WORKING PAPER 115

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International
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# List of Acronyms

| | |
|---|---|
| ACIAR | Australian Centre for International Agricultural Research |
| ADB | Asian Development Bank |
| BW2R | Bed Planted Wheat with 2 rows |
| BW3R | Bed Planted Wheat with 3 rows |
| CIMMYT | International Maize and Wheat Improvement Center |
| CIP | International Potato Center |
| CW | Conventional Wheat |
| DSRB | Direct Seeded Rice on Beds |
| DSRF | Direct Seeded Rice on Flat |
| ICRISAT | International Crops Research Institute for the Semi-Arid Tropics |
| IGP | Indo-Gangetic Plains |
| IRRI | International Rice Research Institute |
| IWASRI | International Waterlogging and Salinity Research Institute |
| IWMI | International Water Management Institute |
| OFWM | On-Farm Water Management |
| PARC | Pakistan Agricultural Research Council |
| RCT | Resource Conservation Technologies |
| RWC | Rice-Wheat Consortium |
| TPRB | Transplanted Rice on Beds |
| TPRF | Transplanted Rice on Flat |
| UAF | University of Agriculture, Faisalabad |
| WAPDA | Water and Power Development Authority |
| WP | Water Productivity |
| ZTW | Zero Tillage Wheat |

# Summary

This working paper presents the results of the Pakistan Component of the Rice-Wheat Consortium Project on ‘Sustaining the rice-wheat production systems of Asia’. Rice and wheat crops are main sources of human food and substantially contribute to feeding livestock. The advent of the green revolution in the 1960s resulted in a tremendous increase in the production of these two cereal crops and the rice-wheat cropping system emerged as a very important source of food supply in South Asia. Recent symptoms of stagnant growth rates in productivity and the degradation of the resource base pose serious challenges to future food security and natural resources management in the region. The growing scarcity of water in the region is the biggest threat to maintaining or increasing the productivity of this cropping system.

This project was designed to develop systems solutions for site-specific productivity and sustainability issues in the Indo-Gangetic Plains of South Asia. The Pakistan Component of this project was executed in the Punjab Rice-Wheat zone during the period 2001–2004. The main goal was to promote improved water management techniques at field, farm and watercourse levels. The project was mainly funded by the Asian Development Bank and was executed in collaboration with the Rice-Wheat Consortium of Indo-Gangetic Plains (RWC), CIMMYT, IRRI, IWMI and the National Agricultural Research Institutions of Pakistan, India, Bangladesh and Nepal. The Pakistan component was lead by IWMI, and the national collaborators were the Pakistan Agricultural Research Council (PARC), On-Farm Water Management, Punjab (OFWM) and the University of Agriculture, Faisalabad (UAF).

Field-scale analyses of typical conventional practices for rice-wheat production showed large gaps between water demand and supply patterns. The average water input to rice was estimated as 1,458 mm against the potential crop water requirement of 532 mm. This resulted in a low gross depleted fraction of 0.40 indicating that about 60 percent of the water was not used in rice evapotranspiration and mainly left the root zone as seepage and deep percolation flows. In contrast, farmers tend to under-irrigate the wheat crop and try to best utilize rainfall by optimizing their irrigation schedules. The field-scale average of $WP_{-GI}$ (grain yield per unit of gross inflow) was estimated as 0.23 Kg/m$^3$ for rice, and 1.48 Kg/m$^3$ for wheat. This indicates that about 4.35 of supplied water were used to produce one kilogram of rice and only 0.675 m$^3$ for one kilogram of wheat. The farm-level comparison showed large variations in water productivity ($WP_{-GI)}$ among the sample farms, which ranged from 0.19–0.32 Kg/m$^3$ for rice and 0.93–1.39 Kg/m$^3$ for wheat. These variations under similar climatic, soil and water quality regimes could be mainly attributed to differences in agronomic and water management practices. The comparison of four sample watercourses showed that physical and economic water productivities were higher for areas with diversified cropping patterns and greater adoption of laser-land-leveling and zero-tillage technologies.

