10.5	10.5	10.5	10.5	10.5	NA
B8. Interest on capital invested	2.0	2.2	2.3	2.3	2.3	0.00
C. Net revenue [A-B]	*8.7[c]*	*7.2b[c]*	*5.3[a]*	*6.0[ab]*	*6.2 (±6.6)*	*0.00*
% plots with positive NR	85%	84%	80%	81%	81%	NS
Benefit:cost ratio [A/B]	1.37[c]	1.27[b]	1.19[a]	1.22[ab]	1.23 (±0.26)	0.00
Production cost (PKR/kg)	8.1[a]	8.5[ab]	9.0[c]	8.7[bc]	8.8 (±2.1)	0.00

Data followed by different letters differ significantly – Duncan (.10), within row comparison. Only included for line item totals (A,B,B1+B2, C) and A sub items.

adoption hinges on a significant 'cost saving effect.' This latter effect seems robust enough to make adoption worthwhile and is the driving force behind the prior spread and acceptance of ZT in Pakistan Punjab, despite the initial and sometimes strong opposition amongst farmers and extension. However, these returns imply that particularly the first year of adoption will prove critical in terms of the adoption or disadoption decision. In the absence of a positive yield effect, the learning costs eat into the cost saving effect and may undermine the apparent returns to adoption.

Table 60 provides financial water productivity indicators for wheat. It presents two sets of indicators, one based on net revenue and one based on gross revenue. Net revenue based water productivity indicators average PKR 2,660 per irrigation, PKR 4.0 per irrigation m^3 and PKR 2.5 per gross m^3. Gross revenue 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 cost and water input differentials.

The net revenue based water productivity indicators for ZT are always significantly higher than for conventional, irrespective of the type of conventional plot. The gross revenue indicators suggest ZT to be superior, but the observed differences are not statistically significant.

6.2 Rice profitability

6.2.1 Revenue

The gross revenue from rice cultivation averages PKR 46,300 per hectare, comprising the value of the rice and the value of the residues/straw. Revenue from the rice is estimated as the product of the farmer reported rice yield and the prevailing market price (PKR 10-12.5 per kg depending on variety). During the adoption survey, farmers were requested to estimate the value of the rice straw/residue per area basis, averaging PKR 2,600 per hectare. Though lower than wheat straw, the rice straw still contributes 5.7% to the gross revenue,

Although there is an observed significant plot effect on gross revenue and underlying grain and straw value, this does not seem to be specifically ZT related but more to underlying management differences between adopter types (Table 61 – section A). Indeed, the differences between the ZT plots and conventional plots of adopters are relatively small and statistically not significant.

6.2.2 Production costs

Total rice production costs average PKR 32,400 per hectare and include the variable costs, land and 9% interest. 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 again PKR 10,500 per hectare, making it the single most important production cost by far (32.4%). After land, the cost factors include irrigation (21.5%), land preparation and crop establishment (15.7%), fertilizer (9.9%), harvesting expenditures (8.3%), plant protection (including weeding, 4.0%), and interest on capital (8.3%).

ZT wheat does not significantly affect production costs of the subsequent rice crop (Table 61 – section B), with similar total costs for rice after ZT and rice after conventional wheat.

Table 60. Financial water productivity indicators for wheat by plot category.

Items	Adopters – ZT plot (n=87)	Wheat sown by conventional method: Adopters -non ZT plot (n=67)	Non-adopters (n=304)	Disadopters (n=64)	Overall (n=522)	Significance
Net revenue based water productivity indicators						
PKR / irrigation	3,380[b]	2,960[ab]	2,370[a]	2,730[a]	2,660 (±2290)	0.00
PKR / irrigation m^3	5.6[b]	4.2[a]	3.4[a]	4.1[a]	4.0 (±4.0)	0.00
PKR / gross m^3 (rain + irrigation)	3.4[b]	2.8[a]	2.2[a]	2.6[a]	2.5 (±2.3)	0.00
Gross revenue based water productivity indicators						
PKR / irrigation	11,000	11,000	10,500	10,900	10,700 (±3900)	NS
PKR / irrigation m^3	17.2	15.2	14.8	15.7	15.4 (±8.6)	0.14
PKR / gross m^3 (rain + irrigation)	10.5	10.0	9.6	10.2	9.9 (±3.7)	NS

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

6.2.3 Performance indicators

The net revenue (or gross margin) of rice production averages PKR 13,900 per hectare, with a standard deviation of PKR 11,000 per hectare. On average, gross revenue (PKR 46,300 per hectare) easily surpasses average total costs (PKR 32,400 per hectare), implying an average return of 46% to production costs. Most of the rice plots (91%) had a positive net revenue (i.e. 9% were below breakeven). Production costs amount to PKR 9.6 per kg rice grain on average.

ZT wheat again did not significantly affect net revenue of the subsequent rice crop (Table 61 – section C), particularly when we contrast rice after ZT and rice after conventional wheat in adopters' plots. We may therefore conclude that ZT wheat does not significantly affect gross revenue, production cost and net revenue of the subsequent rice crop.

Table 62 provides financial water productivity indicators for rice, based on net revenue and gross revenue. Net revenue based water productivity indicators average only PKR 535 per irrigation, PKR 1.4 per irrigation m^3 and PKR 1.1 per gross m^3. Therefore compared to wheat, the higher net revenues for rice are more than annulled by the higher water inputs. The significant plot effect for net revenue income based water productivity indicators does not

Table 61. Crop budget (000 PKR./hectare) for rice crop by plot category.

Items	Rice sown after ZT wheat (n=102)	Rice sown after conventional wheat: Adopters-non ZT plot (n=71)	Non-adopters (n=303)	Disadopters (n=52)	Overall (n=528)	Significance
A. Gross value of output	48.1^{b}	47.6^{ab}	45.6^{ab}	45.3^{a}	46.3 (±9.8)	*0.08*
Grain	45.6^{b}	44.9^{ab}	42.8^{a}	42.9^{a}	43.7	0.05
Straw	2.5^{a}	2.6^{ab}	2.7^{b}	2.5^{a}	2.6	0.01
B. Total cost	32.3	31.8	32.7	31.9	32.4 (±5.4)	*NS*
B1. Land preparation	3.9	3.8	3.7	3.9	3.8	*NS*
Plowing	3.3	3.2	3.1	3.3	3.2	0.07
Planking	0.6	0.6	0.6	0.6	0.6	0.20
B2. Crop establishment	1.2	1.3	1.3	1.3	1.3	0.00
Seed drill	0.0	0.0	0.0	0.0	0.0	NA
Labor for planting	1.1	1.2	1.2	1.2	1.2	0.00
Seed for planting	0.1	0.1	0.1	0.1	0.1	NS
Subtotal B1+B2	5.1	5.1	5.1	5.2	5.1 (±1.1)	*NS*
B3. Fertilizer cost	3.1	3.2	3.3	3.1	3.2	NS
B4. Plant protection cost	1.4	1.3	1.3	1.3	1.3	NS
B5. Irrigation cost	6.9	6.4	7.2	6.5	7.0	NS
B6. Harvesting expenditures	2.7	2.6	2.7	2.7	2.7	NS
B7. Land rent	10.5	10.5	10.5	10.5	10.5	NA
B8. Interest on capital invested	2.7	2.6	2.7	2.6	2.7	NS
C. Net revenue [A-B]	*15.8*	*15.8*	*12.9*	*13.4*	*13.9 (±11.0)*	*0.05*
% plots with positive NR	95%	94%	89%	89%	91%	*0.19*
Benefit:cost ratio [A/B]	1.52^{b}	1.54^{ab}	1.43^{a}	1.46^{ab}	1.46 (±0.40)	*0.06*
Production cost (PKR/kg)	9.2	9.2	9.9	9.5	9.6 (±2.5)	*0.05*

Data followed by different letters differ significantly – Duncan (.10), within row comparison. Only included for line item totals (A,B,B1+B2, C) and A sub items.

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

Items	Rice sown after ZT wheat (n=102)	Rice sown after conventional wheat: Adopters'–non ZT plot (n=71)	Non-adopters (n=303)	Disadopters (n=52)	Overall (n=528)	Significance
Net revenue based water productivity indicators						
PKR / irrigation	614	592	493	544	535 (±444)	0.07
PKR / irrigation m^3	1.6^{ab}	1.9^{b}	1.3^{a}	1.5^{ab}	1.4 (±1.7)	0.05
PKR / gross m^3 (rain + irrigation)	1.3^{ab}	1.4^{b}	1.0^{a}	1.2^{ab}	1.1 (±1.1)	0.05
Gross revenue based water productivity indicators						
PKR / irrigation	1,580	1,510	1,430	1,480	1,480 (±580)	0.16
PKR / irrigation m^3	3.8	4.3	3.5	3.7	3.7 (±2.6)	0.12
PKR / gross m^3 (rain + irrigation)	3.1	3.3	2.8	3.0	3.0 (±1.5)	0.10

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

seem associated with ZT, as indicators for rice on ZT plots take intermediary values that are not statistically different from the other plot types. Gross revenue water productivity indicators show no significant plot effects, and again no association with ZT.

6.3 Rice-wheat system profitability

The current section presents the aggregate implications of ZT on system profitability—i.e. the 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 differ somewhat from those reported earlier based on all plot observations.

The aggregate gross revenue for rice-wheat cultivation averages PKR 79,600 per hectare against an aggregate total production costs of PKR 59,900 per hectare, giving an aggregate net revenue of PKR 19,700 per hectare. On average, rice contributes over half of the aggregate gross revenue (58%) and costs (54%), but approximately two-thirds of the net revenue (69%). Overall, the return to rice-wheat cultivation amounts to 34%.

The aggregate plots show some significant variations in performance indicators over plots related to the use of ZT in 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 64). The aggregate total costs are significantly lower for the ZT plots, primarily reflecting the significant savings for the wheat crop. The significant differences between plots in terms of net revenues are primarily driven by the significant variation in wheat net revenues. ZT plots thereby tend to outperform conventional plots of non-adopters and disadopters, both in terms of net revenue and benefit/cost ratio. However, compared to the conventional plots of adopters the more favorable net revenue and benefit/cost ratio are not statistically significant.

Table 63. System-level profitability indicators (000 PKR/ha/year) by plot category (rice + wheat, aggregation before averaging).

		Conventional rice-wheat				
	Adopters – ZT plot (n=59)	Adopters – non ZT plot (n=57)	Non-adopters (n=302)	Disadopters (n=56)	Overall (n=474)	Significance
Gross revenue ('000 PKR/ha):	81.0	82.7	78.8	79.3	79.6 (±13.6)	NS
Rice crop	47.6	47.7	45.6	45.8	46.1 (±9.9)	NS
Wheat crop	33.4	34.9	33.2	33.5	33.5 (±6.8)	NS
Total costs ('000 PKR/ha):	56.8^{a}	59.4^{b}	60.6^{b}	60.0^{b}	59.9 (±6.5)	.00
Rice crop	32.4	32.2	32.7	32.1	32.5 (±5.4)	NS
Wheat crop	24.4^{a}	27.3^{b}	27.9^{b}	27.9^{b}	27.4 (±2.6)	.00
Net revenue ('000 PKR/ha):	24.2^{c}	23.2^{bc}	18.2^{a}	19.3^{ab}	19.7 (±14.4)	.01
Rice crop	15.2	15.6	12.9	13.7	13.6 (±11.1)	NS
Wheat crop	9.0^{b}	7.7^{b}	5.3^{a}	5.6^{a}	6.1 (±6.6)	.00
Benefit/cost ratio	1.44^{c}	1.40^{bc}	1.31^{a}	1.34^{ab}	1.34 (±0.26)	.00

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

Table 64. System-level financial water productivity indicators by plot category (rice + wheat, aggregation before averaging).

		Conventional rice-wheat				
	Adopters – ZT plot (n=59)	Adopters–non ZT plot (n=57)	Non-adopters (n=304)	Disadopters (n=56)	Overall (n=476)	Significance
Net revenue based water productivity indicators						
PKR / irrigation	727^{b}	659^{ab}	523^{a}	595^{ab}	574 (±483)	.01
PKR / irrigation m^3	1.7^{b}	1.9^{b}	1.2^{a}	1.4^{ab}	1.4 (±1.5)	.01
PKR / gross m^3 (rain + irr)	1.3^{b}	1.4^{b}	1.0^{a}	1.1^{ab}	1.1 (±1.0)	.01
Gross revenue based water productivity indicators						
PKR / irrigation	2,430	2,300	2,220	2,280	2,270 (±770)	NS
PKR / irrigation m^3	5.2	5.9	4.9	5.2	5.1 (±2.9)	.13
PKR / gross m^3 (rain + irr)	4.1	4.5	3.9	4.1	4.0 (±1.7)	.13

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

Table 64 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. In view of the higher water inputs into rice, the aggregate water productivity indicators fall in the lower end of the range. Net revenue based water productivity indicators average PKR 574 per irrigation, PKR 1.4 per irrigation m^3 water and PKR 1.1 per gross m^3. All net revenue water productivity indicators show a largely similar pattern whereby the ZT and conventional plots of adopters tend to outperform non-adopters and disadopters, but do not differ significantly from each other. Gross revenue water-productivity indicators show a non-significant but largely similar pattern, which in turn largely parallels the variations in gross revenue based water productivity for the rice crop alone discussed earlier, reflecting the significantly larger water input into the rice crop.

We can therefore conclude that the aggregate system performance primarily mirrors the ZT effects on wheat performance. It thereby highlights no significant positive or negative carry-over 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 we would need to alter the way that rice is grown, by doing dry direct seeded rice and start retaining crop residues as mulch. As long as the rice crop remains puddled, the ZT gains for wheat remain purely seasonal, with no cumulative gains in terms of enhanced soil productivity and water productivity at the cropping system level.

7 Farm and regional impacts of zero-tillage

The impact of the ZT technology so far was assessed in technical and financial terms at the plot level. The present section looks and discusses some of the higher system-level implications. At a first level we assess the farm-level implications of ZT for the adopting farms. At a second level we assess the regional implications of ZT, including social and environmental considerations.

7.1 Farm-level impacts

To dwell on the farm-level impact a number of additional queries were posed to ZT adopters and disadopters.[16] Adopter and disadopter respondents were near unanimous that they spend less time cultivating wheat after ZT adoption. The time saved in wheat cultivation was primarily used for other agricultural activities (60% of those reporting) and more leisure time (44% - Table 65). A small minority of adopters (16% of those responding) were of the opinion that the adoption of ZT wheat subsequently reduced the time for cultivating rice.

Adopters and disadopters differed significantly in terms of whether ZT had increased the family's income. Whereas most of the adopters reported an increase (79% of those responding), this was only half for the disadopters (Table 65). Adopters and disadopters also differed in terms of whether the adoption of ZT increased the family's food consumption, with nearly half of the adopters reporting an increase as against a quarter of the disadopters. As there was no significant yield increase linked to the adoption of ZT, this may reflect the cost savings induced by ZT and correspondingly higher disposable income being used to enhance family food consumption.

Adopters and disadopters were also requested to enlist the main changes that ZT had brought to their farming activities and family. The array of open responses was subsequently categorized and is presented in Table 66. In terms of changes in farming activities, the responses primarily reflect productivity effects of ZT proper, with most farmers reporting time savings and to a lesser extent (and in decreasing order) costs savings, production increases, water savings, more time to finish farming, concentration on other farming activities and labor savings. There were relatively few responses in relation to changes to the family. The two most prominent responses revolved around income increase and educational expenditures, and to a lesser extent (and in decreasing order) to less expenditure, less labor required, clothing and more time to family members. It is interesting to note that adopters and disadopters largely concurred in terms of these farm and family

Table 65. Selected impact indicators of adoption of zero-tillage technology reported by plot category (adopters and disadopters only).

	Adopters	Disadopters	Sample mean	Significance
Farmer spends less time cultivating wheat after adoption ZT (% reporting)	100%	87%	95% (n=69+45 =114)	NA
Reported use of wheat cultivation time saved (% of those reporting savings)			(n=69+39=108)	
Other agricultural activities	62%	56%	60%	NS
More leisure time	48%	39%	44%	NS
Other non-agricultural activities	9%	5%	7%	NS
Other	6%	5%	6%	NR
Farmer spends less time cultivating rice after adoption ZT (% reporting)	16%	3%	10% (n=38+30=68)	NA
Family's income has increased after adoption ZT (% reporting)	79%	49%	67% (n=56+33=89)	.00
Family's food consumption has increased after adoption ZT (% reporting)	45%	27%	38% (n=56+33=89)	.10

16 Two issues should be noted. First, the responses only reflect a subset of the sample (153 households, comprising 89 adopters and 64 disadopters). Second, there are an increasing number of missing responses. Care should therefore be taken in interpreting the shares presented in the text and tables.

changes. This reiterates that in Punjab-Pakistan ZT disadoption reflects a complex group of factors. For some disadopters, the yield considerations reported earlier were more important than time and cost-savings considerations. Other disadopters may have had such favorable perceptions, but were unable to act upon them in view of problematic access to the ZT drill in the survey year.