Evaluation of rice-wheat crop establishment methods indicated that the direct seeding of rice and bed planting of rice and wheat showed considerable reductions in total irrigation water applications. However, lower yields were obtained with these methods compared to the conventional practices and, as such, pose a major hurdle in its adoption by the farming community. Further efforts are required to devise suitable local solutions for improved weed management, seed-drilling machinery and to develop farmer experience with agronomic practices and irrigation scheduling. Better performance of canal water delivery plus good conjunctive use of groundwater could help the farmers in achieving better results in their fields. The successful development of machinery for crop-residue management (such as CSIRO’s ‘Happy Seeder’) could further facilitate the development of new technologies for rice-wheat systems.

Higher land and water productivity together with increased net income has attracted farmers to adopt the zero-tillage technology. However, financial problems, lack of machinery, lack of familiarity are major constraints to accelerating the adoption of new technologies among the small-scale farmers. Formulation of a suitable policy framework and actions for the promotion of promising 'Resource Conservation Technologies' is an essential requirement.

Farmers in Pakistan's Punjab and many parts of South Asia have opted to increase economic returns from rice production by diverting large amounts of fresh water. They are more concerned to increase land productivity to ensure enhanced farm incomes and food security as compared to focusing on efforts for improved water productivity. Therefore more research and development efforts are needed to realize the dual goals of increased water and land productivity using innovative water management techniques for rice-wheat systems. The study shows that the resource conservation technologies result in water savings at the field level, but whether these can be translated into real water savings at the system scale is not yet well understood. The up-scaled adoption of resource conservation technologies is likely to result in complex interactions among various water balance components. Therefore, the impact of these technologies on real water savings and water productivity needs to be further evaluated at various scales of an irrigation system/river basin.

# 1 INTRODUCTION

## 1.1 Background

Rice and wheat are of central importance in meeting food needs of the growing population in the world. These two cereal crops provide 45 percent of the digestible energy and 30 percent of the total protein in the human diet, as well as substantially contributing to livestock feed (Evans 1993). Rice and wheat crops are grown sequentially on about 13.5 Mha in the Indo-Gangetic Plains (IGP), including the Indus (areas in Pakistan, and parts of Punjab and Haryana India) and the Gangetic Plains extending over Uttar Pradesh, Bihar and West Bengal in India, Nepal and Bangladesh, respectively (Timsina and Connor 2001). Rice-wheat is a major cropping system for sustaining food security in the region, and millions of farmers and agricultural workers depend on this system for employment and livelihoods.

The advent of the green revolution in the early 1960s dramatically increased the area and productivity of rice-wheat systems in the IGP. The main contributory factors were the introduction of improved varieties, increased use of fertilizers and other chemicals, and the expansion of irrigation. However, more recently yields have stagnated or even declined, and there remain large gaps between potential, experimental and farmers' yields (Ladha et al. 2003). Therefore, the sustainability of rice-wheat systems of the IGP and their ability to enhance productivity to keep pace with population growth are major concerns. Symptoms of degradation of the resource base include: a) declining soil organic matter content and nutrient availability; b) increasing soil salinization and weed; and c) pathogen and pest populations (Pingali and Shah 1999; Timsina and Connor 2001).

The biggest threat to sustaining or increasing the productivity of rice-wheat systems of South Asia is water shortage. Supply of fresh water to the agriculture sector will be reduced in the future due to the increasing demand and competition from environmental, industrial and domestic sectors. The major challenge for the agriculture sector during the twenty-first century is to produce more food with less water. Water savings from rice-based cropping systems will be of significant importance, as nearly 50 percent of the freshwater used in Asian agriculture is utilized for rice production (Gleick 1993). To meet the increasing demand for food, and cope with an increasing scarcity of water, more rice needs to be produced using less water (Guerra et al. 1998).

The Rice-Wheat Consortium (RWC) of Indo-Gangetic Plains initiated a project called 'Sustaining the rice-wheat production systems of Asia', with the main objective of developing systems that would provide solutions to site-specific productivity and sustainability problems of intensive rice-wheat cropping systems in the Indo-Gangetic Plains. The project was funded by Asian Development Bank, National Agricultural Research Systems of the participating countries, International Agricultural Research Centers (CIMMYT; IRRI; IWMI; ICRISAT; and CIP) and other sources (Governments of the United Kingdom and the Netherlands). This project was proposed to help the farmers in the rice-wheat zones of the four consortium countries, Bangladesh, Nepal, India and Pakistan, to: 1) improve food production at least cost; 2) sustain the production capacity of the resource base; and 3) diversify the rice-wheat cropping system to obtain alternative sources of income.

The study was mainly focused on intensively cultivated and irrigated rice-wheat cropping systems of the Indo-Gangetic Plains, which occupy large areas in these four countries. New technologies that address issues of crop productivity and natural resource conservation along with packages of agronomic and crop management practices (called resource conserving technologies (RCT) have been developed with extensive farmer participation. These technologies include: a) zero-tillage; b) bed-planting; and c) surface-seeding and direct-seeded rice on a raised bed-planting system.

### 1.2 Project Goal and Purpose

The Pakistan component of the overall project on ‘Sustaining the rice-wheat production systems of Asia’ was called ‘Sustaining crop and water productivity in the irrigated rice-wheat cropping systems of the Pakistan’s Punjab’. The 3-year project started in April 2001 and was completed successfully in 2004. The International Water Management Institute (IWMI) led the Pakistan component and the other collaborators were: Pakistan Agricultural Research Council (PARC); On-Farm Water Management (OFWM), Punjab; and the University of Agriculture Faisalabad (UAF). The main objective of this component of the project was the promotion of water management techniques to achieve a sustainable productivity increase in rice-wheat system at the field, farm and watercourse command levels. The main purpose was the assessment of the water saving potential at the field, farm and watercourse levels through the establishment of alternative wheat and rice crop management practices and their effects on the groundwater table and quality.