The companion study to this one did provide some support to the postulated water saving nature of ZT wheat at the field scale (Erenstein et al. 2007b). The water-use survey in Haryana-India in particular showed that ZT for 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 kilograms per hectare). The absence of any reported significant change in farm activities or area cultivated in Punjab-Pakistan suggests that water savings, if any, did generally not lead to an immediate alternative use of the water saved on the farm. A different 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). Our study found some rabi fallow (18% of households reported some rabi fallow, averaging 0.35 hectare per household) and this was found to be positively associated with ZT adoption. Part of the incentive to adopt ZT may thus have been the potential of ZT to increase the area cultivated in rabi—although we cannot unambiguously make this assertion based on the available data. In any case, the eventual increase in area due to ZT may still be

Table 66. 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=63)	(n=30)	(n=93)
Time saving	48	47	47
Cost saving	33	23	30
Production increase	27	23	26
Water saving	18	20	18
More time to finish farming	13	17	14
Concentration on other farming activities	16	10	14
Labor saving	13	7	11
Reported changes to family (% reporting)	(n=38)	(n=15)	(n=53)
Income increase	37	33	36
Educational expenditure	29	13	25
Less expenditure	13	13	13
Less labor required	8	20	11
Clothing	11	13	11
More time to family members	11	7	9

limited by the overall limited fallow area (with on average 97% of the operational area already being cultivated during rabi season).

The present study has highlighted that adopters typically have a more favorable resource base and tend to variously outperform non-adopters and disadopters. However, for most indicators ZT and conventional plots of adopters do not differ significantly from each other in our sample, although with the exception of yield, they consistently suggest ZT indicators to be typically superior to conventional tillage. The present section will therefore limit itself to scaling up of the significant effects only, which basically leaves the ZT induced savings in diesel use, tractor time and production cost in wheat cultivation.

With an average ZT wheat area of 8.3 hectares per household, ZT adopters save an average of 288 liters of diesel, 57 tractor hours and PKR 21,500 per season. Most ZT adopting households have postponed the investment decision to buy a ZT drill, with the majority of adopters (74%) 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. Particularly in Punjab-Pakistan the lack or untimely availability of drills and the high drill cost have been raised as issues limiting ZT diffusion (Jehangir et al. 2007; Tahir and Younas 2004). To put the investment in a ZT drill in perspective, we have estimated the ZT drill investment recovery indicator—the number of wheat seasons needed to recap the investment. With an average ZTD cost of PKR 32,200 and some simplifying assumptions (e.g. no interest, no renting out), the cost saving alone implies the ZTD would be recovered within 1.5 wheat seasons. ZT adopters have an additional conventional tillage wheat area of 5.8 hectares per household.[17] In case they would extend ZT to the entire wheat area, ZT adopters would potentially save an average of 490 liters of diesel, 98 tractor hours and PKR 36,600 per season and recover a ZTD investment within 0.9 wheat seasons. 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 already owning a tractor.

ZT adopters have the largest farms and wheat areas and therefore potentially benefit most on aggregate household basis from a cost-saving technology

[17] Partial and full ZT adopters combined (n=87). Partial adopters have an average CT plot size of 7.54 hectares (n=67).

such as ZT. The disadopter households with an average of 7.2 hectares of wheat could conceivably save PKR 18,600 per season and recover a ZTD investment within 1.7 wheat seasons. The non-adopter households with only 4.1 hectares of wheat could conceivably save PKR 10,600 per season and recover a ZTD investment within 3.1 wheat seasons. Tractor ownership is also least common amongst non-adopters (37%). This highlights that the investment in a ZT drill is typically less attractive for the disadopters and particularly for non-adopters as compared to adopters, although this may change if they could benefit from providing significant ZT drill rental services.

The diesel and tractor time saving are major contributors to the cost savings induced by ZT and applies to tractor-owning and tractor-hiring households alike. Indeed, the tractor time saving is beneficial to tractor-owning households through both extended tractor life time and alternative use, as tractors are variously used and in much demand. The alternative tractor uses are particularly important for the income security of tractor service providers, as an eventual increase in income from ZT services is likely offset by a more than proportional 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 farm 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 combine harvesting, residue collection and residue burning practices for the preceding rice crop, with generally still limited consideration for the retention of crop residues as mulch—a necessary component of conservation agriculture. Labor savings induced by ZT are relatively minor in view of the prevailing mechanization levels and crop management practices.

With rice still being cultivated in the traditional way in the subsequent season, ZT induced enhancement of land quality is relatively short-lived. Farm-level impact of ZT thereby primarily reflects immediate effects on the wheat crop budget through costs savings. A separate study in the area requested ZT users for their perception of ZT effects on soil quality (Tahir and Younas 2004). This revealed that farmers generally perceive ZT to have either no effect or a favorable effect, including enhanced soil fertility (24% of cases), decreased soil salinity (15%), decreased soil sodicity (38%) and decreased water logging (25%). Farmers were unanimous in that ZT decreased soil erosion. However, 73% perceived ZT to increase soil compactness.

7.2 Regional-level impacts

According to expert estimates about 0.3 million hectares of wheat was planted by ZT drill during 2003-04 (RWC 2004). Extrapolating our plot-level findings to this area, ZT implied a saving of 10.4 million liters of diesel, 2.1 million tractor hours and PKR 780 million per season. If we assume that ZT can be extended to a third of the total rice-wheat area in Pakistan of 2.2 million hectares, these aggregate savings would be increased with a factor 2.4. However, the study flags the significant ZT disadoption in the study area, which thereby questions the extent to which these savings will be actually realized.

Water is a major concern for the sustainability of intensive cropping systems in Punjab-Pakistan and for the Pakistan economy as a whole. Perhaps somewhat disappointingly, the adoption survey could not unambiguously verify that ZT generated significant water savings. In part, this is likely due to measurement error in view of our survey estimates. Nonetheless, the farmer responses imply there is some water saving, but maybe less significant than often suggested. Only in the companion study in Haryana-India did the water- use survey verify that ZT generated significant water savings in wheat fields (Erenstein et al. 2007b).

The available studies concur that resource-conservation technologies (RCTs) like ZT can be successful in improving field scale irrigation efficiency through irrigation savings (Ahmad et al. 2007; Gupta et al. 2002; Humphreys et al. 2005; Jehangir et al. 2007). However, as highlighted by Ahmad et al. (2007:1), "whether or not improved irrigation efficiency translates to 'real' water savings depends on the hydrologic interactions between the field and farm, the irrigation system and the entire river basin. In fact, the water saving impacts of RCTs beyond the field level are not well understood and documented." For instance, some of the irrigation water 'saved' would 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).

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

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

The study does flag some equity concerns. Pakistan Punjab has a skewed land distribution and the survey reveals that ZT uptake and the corresponding benefits are positively associated with farm size. Although in principle accessible to smallholders through service providers, various constraints have limited its uptake amongst smallholders. In the present context, ZT wheat is basically tractor and cost saving and therefore has relatively limited implications for labor use. Consequently, whereas ZT by necessity has bypassed landless people, it also seems to have had limited negative impact on them through labor displacement. Clearly, monitoring and better understanding the equity implications of extending ZT and RCTs to the rice component of the rice-wheat system is imperative.