## 2 RESEARCH METHODOLOGY

### 2.1 Research Locale

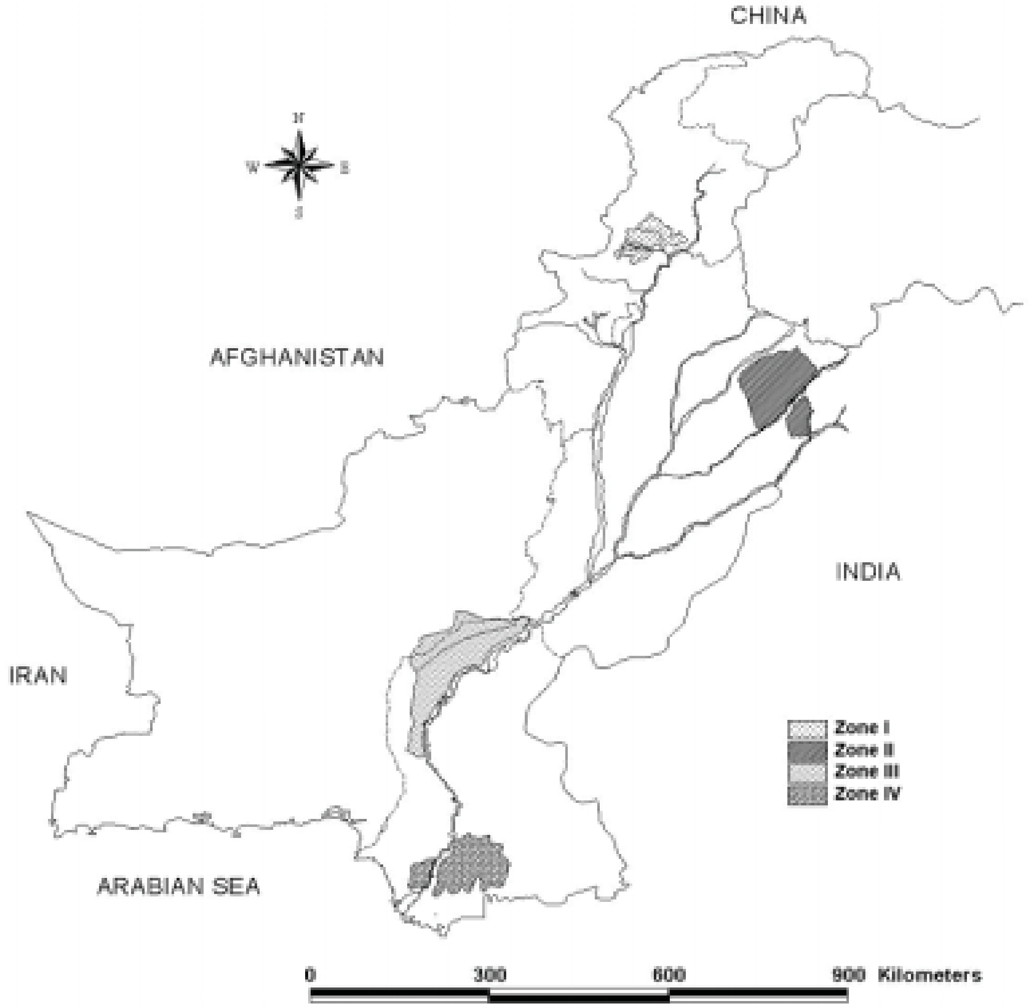
The rice-wheat production system of Pakistan occupies about 2.2 Mha of the total farmland of the country (21 Mha), and is distributed into four rice-wheat growing zones categorized on the basis of climate, land and water use as shown in figure 1 (Aslam et al. 2002). This study was conducted in the Punjab rice-wheat agro-ecological region (zone 2) located in the Northern Irrigated Plain of the Punjab Province of Pakistan. The climate is sub-tropical continental, characterized as semi-arid with large seasonal fluctuations in temperature and rainfall. Summers are long and hot, lasting from April through September with maximum daytime temperature varying between 27°C and 43°C, while in winter it varies between 4°C and 24°C. The average annual rainfall in the area is about 550 mm, while the average annual evaporation is around 1,400 mm. About 80 percent of the total rainfall is received during the monsoon period (July to November), which coincides with rice cultivation.

The soils in the Indus River System are predominantly alluvial, mostly brown to grayish brown, calcareous and weakly structured. The soil texture ranges from coarse to fine with about 85 percent in the moderately coarse to moderately fine categories, mostly suitable for irrigated agriculture. The rice-wheat sequence is practiced on different kinds of soil textures such as loam, silt loam, silty clay loam and sandy loam. The rice-wheat zone of the Punjab is served by an intensively developed canal irrigation system, providing water on a perennial and non-perennial basis. Groundwater provides the major share of total water supply at the farm gate. Groundwater has been extensively developed over the past 50 years by public sector (during initial phase of the green revolution, in 1960s) and by the private sector after the 1980s. Cropping intensities are more than 150 percent and are high compared to other cropping systems of the Punjab Province. The main crops are rice and wheat along with fodder, orchards, vegetables and sugarcane.

#### *2.1.1 Research Sites and Experimental Set Up*

Four watercourses were selected from the Sheikhupura District (figure 1). The salient features of these watercourses are given in table1. Water balance and water productivity analyses were done at the field, farm and watercourse levels. Seven sample farms were selected from the sample watercourses for in-depth water balance, water productivity and agronomic studies. Two farms were selected from the command areas of 21900/TF, 28915/L and 74634/R, and one from the command area of 32326/L (figure 2). Out of the seven sample farms, three were selected for field level testing and development of various rice-wheat establishment methods. These sample farms were termed as 'Zaidi Farm' (located at watercourse 21900/TF), 'Malik Farm' (located at 28915/L) and 'Dogar Farm' (located at watercourse 74634/R).

*Figure 1. Rice-wheat cropping zones in Pakistan.*



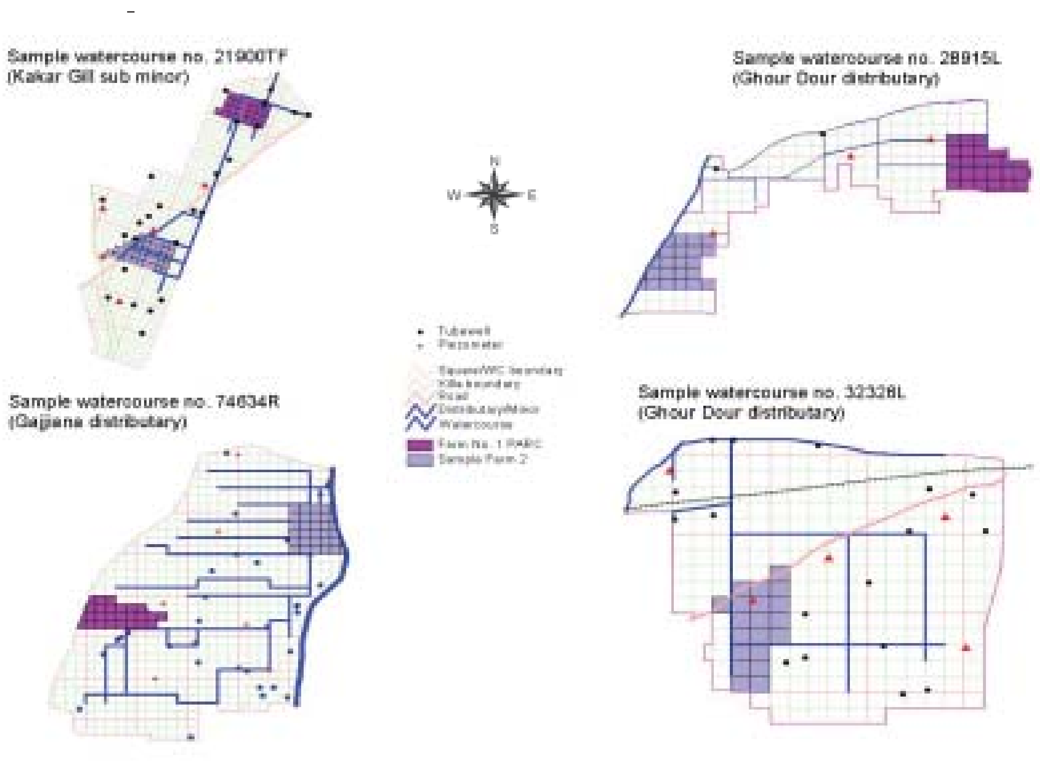
*Note*: Data generated by the project research

*Table 1. Salient features of the sample watercourses.*

| Salient features | Sample watercourses | | | |
|---|---|---|---|---|
| | 21900/TF | 28915/L | 32326/L | 74634/R |
| Canal command | | | | |
| Main Canal | Upper Chenab Canal (UCC) | Upper Gugera branch canal | Upper Gugera branch canal | Upper Gugera branch canal |
| Distributary/minor | Kakar Gill Sub-minor | Ghour Dour Distributary | Ghour Dour Distributary | Gajjiana Distributary |
| District | Sheikhupura | Sheikhupura | Sheikhupura | Sheikhupura |
| GCA (ha) | 232 | 72 | 110 | 268 |
| CCA (ha) | 199 | 72 | 108 | 267 |
| Design canal discharge ($m^3/s$) | 0.068 | 0.007 | 0.016 | 0.040 |
| Number of tubewells (average discharge capacity 0.028 $m^3/s$) | 25 | 2 | 17 | 38 |
| Average Tubewell water electrical conductivity (dS/m) | 0.8 | 1.1 | 1.2 | 0.8 |
| Area under rice-wheat (%) | | | | |
| Rice 2001 | 88 | 42 | 65 | 60 |
| Wheat 2001-2 | 78 | 45 | 81 | 72 |