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

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

From a national perspective, the rice-wheat belt is of extreme importance, with rice being a major export crop, wheat being a national food security concern, and wheat also being the main staple food of Pakistani population. Options to enhance national wheat production through increasing area are severely limited, thereby making it imperative to enhance wheat competitiveness in this belt. Wheat competitiveness could benefit from varietal renewal (e.g., more diverse and stem rust resistant wheat varieties; non-puddled rice varieties), other resource-conserving technologies (e.g., for rice; laser leveling) and diversification of rice-wheat systems. Furthermore, the advent of the virulent new stem rust for wheat (Ug99, Mackenzie 2007; Raloff 2005) and global warming (Ortiz et al. 2006) could have far-reaching consequences across the IGP. Late establishment of wheat is a structural problem in these systems and ZT has the potential to alleviate this. The present study did find significant cost savings, but did not find any significant ZT induced yield effect, which is largely a reflection of the lack of a ZT induced planting date effect. More emphasis should be placed on highlighting the enhanced timeliness aspect of ZT—which would further boost the returns to adopting ZT and alleviate yield concerns. In the end, the sheer size of the rice-wheat system implies even small gains add up to a significant regional impact.

8 Conclusions and recommendations

The study confirmed significant adoption of ZT wheat (19%) in the rice-wheat systems of Pakistan's Punjab province. Driving adoption are the significant ZT induced cost savings for wheat cultivation. Thus, the major driving force for ZT adoption is monetary gain, not water savings or natural resource conservation. Water savings are only a potential added benefit.

ZT adoption for wheat accelerated from insignificant levels from 2000 onwards. Geographic penetration of ZT is far from uniform, suggesting the potential for further diffusion. However, diffusion seems to have stagnated in the study area, and further follow-up studies are needed to confirm this. The study also revealed significant disadoption in the survey year (14%). Better understanding the rationale for disadoption merits further scrutiny. Our findings suggest that there is no clear single overarching constraint, but a combination of factors is at play, including technology performance, technology access, seasonal constraints and the institutional ZT controversy. In terms of technology performance the relative ZT yield was particularly influential: disadopters reporting low ZT yields as a major contributor to farmer disillusionment. For the survey as a whole there was no significant effect of ZT on wheat yield. The ZT induced time savings in land preparation did not translate into timelier establishment, contributing to the general lack of a yield increase.

The present study could not confirm a significant water saving effect of ZT, only that ZT saved diesel and tractor time. ZT induced effects primarily apply to the wheat crop establishment and production costs, with limited implications for the overall wheat crop management, the subsequent rice crop and the rice-wheat system as a whole.

The study highlights that ZT has been primarily adopted by the larger and more productive farmers. The structural differences between the adopters and non-adopters/-disadopters in terms of resource base, crop management and performance, thereby easily confound the assessment of ZT impact across adoption categories. This calls for the comparison of the ZT plots and conventional plots on adopter farms. Whether this introduces new biases merits further scrutiny. For most indicators, ZT and conventional plots of adopters do not differ significantly from each other in our sample, although they consistently suggest ZT indicators to be typically superior to conventional tillage. In the end, ZT so far is primarily a cost-saving technology.

Recommendations

There is a need to more emphatically stress timeliness of wheat establishment. Late establishment is a major contributor to low wheat productivity. ZT has the potential to significantly alleviate untimeliness, but in practice this did not materialize—thereby foregoing a potential benefit.

There is a need to enhance farmers' access to reliable ZT drills, particularly to smallholders. The majority of ZT adopters (74%) so far are large farmers that relied on contracted ZT drill services. Such services have much merit, but only when they are timely, reliable, knowledgeable and widely accessible. Much of the potential benefits from ZT are easily thwarted by a late or uncertain arrival of the ZTD or its improper use—calling for well-trained operators and properly maintained ZT drills.

There is the need to address some of the operational problems of the ZTD such as the raking of loose residues during drilling, clogging of pipes and breakage of tines. There is some scope for improvements in both the operation/handling of the drills and in their design and quality.

There is a need to enhance the accessibility of ZT knowledge. There is an important role here for agricultural extension. ZT must be duly projected as one option in the wheat planting campaign run through mass media (radio, TV and printed material) by the department of agricultural extension. There is also particular scope for more field days, farmer exchanges, farmer to farmer extension and a more participatory and farmer field school approach.

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

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 being applied to the wheat crop only. The environmental and soil implications of ZT wheat for the rice-wheat system as a whole remain short-lived as long as the subsequent rice crop remains intensively tilled and puddled. ZT can be a stepping stone to conservation agriculture—but this implies changes to the way rice is grown, and managing crop residues so as to maintain some soil cover and enhance crop rotation. This calls for changes in the prevailing ZT equipment design to enable sowing with residue retention. Some "second generation ZT drills" have recently been developed in the IGP and these merit further testing and adaptation with concerned stakeholders. It also calls for research on how much residue is needed, particularly in view of the prevailing alternative use of crop residues as basal animal feed (Erenstein et al. 2007d).

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

There is scope for combining qualitative and quantitative approaches in impact assessment. The 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 will be useful and should enhance the relevance and equity of research and development interventions.

Finally, a more objective approach to ZT is needed in Pakistan. The advent of ZT in Pakistan Punjab has been severely hampered by the polarization of the field in terms of ZT advocates and ZT opponents, with farmers facing conflicting information and lack of institutional support. The ZT controversy and institutional rivalry has proven counterproductive and has wasted scarce resources. It is advisable that both camps come to a neutral and modest middle ground. ZT is neither a silver bullet nor a Pandora's Box. It is just a valuable technological option that can save scarce farmer resources.

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

- More rigorous documentation of the water savings from 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 imponderables. For instance, the site-specific circumstances disadopters faced in terms of their access to drill, the quality of the drill, timeliness, quality of soil, the skill of the operator, etc. Participatory approaches could provide useful complementary information.
- A better understanding of partial ZT adoption—particularly in terms of the rationale and underlying field selection criteria and the eventual biases this may imply in terms of technology performance.
- The possible refinement of recommendation domains for technologies like ZT—For instance, anecdotal evidence coming from Pakistan suggests ZT by soil type interactions. Also, the implications and potential use of ZT in wheat-cotton systems with low cotton residue retention levels and the extrapolation to other systems like 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.

References

Abrol, I.P. 1999. Sustaining rice wheat system productivity in the Indo-Gangetic Plain: Water management related issues. *Agricultural Water Management* 40:31-35.

ACO (Agricultural Census Organization). 2003. Pakistan 2000 Agricultural Census (ACO), Statistics Division, Ministry of Economic Affairs and Statistics, Government of Pakistan, Lahore, Pakistan.

Ahmad, M.D., I. Masih, and H. Turral. 2004. Diagnostic analysis of spatial and temporal variations in crop water productivity: A field scale analysis of the rice-wheat cropping system of Punjab. *Pakistan Journal of Applied Irrigation Science* 39:43-63.

Ahmad, M.D., H. Turral, I. Masih, M. Giordano, and Z. Masood. 2007. Water saving technologies: Myths and realities revealed in Pakistan's rice-wheat systems. IWMI Research Report 108. Colombo: International Water Management Institute.

Ahmad, M.U.D., W.G.M. Bastiaanssen, and R.A. Feddes. 2002. Sustainable use of groundwater for irrigation: A numerical analysis of the subsoil water fluxes. *Irrigation and Drainage* 51:227-241.

Amir, P., and M. Aslam. 1992. The rice-wheat system of the Punjab: A conflict in crop management. In: D. Byerlee and T. Husain (eds.), *Farming Systems of Pakistan.* Lahore: Vanguard Press. Pp. 62-88.

Anwar, M.Z., M.A. Khan, and M. Asif Masood. 2002. Socioeconomic assessment of wheat technologies tested in the rice-wheat project areas. In: *Socioeconomic Research Studies 2001-2002*. Islamabad: Pakistan Agricultural Research Council, Social Sciences Division. Pp. 89-106.

Anwar, M.Z., U. Farooq, Ch.M. Sharif, N. Akmal, and M. Morris. 2004. Diffusion of zero-till seed drills in Punjab province, Pakistan. Internal report. Islamabad: Social Sciences Institute, National Agricultural Research Center.

Aslam, M., A. Majid, N.I. Hashmi, and P.R. Hobbs. 1993. Improving wheat yield in the rice-wheat cropping system of the Punjab through zero-tillage. *Pakistan Journal of Agricultural Research* 14:8-11.

Aslam, M., A. Majid, P.R. Hobbs, N.I. Hashmi, and D. Byerlee. 1989. Wheat in the rice-wheat cropping system of the Punjab: A synthesis of on-farm research results *1984-88*. PARC/CIMMYT Paper 89-3. Islamabad: Pakistan Agricultural Research Council.

Byerlee, D., M. Ali, and A. Siddiq. 2003. Sustainability of the rice-wheat system in Pakistan's Punjab: How large is the problem? In: J.K. Ladha, J.E. Hill, J.M. Duxbury, R.K. Gupta, and R.J. Buresh, (eds.), *Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts.* ASA Special Publication Number 65. Madison, Wisconsin: ASA-CSSA-SSSA. Pp. 777-96.

Byerlee, D., A.D. Sheikh, M. Aslam, and P.R. Hobbs. 1984. Wheat in the rice-based farming system of the Punjab: Implications for research and extension. NARC/CIMMYT Wheat Paper Series. Islamabad: National Agricultural Research Center and CIMMYT.

Cabangon, R.J., T.P. Tuong, and N.B. Abdullah. 2002. Comparing water input and water productivity of transplanted and direct-seeded rice production systems. *Agricultural Water Management* 57:11-31.

Chandra, R., A. Sikka, S. Singh, R. Gupta, A.K. Upadhyaya, and R. Sakthivadivel. 2007. Impact of resource conserving technologies on water use and water productivity in Pabnawa Minor of Bhakra Canal System. RWC Technical Bulletin No. 10. New Delhi: Rice-Wheat Consortium for the Indo-Gangetic Plains.

CIMMYT. 1993. *The adoption of agricultural technology: A guide for survey design*. Mexico, D.F.: CIMMYT.

Connor, D.J., J. Timsina, and E. Humphreys. 2003. Prospects for permanent beds for the rice-wheat system. In: J.K. Ladha, J.E. Hill, J.M. Duxbury, R.K. Gupta, and R.J. Buresh (eds.), *Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts.* ASA Special Publication Number 65. Madison, Wisconsin: ASA-CSSA-SSSA. Pp. 197-210

Ekboir, J. 2002. Developing no-till packages for small-scale farmers. In: J. Ekboir (ed.), CIMMYT 2000-2001 World Wheat Overview and Outlook, pp. 1-38. Mexico, DF: CIMMYT.

Erenstein, O., U. Farooq, R.K. Malik, and M. Sharif. 2007a. Adoption and impacts of zero- tillage as a resource conserving technology in the irrigated plains of South Asia. Comprehensive Assessment of Water Management in Agriculture - Research Report 19. Colombo: International Water Management Institute.

Erenstein, O., R.K. Malik, and S. Singh. 2007b. Adoption and impacts of zero tillage in the irrigated rice-wheat systems of Haryana, India. Research Report. New Delhi: CIMMYT and the Rice-Wheat Consortium for the Indo-Gangetic Plains.

Erenstein, O., J. Hellin, and P. Chandna. 2007c. Livelihoods, poverty and targeting in the Indo-Gangetic Plains: A spatial mapping approach. Research Report. New Delhi: CIMMYT and the Rice-Wheat Consortium for the Indo-Gangetic Plains.

Erenstein, O., W. Thorpe, J. Singh, and A. Varma. 2007d. Crop-livestock interactions and livelihoods in the Indo-Gangetic Plains, India: A regional synthesis. Crop-Livestock Interactions Scoping Study. New Delhi: CIMMYT, ILRI and, RWC.

Erenstein, O., W. Thorpe, J. Singh, and A. Varma. 2007e. Crop-livestock interactions and livelihoods in the Trans-Gangetic Plains, India: Report 1. Crop-livestock Interactions Scoping Study. New Delhi: CIMMYT, International Livestock Research Institute and the Rice-Wheat Consortium for the Indo-Gangetic Plains.

Ervin, C.A., and D.E. Ervin. 1982. Factors affecting the use of soil conservation practices: Hypotheses, evidence, and policy implications. *Land Economics* 58:277-292.

FAO (Food and Agriculture Organization of the United Nations). 2007. Conservation agriculture website. Available online at http://www.fao.org/ag/ca/ (22 October 2007).

Farooq, U. 1997. Production, consumption and labour supply linkages of farm households in Punjab, Pakistan. PhD thesis, School of Economic Studies, The University of Manchester.

Feder, G., R. E. Just, and D. Zilberman. 1985. Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change* 33:255-298.

Gupta, R., and K. Sayre. 2007. Conservation agriculture in South Asia. *Journal of Agricultural Science* 145:207-214.

Gupta, R.K., R.K. Naresh, P.R. Hobbs, Z. Jiaguo, and J.K. Ladha. 2003. Sustainability of post-green revolution agriculture: The rice-wheat cropping systems of the Indo-Gangetic Plains and China. In: J.K. Ladha, J.E. Hill, J.M. Duxbury, R.K. Gupta, and R.J. Buresh (eds.), *Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts.* ASA Special Publication Number 65. Madison, Wisconsin: ASA-CSSA-SSSA. Pp. 1-26.

Gupta, R.K., R.K. Naresh, P.R. Hobbs, and J.K. Ladha. 2002. Adopting conservation agriculture in the rice-wheat system of the Indo-Gangetic Plains: New opportunities for saving water. In: B.A.M. Bouman, H. Hengsdijk, B. Hardy, P.S. Bindraban, T.P. Tuong, and J.K. Ladha. (eds.), *Water Wise Rice production. Proceedings of the International Workshop on Water Wise Rice Production*. Los Baños, Philippines: International Rice Research Institute. Pp. 207-222.

Gupta, R., and A. Seth. 2007. A review of resource conserving technologies for sustainable management of the rice-wheat cropping systems of the Indo-Gangetic Plains (IGP). *Crop Protection* 26:436-447.

Harrington, L., and O. Erenstein. 2005. Conservation agriculture and resource conserving technologies: A global perspective. In: I.P Abrol, R.K. Gupta, and R.K. Malik (eds.), Conservation agriculture: Status and prospects. New Delhi: Centre for Advancement of Sustainable Agriculture. Pp. 1-12.

Harrington, L.W., S. Fujisaka, P.R. Hobbs, H.C. Sharma, R.P Singh, M.K. Chaudhary, and S.D. Dhiman. 1993. Wheat and rice in Karnal and Kurukshetra Districts, Haryana, India: Farmer's practices, problems and an agenda for action. Mexico, DF.: Haryana Agricultural University (HAU), Indian Council of Agricultural Research (ICAR), CIMMYT, IRRI.

Hobbs, P.R. 2007. Conservation agriculture: What is it and why is it important for future sustainable food production? *Journal of Agricultural Science* 145:127-137.

Hobbs, P.R., and R.K. Gupta. 2003a. Resource-conserving technologies for wheat in the rice-wheat system. In: J.K. Ladha, J.E. Hill, J.M. Duxbury, R.K. Gupta, and R.J. Buresh (eds.), *Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts.* ASA Special Publication Number 65. Madison, Wisconsin: ASA-CSSA-SSSA. Pp. 149-172.

Hobbs, P.R., and R.K. Gupta. 2003b. Rice-wheat cropping systems in the Indo-Gangetic Plains: Issues of water productivity in relation to new resource-conserving technologies. In: J.W. Kijne, R. Barker, and D. Molden (eds.), *Water Productivity in Agriculture: Limits and Opportunities for Improvement*. Wallingford, UK: CABI. Pp. 239-253.

Hobbs, P.R., and M. Morris. 1996. Meeting South Asia's future food requirements from rice- wheat cropping systems: Priority issues facing researchers in the post-green revolution era. CIMMYT NRG Paper 96-01. Mexico, D.F.: CIMMYT.

Humphreys, E., C. Meisner, R. Gupta, J. Timsina,, H.G. Beecher, T.Y. Lu, Yadvinder-Singh, M.A. Gill, I. Masih, Z.J. Guo, and J. A. Thompson. 2005. Water saving in rice-wheat systems. *Plant Production Science* 8:242-258.

Inayatullah, C., Ehsan-ul-Haq, Ata-ul-Mohsin, A. Rehman, and P.R. Hobbs. 1989. Management of rice stem borers and feasibility of adopting no-tillage in wheat. Islamabad: Pakistan Agricultural Research Council (PARC).

Iqbal, M., M.A. Khan, and M.Z. Anwar. 2002. Zero-tillage technology and farm profits: A case study of wheat growers in the rice zone of Punjab. *The Pakistan Development Review* 411:6655-682.

Jat, M.L., P. Chandna, R.K. Gupta, S.K. Sharma, and M.A. Gill. 2006. Land leveling: A precursor technology for resource conservation. Rice-Wheat Consortium Technical Bulletin Series 7. New Delhi: The Rice-Wheat Consortium for the Indo-Gangetic Plains.