*Note*: Data generated by the project research

*Figure 2. Schematic layout of the sample watercourses and farms.*



*Note*: Data generated by the project research

## 2.2 Data Collection and Analysis for Water Balance and Water Productivity

The data collected for the water balance and water productivity analyses at the field, farm and watercourse scales are presented in annex 1. The water balance analysis was carried out using the principle of mass balance (inflow – outflow = change in storage) that involves the monitoring of all inflow and outflow components (Perry 1996; Kijne 1996). The main inflow components for the study area are irrigation from the canal and tubewell sources, rainfall, surface and subsurface inflows. Outflow components are evapotranspiration, seepage, deep percolation, surface and subsurface outflows. Water productivity was estimated on the basis of the yield and monetary value per unit of the gross inflow and irrigation inflow.

### *2.2.1 Field Level Analysis*

At one site (watercourse 32326/L), only conventional practices were monitored and at the other three sites, the four rice-wheat treatments were:

1. T1: Direct seeding of rice on flat fields (DSRF) and wheat with the zero-tillage method (ZTW)
2. T2: Direct seeding of rice on beds (DSRB) and wheat on beds with two rows (BW2R)
3. T3: Transplanting of rice on beds (TPRB) and wheat on beds with three rows (BW3R)
4. T4: Transplanting of rice by conventional method (TPRF) and conventional wheat (CW)

These trials were established at Zaidi, Malik and Dogar farms located in the watercourse command areas of 21900/TF, 28915/L and 74634/R, respectively. A randomized complete block design was used with three replicates at each site. Cut throat flumes were used to measure the irrigation inflow to the sample fields. The duration and source of irrigation were also recorded for each irrigation interval. The amount of irrigation water was calculated by integrating discharge rate over the time of irrigation. Rainfall was measured by rain gauges installed in each selected watercourse command area, and crop evapotranspiration was calculated by using Hargreave's equation and suitable crop coefficients for the study area (Allen et al.1998; Ullah et al. 2001). The climatic data from a nearby station belonging to WAPDA (Water and Power Development Authority) were used to calculate the daily reference evapotranspiration ($ET_0$). The potential crop water requirements were used in the water balance and water productivity analyses, as the required equipment to estimate actual evapotranspiration was not available. For a more robust water balance analysis, the actual evapotranspiration can be estimated using simulation models and remote sensing techniques (Sarwar and Bastiaanssen 2001; Ahmad et al. 2002; Bastiaanssen et al. 2002). Land and water productivity of the rice-wheat establishment methods were estimated using the indicators given in table 2 (Molden 1997; Molden and Sakthivadivel 1999).

*Table 2. Performance indicators for water productivity analysis.*

| Performance indicators | Unit | Estimation method |
|---|---|---|
| Gross depleted fraction | (-) | Evapotranspiration/Gross inflow |
| Land productivity | Kg/ha | Crop yield per unit area |
| Water Productivity | Kg/m$^3$ and Rs/m$^3$ | Crop yield per unit of water (Kg/m$^3$) and gross value of crop yield per unit of water (Rs/m$^3$) |
| $\mathrm{WP}_{\text{\_Gross inflow}} = \mathrm{WP}_{-\mathrm{GI}}$ |  | Crop yield/Gross inflow |
| $\mathrm{WP}_{\text{\_Irrigation inflow}} = \mathrm{WP}_{-\mathrm{I}}$ |  | Crop yield/Irrigation inflow |

*Note:* Data generated by the project research

*2.2.1.1 Data collection and analysis for agronomic evaluation of rice-wheat establishment methods:* During the Kharif season, rice was established using direct seeding (T1 and T2) and transplanting methods (T3 and T4). Then during Rabi season, wheat was established through zero tillage (T1), bed planting (T2 and T3) and the conventional method (T4). The direct seeding of rice on a flat field and on beds was performed in June and transplanting of 25–30 days old seedlings occurred about one month later in July. Rice was direct seeded into a finely prepared seedbed using a direct drill at 30 cm row-to-row distance. Beds were formed using a shaper and set at 76 cm between rows i.e., top width for bed and furrow were 42 cm and 34 cm, respectively. The rice crop was harvested during the month of November and then the wheat crop was sown by way of zero-tillage, bed-planting and the conventional methods during the month of November.  Wheat was harvested in April. The plot area was 0.2 ha for all the four treatments. The fertilizer use and plant protection measures were standardized and uniform. The seed rate for direct- seeded rice was 50 Kg/ha and 75-85 kg/ha for wheat with zero-tillage and beds, while 135 kg/ha for conventional sowing. The crop varieties for rice and wheat were ‘Super Basmati and Inqlab 91’, respectively. The following data were recorded:

- Yield and yield components
- Incidence of insect pests
- Population of bio-control agents
- Incidence of diseases
- Population of weeds
- Plant population of rice and wheat

### *2.2.2 Farm Level Analysis*

The agronomic and irrigation details of the experiments were collected at each sample farm, and they included: tillage practice; sowing and harvesting dates; fertilizer use; weedicide/pesticide use; and yield and market value. The number, duration and source of irrigations were recorded for each field in the command of the sample farm. Farm-level crop-productivity was estimated in terms of gross value of production per unit of land (Rs/ha) and water (Rs/m$^3$).

### *2.2.3. Watercourse Level Analysis*

At the watercourse level, the gross inflow was estimated by recording canal inflow, rainfall and total groundwater pumped from tubewells. Discharges were recorded daily at the inlet to sample distributaries/minors. The total groundwater pumped in a sample watercourse command was estimated by recording the daily operational hours of every tubewell in a watercourse command, and periodically measuring their flow rates. Daily rainfall was measured through the rain gauges installed at each of the sample watercourse commands. The crop-water demand for each watercourse command was estimated by taking the average sowing and harvesting dates of every crop grown in each watercourse command. Then based on the area of each crop, the weighted average crop water requirement was estimated for each watercourse command.

To keep the analysis simple, the water balance of the root zone domain and study of groundwater behavior were kept separate. The comparison of the gross water inflow and crop-water requirement provided a good overview of the water demand and supply pattern in the study area. The impact on the groundwater table and groundwater quality was evaluated through the analysis of the data on groundwater table depth and groundwater quality. For this data set, piezometers were installed at various locations of each sample watercourse (figure 2). The land productivity (yield per unit of land, Kg/ha) and farm market value were estimated for every crop through seasonal and annual surveys. The economic productivity of land (Rs/ha) and water (Rs/m$^3$) were estimated on both a seasonal and annual basis for the four sample watercourses.

## 2.3 Framework for the Promotion of Resource Conservation Technologies

A framework was developed to promote resource conservation technologies in the sample areas. The promotion of RCT was carried out through:

- Provision of information through farmers' meetings, farmers' field days and field demonstrations
- Facilitation of LASER leveling services, establishment of rental services of RCT equipment and technical assistance in RCT adoption
- Enhancing interaction among farmers through cross-farm visits, arranging field days to gather various stakeholders i.e., farmers, researchers, government officials and manufacturers
- Providing feedback to government and private machinery manufactures for improving the quality of RCT equipment

## 2.4 SocioeconomicAspects of RCT Adoption

Socioeconomic surveys were conducted on a seasonal and annual basis to study the socioeconomic aspects of the RCT adoption in the study area. The questionnaires were prepared to study farmers' socioeconomic characteristics in detail, as well as water use patterns and agronomic practices. Survey data was also collected to compare RCT with the traditional methods, understand farmers' views about the advantages and pitfalls of RCTs and, identify technical, socioeconomic and policy issues constraining the adoption of RCT in the rice-wheat zone of Pakistan's Punjab.