Jehangir, W.A., I. Masih, S. Ahmed, M.A. Gill, M. Ahmad, R.A. Mann, M.R. Chaudhary, and H. Turral. 2007. Sustaining crop water productivity in rice-wheat systems of South Asia: A case study from Punjab Pakistan. IWMI Working Paper 115. Colombo: International Water Management Institute.

Khan, M.A., M.Z. Anwar, M. Aslam Gill, N.I. Hashmi, and P.R. Hobbs. 2002. Impact assessment of zero-tillage wheat sowing technologies in the rice-wheat farming system of Punjab. In: *Socioeconomic Research Studies 2001-2002*. Islamabad: Pakistan Agricultural Research Council. Pp. 53-88.

Kijne, J.W., R. Barker, and D. Molden, (eds.). 2003. *Water Productivity in Agriculture: Limits and Opportunities for Improvement.* Wallingford, UK: CABI.

Ladha, J.K., K.S. Fisher, M. Hossain, P.R. Hobbs, and B. Hardy. 2000. Improving the productivity of rice-wheat systems of the Indo-Gangetic Plains: A synthesis of NARS-IRRI Partnership Research. IRRI Discussion Paper No. 40. Los Baños, Philippines: IRRI.

Ladha, J.K., J.E. Hill, J.M. Duxbury, R.K. Gupta, and R.J. Buresh, (eds.). 2003. Improving the productivity and sustainability of rice-wheat systems: Iissues and impacts. ASA Special Publication Number 65. Madison, Wisconsin: ASA-CSSA-SSSA.

Laxmi, V., O. Erenstein, and R.K. Gupta. 2007. Impact of zero-tillage in India's rice-wheat systems. New Delhi: CIMMYT and The Rice Wheat Consortium for the Indo-Gangetic Plains.

Mackenzie, D. 2007. Billions at risk from wheat super-blight. *New Scientist* 2598:6-7.

Malik, R.K., R.S. Balyan, A. Yadav, and S.K. Pahwa, (eds.). 2002. *Herbicide Resistance Management and Zero-Tillage in Rice-Wheat Cropping System.* Proceedings of International Workshop, Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), 4-6 March, 2002. Hisar, India: CCSHAU.

Malik, R.K., R.K. Gupta, C.M. Singh, A. Yadav, S.S. Brar, T.C. Thakur, S.S. Singh, A.K. Singh, R. Singh, and R.K. Sinha. 2005a. *Accelerating the adoption of resource conservation technologies in rice wheat system of the Indo-Gangetic Plains.* Proceedings of Project Workshop, Directorate of Extension Education, Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), June 1-2, 2005. Hisar, India: CCSHAU.

Malik, R.K., R.K. Gupta, A. Yadav, P.K. Sardana, and C.M. Singh. 2005b. Zero tillage - the voice of farmers. Technical Bulletin No.9. Hisar, India: Directorate of Extension Education, Chaudhary Charan Singh Haryana Agricultural University.

Mann, R.A., and C.A. Meisner. 2003. Outcome of the workshop. In: PARC-RWC (ed.), *Proceedings of the National Workshop on Rice-Wheat Systems in Pakistan*, 11-12 December 2002, Islamabad, Pakistan. Rice-Wheat Consortium Paper Series No. 15. New Delhi: Pakistan Agricultural Research Council and Rice-Wheat Consortium for the Indo-Gangetic Plains. Pp. 1-7.

Molden, D. 1997. Accounting for water use and productivity. SWIM paper 1. Colombo: International Water Management Institute.

Molden, D.J., R. Sakthivadivel, C.J. Perry, C. de Fraiture and W.H. Kloezen. 1998. Indicators for comparing performance of irrigated agricultural systems. Research Report 20. Colombo: International Water Management Institute (IMWI).

Morris, M. 2003. Adoption and impacts of resource conserving technologies in the irrigated plains of South Asia: Inception Report. Mexico, D.F.: CIMMYT.

Napier, T.L., A.S. Napier, and M.A. Tucker. 1991. The social, economic and institutional factors affecting adoption of soil conservation practices: The Asian experience. *Soil and Tillage Research* 20:365-382.

Ortiz, R., K.D. Sayre, B. Govaerts, R. Gupta, G.V. Subbarao, T. Bana, D. Hodson, J.M. Dixon, J.I. Ortiz-Monasterio, and M. Reynolds. Climate change: Can wheat beat the heat? Unpublished paper. Mexico, D.F.: CIMMYT.

Ortiz-Monasterio, J.I., S.S. Dhillon, and R.A. Fischer. 1994. Date of sowing effects on grain yield and yield components of irrigated spring wheat cultivars and relationships with radiation and temperature in Ludhiana, India. *Field Crop Research* 37:169-184.

PARC-RWC (Pakistan Agricultural Research Council and the Rice-Wheat Consortium for the Indo-Gangetic Plains). 2003. *Proceedings of the National Workshop on Rice-Wheat Systems,* Islamabad, Pakistan. 11-12 December 2002. Rice-Wheat Consortium Paper Series 15. New Delhi: PARC-RWC.

Pingali, P.L., and M. Shah. 2001. Policy re-directions for sustainable resource use: The rice-wheat cropping system of the Indo-Gangetic Plains. *Journal of Crop Production* 3:103-118.

Qureshi, A.S., T. Shah, and M. Akhtar. 2003. The groundwater economy of Pakistan. IWMI Working Paper 64. Pakistan Country Series No. 19. Lahore: International Water Management Institute.

Raloff, J. 2005. Wheat warning—new rust could spread like wildfire. *Science News Online* 168:13. http://www.sciencenews.org/articles/20050924/food.asp (22 October 2007).

RWC (The Rice-Wheat Consortium for the Indo-Gangetic Plains). 2002. *Proceedings of the International Workshop on Developing an Action Program for Farm-Level Impact in Rice-Wheat Systems of the Indo-Gangetic Plains*, 25-27 September 2000, New Delhi, India. Rice-Wheat Consortium Paper Series 14. New Delhi: RWC.

RWC (The Rice-Wheat Consortium for the Indo-Gangetic Plains). 2004. Highlights 2003-2004. New Delhi: RWC.

Seckler, D. 1996. New era of water resources management: From dry to wet water savings. Research Report 1. Colombo: International Water Management Institute.

Seth, A., K. Fischer, J. Anderson, and D. Jha. 2003. The Rice-Wheat Consortium: An institutional innovation in international agricultural research on the rice-wheat cropping systems of the Indo-Gangetic Plains (IGP). The Review Panel Report. New Delhi: The Rice-Wheat Consortium for the Indo-Gangetic Plains.

Sharif, M., J. Longmire, M. Shafique, and Z. Ahmad. 1992. System implications of varietal adoption: Basmati-385 in the rice-wheat zone of the Punjab. In: D. Byerlee, and T. Husain (eds.), *Farming Systems of Pakistan*. Islamabad: Vanguard Press. Pp. 89-104

Sheikh, A.D., M.A. Khan, M. Aslam, Z. Ahmad, and M. Ahmad. 1993. Zero-tillage wheat cultivation technology in the rice-wheat areas of the Punjab, Pakistan. Social Sciences Institute, Islamabad: National Agricultural Research Center.

Sheikh, A.D., T. Rehman, and C.M. Yates. 2003. Logit models for identifying the factors that influence the uptake of new 'no-tillage' technologies by farmers in the rice-wheat and the cotton-wheat farming systems of Pakistan's Punjab. *Agricultural Systems* 75:79-95.

Srivastava, S.K., R. Biswas, D.K. Garg, B.K. Gyawali, N.M.M. Haque, P. Ijaj, S. Jaipal, N.Q. Kamal, P. Kumar, M. Pathak, P.K. Pathak, C.S. Prasad, M. Ramzan, A. Rehman, M. Rurmzan, M. Salim, A. Singh, U.S. Singh, and S.N. Tiwari. 2005. Management of stem borers of rice and wheat in rice-wheat system of Pakistan, Nepal, India and Bangladesh. Rice-Wheat Consortium Paper Series 17. New Delhi: The Rice-Wheat Consortium for the Indo-Gangetic Plains.

SBP (State Bank of Pakistan). 2005. Handbook of Statistics on Pakistan Economy 2005, SBP. Available online at http://www.sbp.org.pk/departments/stats/PakEconomy_HandBook/index.htm. (26 November 2007).

Tahir, M.A., and M. Younas. 2004. Feasibility of dry sowing technology of wheat in cotton growing districts and impact evaluation of zero-tillage technology in rice growing districts. Publication No. 364. Lahore: Punjab Economic Research Institute (PERI).

Timsina, J., and D.J. Connor. 2001. Productivity and management of rice-wheat cropping systems: Issues and challenges. *Field Crop Research* 69:93-132.

Ullah, M.K., Z. Habib, and S. Muhammad. 2001. Spatial distribution of reference and potential evapotranspiration across the Indus Basin irrigation systems. IWMI Working Paper 24. Pakistan Country Series 8. International Water Management Institute, Lahore, Pakistan.

Annex 1. List of sample villages and sample breakdown

District	Tehsil	Village	Village #	Sample per village	Tehsil sample size	District sample size
Gujranwala	Gujranwala	Tatle wali; Thatta Ghulab Singh Wahndo	2	8	61	114
		Batala Sharm Singh; Chak Sada; Disar Bala; Ludey Wala Guraye; Maju Chak	5	9		
	Nowsshera	Bado Rata	1	8	53	
		48 virkan; Baig Pur; Chak Choudhry; Mangoki; Panjgrain	5	9		
Hafizabad	Hafizabad	Mandrianwala; Mangat Nicha	2	7	41	41
		Beriwala	1	8		
		Balkoon Kalan	1	9		
		Jaidkey	1	10		
Lahore	Lahore	Sundar (Multan Road)	1	8	17	17
		Chak No. 62 (Bath)	1	9		
Mandi Bahudin	Mandi Baha-ud-Din	Sohava Dilevan	1	2	18	44
		Chak 11	1	7		
		Aidal	1	9		
	Phalia	Basi Kalan	1	8	26	
		Bhagat; Ragh	2	9		
Sheikhupura	Ferozewala	Ahdian; Dhamkey (Sharaqpur Road)	2	8	57	148
		Pindi Machian	1	9		
		Joyanwala; Mondianwala	2	10		
		Mahay Virkan	1	12		
	Nankana Sahib	Tarkanwali	1	7	51	
		Chan Pur Warbartan	1	8		
		Mora Kalan	1	9		
		Nazar Pacca	1	10		
		Pindi Perran di	1	17		
	Safdar Abad	Sheroky	1	15	15	
	Sheikhupura	Manga	1	11	25	
		Kakargil	1	14		
Sialkot	Daska	Bambanwala; Dugri Klan; Kottli Bakha; Shamsa; Tahkar Mahay	5	8	94	94
		Bina; Ghanookey; Jando Sahian; Kotli Nowshera; Malianwala; Zafar Wali Sambarial	6	9		
Total districts=6	Total tehsils=11	Total Villages=51				Total=458

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

Traction	Operation	Indicator (per operation)	Rice	Wheat	Overall	Significance
Tractor	Disc plowing	Time (hr/ha)	2.47 (n=74)	2.23 (n=276)	2.28 (±0.62, n=350)	0.00
		Diesel (l/ha)	8.48 (n=74)	9.78 (n=276)	9.51 (±1.90, n=350)	0.00
		Rental cost (PKR/ha)	660 (n=71)	645 (n=276)	648 (±84, n=347)	NS
	Dry plowing	Time (hr/ha)	1.20 (n=412)	1.18 (n=434)	1.19 (±0.34, n=846)	NS
		Diesel (l/ha)	5.81 (n=412)	5.54 (n=435)	5.67 (±1.33, n=847)	NS
		Rental cost (PKR/ha)	359 (n=412)	368 (n=435)	364 (±40, n=847)	.00
	Dry planking	Time (hr/ha)	0.77 (n=77)	0.68 (n=435)	0.69 (±0.17, n=512)	0.09
		Diesel (l/ha)	3.05 (n=74)	2.62 (n=435)	2.68 (±0.61, n=509)	NS
		Rental cost (PKR/ha)	181 (n=70)	188 (n=435)	187 (±36, n=505)	NS
	Wet plowing	Time (hr/ha)	2.43 (±0.66, n=528)	-	-	NA
		Diesel (l/ha)	9.86 (±,1.38, n=528)	-	-	NA
		Rental cost (PKR/ha)	548 (±97, n=528)	-	-	NA
	Wet planking	Time (hr/ha)	1.23 (±0.28, n=528)	-	-	NA
		Diesel (l/ha)	5.27 (n=528)	-	-	NA
		Rental cost (PKR/ha)	263 (n=528)	-	-	NA
	Planting ZTD	Rental cost (PKR/ha)	-	1048 (±151, n=87)	-	NA
Animal	Wet planking	Rental cost (PKR/ha)	165 (±57,n=3)	-	-	NA

Annex 3. Questionnaire for drill manufacturer survey

Study on Adoption and Impact of Resource Conservation Technologies in the Irrigated Zones of Pakistan

Questionnaire for ZT drill manufacturers

1. Enumerator information

Questionnaire ID number	(1)
Name of enumerator	(2)
Date of interview	(3)

2. Respondent information

Name of the respondent	(4)
Name of firm	(5)
Tehsil / District	(6)
First year manufacturing ZT drills	(7)
Number of other firms manufacturing ZT drills in your area	(8)
Initial Source of Information (specify)	(9)

3. ZT drill manufacturing history

Year	Model # or name	# of drills sold	Price (Rs)	Specifications
1998-1999	(10)	(11)	(12)	(13)
	(14)	(15)	(16)	(17)
	(18)	(19)	(20)	(21)
1999-2000	(22)	(23)	(24)	(25)
	(26)	(27)	(28)	(29)
	(30)	(31)	(32)	(33)
2000-2001	(34)	(35)	(36)	(37)
	(38)	(39)	(40)	(41)
	(42)	(43)	(44)	(45)
2001-2002	(46)	(47)	(48)	(49)
	(50)	(51)	(52)	(53)
	(54)	(55)	(56)	(57)
2002-2003	(58)	(59)	(60)	(61)
	(62)	(63)	(64)	(65)
	(66)	(67)	(68)	(69)

4. Supplemental information

How did you first learn about ZT drills?

(1)

How has your firm contributed to the spread of ZT drills?

(2)

What technical modifications do you plan to introduce in future?

(3)

Annex 4. Questionnaire for adoption survey

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

Adoption and Impacts Survey Questionnaire

1. Village information

Village	(1)	Block / Union Council	(2)
Tehsil	(3)	District	(4)

Distance of village in km from:		Grain market	(7)
AO office	(5)	Input market	(8)
Research station	(6)	District headquarters	(9)

2. Farmer information

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

Caste codes: 1 = , 2 = , 3 = , 4 = , 5 =

Farmer's education	*Codes: 1 = none 2 = primary school 3 = secondary school 4 = higher*		(13)
Composition of farmer's family *(indicate number)*			
Adult men	(14)	Boys under 16 years	
Adult women	(15)	Girls under 16 years	
		Total under 16 years	(16)
Farmer's memberships in organizations	*(Codes: 1 = yes, 2 = no)*		
Water user association	(17)	Market committee	(18)
VO/CBO	(19)	Zakat Usher Committee	(20)
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 5 = chamb 6 = kalrathi/saline 6= rohi/pacci

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 5= Chamb 6= Kalrathi/saline 6=Rohi/pacci

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)
ZTBL	(118)	(119)	(120)	(121)
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

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)		
Other crops:	(143)	Other:	(152)
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)

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=ofwm 10=Drill Manufacturers 11= NARC

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

		Rice (Kharif 2003)		Wheat (Rabi 2003-4)	
		Sown after no-till wheat	Sown after conventional wheat	No-till	Convention
General	Wheat tillage method *(1 = wadwatter, 2 = rauni)*	N / A	(238)	N / A	(36
	Plot size (acres)	(161)	(239)	(316)	(36
	Main soil type	(162)	(240)	(317)	(36
Deep plowing (tractor only)	Number of deep plowings per season	(163)	(241)	N / A	(36
	Tractor hours required for each deep plowing (h/acre)	(164)	(242)	N / A	(36
	Diesel consumed for each deep plowing (l/acre)	(165)	(243)	N / A	(36
	Tractor rental rate for deep plowings (Rs/acre)	(166)	(244)	N / A	(37
Disk plowing (tractor only)	Number of disk plowings per season	(167)	(245)	N / A	(37
	Tractor hours required for each disk plowing (h/acre)	(168)	(246)	N / A	(37
	Diesel consumed for each disk plowing (l/acre)	(169)	(247)	N / A	(37
	Tractor rental rate for disk plowings (Rs/acre)	(170)	(248)	N / A	(37
Dry plowing (tractor / animals)	Number of dry plowings per season (tractor)	(171)	(249)	N / A	(37
	Number of dry plowings per season (animals)	(172)	(250)	N / A	(37
	Tractor hours required for each dry plowing (h/acre)	(173)	(251)	N / A	(37
	Diesel consumed for each dry plowing (l/acre)	(174)	(252)	N / A	(37
	Tractor rental rate for dry plowings (Rs/acre)	(175)	(253)	N / A	(37
	Animal rental rate for dry plowings (Rs/acre)	(176)	(254)	N / A	(38
Dry planking (tractor / animals)	Number of dry plankings per season (tractor)	(177)	(255)	N / A	(38
	Number of dry plankings per season (animals)	(178)	(256)	N / A	(38
	Tractor hours required for each dry planking (h/acre)	(179)	(257)	N / A	(38
	Diesel consumed for each dry planking (l/acre)	(180)	(258)	N / A	(38
	Tractor rental rate for dry plankings (Rs/acre)	(181)	(259)	N / A	(38
	Animal rental rate for dry plankings (Rs/acre)	(182)	(260)	N / A	(38
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

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

		Rice (Kharif 2003)		Wheat (Rabi 2003-4)	
		Sown after no-till wheat	Sown after conventional wheat	No-till	Conventic
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)	
	Diesel required for planting (l/acre)	(196)	(274)	(319)	
	If ZT drill hired, what was the hiring rate? (Rs/??)	(197)	(275)	(320)	
	Human labour required for planting (h/acre)	(198)	(276)	(321)	
	Planting date (dd/mm)	(199)	(277)	(322)	
Variety / Seed	Name of variety	(200)	(278)	(323)	
	Seed rate (kg/acre)	(201)	(279)	(324)	
	Seed source *(1 = own , 2 = neighbor , 3 = purchased)*	(202)	(280)	(325)	
	If seed purchased, what was the cost? (Rs/kg)	(203)	(281)	(326)	
Fertilization	Amount of urea applied (kg/acre)	(204)	(282)	(327)	
	Cost of urea (Rs/kg)	(205)	(283)	(328)	
	Amount of all other fertilizers applied (kg/acre)	(206)	(284)	(329)	
	Average cost of other fertilizers (Rs/kg)	(207)	(285)	(330)	
	Amount of manure applied (trolleys/acre)	(208)	(286)	(331)	
	Cost of manure (Rs/trolley)	(209)	(287)	(332)	
Weed control	Number of hand weedings per season	(210)	(288)	(333)	
	Human labour required per hand weeding (h/acre)	(211)	(289)	(334)	
	Hand weeding labour cost (Rs/acre)	(212)	(290)	(335)	
	Number of herbicide applications per season	(213)	(291)	(336)	
	Herbicide cost (Rs/acre)	(214)	(292)	(337)	
Pesticides/ fungicides	Cost pesticide used (Rs/acre)	(215)	(293)	(338)	
	Cost of fungicide (Rs/acre)	(216)	(294)	(339)	

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

		Rice (Kharif 2003)		Wheat (Rabi 2003-4)	
		Sown after no-till wheat	Sown after conventional wheat	Sown after no-till wheat	Sown after conventiona wheat
Irrigation	Irrigation source *(1 = canal, 2 = tubewell, 3 = both)*	(217)	(295)	(340)	(4(
	Number of irrigations, canal water	(218)	(296)	(341)	(41
	Time required for 1st irrigation (hrs), canal water	(219)	(297)	(342)	(41
	Time required for later irrigation (hrs), canal water	(220)	(298)	(343)	(41
	If you own tubewell, what is its depth (m)?	(221)	(299)	(344)	(41
	Number of irrigations, tubewell	(222)	(300)	(345)	(41
	Time required for 1st irrigation (hrs), tubewell	(223)	(301)	(346)	(41
	Time required for later irrigation (hrs), tubewell	(224)	(302)	(347)	(41
	How much tubewell water did you buy?	(225)	(303)	(348)	(41
	How much tubewell water did you sell?	(226)	(304)	(349)	(41
	Quality of tubewell water *(1 = good, 2 = poor)*	(227)	(305)	(350)	(41
	Did you face water scarcity? *(1= yes, 2 = no)*	(228)	(306)	(351)	(42
Harvesting	Date of harvesting (mm/dd)	(229)	(307)	(352)	(42
	Manual harvesting labour use (mandays/acre)	(230)	(308)	(353)	(42
	Labour cost (Rs/manday)	(231)	(309)	(354)	(42
	Combine harvesting time (hrs)	(232)	(310)	(355)	(42
	Cost of combine (Rs/acre)	(233)	(311)	(356)	(42
	Grain yield (kg/acre)	(234)	(312)	(357)	(42
	Residue management *(1 = burn, 2 = remove, 3 = plow)*	(235)	(313)	(358)	(42
	Value of by-products (straw) (Rs/acre)	(236)	(314)	(359)	(42
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)	(42
	If wheat hand threshed, threshing cost (% of crop)	N / A	N / A	(361)	(43
	If wheat machine harvested, threshing cost (Rs/acre)	N / A	N / A	(362)	(43
	If wheat machine harvested, threshing cost (% of crop)	N / A	N / A	(363)	(43

4.4 Constraints to adoption of zero tillage technology

For RATING assign each factor a score on a scale of 1-5, where:

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

Technical factors	**Rating**
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)
Other (specify):	(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)

For RATING assign each factor a score on a scale of 1-5, where:

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

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)
Other (specify)	(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)

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)

Last revised: January 21, 2004

Tube well technical information

Do you use a tubewell, to irrigate rice and/ or wheat? 1 = yes, 2= no.	
If you use a tubewell, do you own the tubewell? 1=yes, 2= no.	

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

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

If Diesel, consumption of diesel per hours (Lit/Hour)	

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

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

If you use a tubewll, what is the position of the pump?	

1=at the surface, 2=submerged

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

Irrigation information

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

Please provide the following information for irrigation practices for WHEAT:

# of Irrigation	Zero till		Con. Tillage (Runi)		Conventional tillage (wadwatter)	
Irrigation	Quantity of water used (Units)	Time needed (Hours)	Quantity of water used (units)	Time needed (Hours)	Quantity of water used (Units	Time needed hours)
Pre-sowing irrigation						
First irrigation						
Subsequent irrigations						
1.						
2.						
3.						
4.						
5.						
6.						

Annex 5. Questionnaire for village survey

Village and ZT Drill Owners Questionnaire

Village Name ____________________________ Tehsil and District ________________
ZT-Promotion Status: Promoted / Non-Promoted

1) No. of households in the village ______________________ (No)
- ❋ Farming households in the village ______________________ (No)
- ❋ Non-farming households in the village ______________________ (No)

2) Area of the village (squares) ______________________ (No)
3) Total village population ______________________ (No)
4) No. of Tractors in the village ______________________ (No)
5) No. of Threshers in the village ______________________ (No)
6) No. of Disc plows in the village ______________________ (No)
7) No. of ZT drills in the village ______________________ (No)
- ❋ In 2002-03 ______________________ (No)
- ❋ In 2003-04 ______________________ (No)
- ❋ In 2004-05 ______________________ (No)

8) Land rent (Rs./acre) ______________________ (No)
9) Rental changes of ZT drill ______________________ (No)
- ❋ In 2002-03 ______________________ (No)
- ❋ In 2003-04 ______________________ (No)
- ❋ In 2004-05 ______________________ (No)

10) Disc ploughing charges ______________________ (No)
11) Water charges (Rs./acre/season)
- ❋ Kharif season ______________________
- ❋ Rabi season ______________________

12) Transport charges Wheat ____________Rice_________FYM___________

13) Drill Use Trends (Acres)

	2004-05	2003-04	2002-03	2001-02	2000-01
Owner-1:					
Own Farm					
Others Farms					
Owner-2:					
Own Farm					
Others Farms					
Owner-3:					
Own Farm					
Others Farms					
Owner-4:					
Own Farm					
Others Farms					
Owner-5:					
Own Farm					
Others Farms					

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