## 3 RESULTS AND DISCUSSION

### 3.1 Water Balance and Water Productivity at Various Scales

### *3.1.1 Field Level Evaluation of Conventional Rice-Wheat Rotation*

The water balance and water productivity analyses of conventional rice-wheat cultivation practices for one sample location are presented in table 3. The gross inflow (sum of canal water irrigation, groundwater irrigation and rainfall) to rice cultivation was 1,458 mm. The crop evapotranspiration was estimated as 532 mm, which when compared to gross inflow indicated a large excess in the water supply. This was due to the large volume of deep percolation during 'puddling' and then in 'ponded' water conditions usually associated with conventional rice cultivation. The gross depleted fraction was estimated as 0.40, which indicates that 60 percent of gross inflow was not beneficially used as crop evapotranspiration. Wheat had a higher water use efficiency than rice, as farmers restricted the total water supply.

*Table 3. Water balance and water productivity analysis for conventional rice-wheat rotation at farmer's field, watercourse 32326/L, Ghour Dour Distributary, Punjab, Pakistan.*

| Performance indicators | Rice | Wheat |
|---|---|---|
| Field area, ($m^2$) | 4,160 | 4,049 |
| Inflow components, (mm) | | |
| *Irrigation* | 1,244 | 253 |
| *Rainfall* | 214 | 103 |
| *Gross inflow* | 1,458 | 357 |
| Outflow components, (mm) | | |
| *Evapotranspiration* | 532 | 396 |
| *Seepage and percolation* | 1,202 | -40 |
| Performance | | |
| *Gross depleted fraction, (-)* | 0.39 | 1.12 |
| *Grain yield , (Kg/ha)* | 3,243 | 5,245 |
| *Water productivity, (Kg/m$^3$)* | | |
| $WP_{-GI}$ | 0.23 | 1.48 |
| $WP_{-I}$ | 0.29 | 2.15 |

*Notes:* Data generated by the project research
The values represent averages of three fields extensively monitored during 2001-2003. The results for rice are the average of three seasons (Kharif 2001; Kharif 2002; Kharif 2003), whereas the wheat results represent a two season average (Rabi 2001/2002; Rabi 2002/2003). For seasonal detail, see annex 2.

The average grain yields for rice (paddy) and wheat were 3.3 t/ha and 5.3 t/ha, respectively. At this location, the average yield of rice was comparable to that of neighboring farmers. However, the wheat yield was above average, which was only 3.5 t/ha on local farmers' fields. The $WP_{-GI}$ (grain yield per unit of gross inflow) was estimated as 0.23 $Kg/m^3$ for rice and 1.48 $Kg/m^3$ for wheat. The irrigation water productivity was estimated as 0.29 $Kg/m^3$ and 2.15 $Kg/m^3$ for rice and wheat, respectively. However, the meaning of this is not clear, given that more than 30 percent of crop water demand is sourced from rainfall in the case of wheat cultivation. The lower water productivity of rice indicates potential scope for enhancement through focusing on targeting yield increases and water conservation strategies. However, the water productivity per unit of evapotranspiration (Et) for rice is similar to that for wheat, and in fresh groundwater areas, the recharge by deep percolation will be re-pumped for irrigation elsewhere.

### *3.1.2 Farm Level Water Balance and Water Productivity*

The results of farm level analysis of water balance, land and water productivity are presented in table 4. The results represent farm level average values for rice and wheat for the study period (three seasons for rice and two seasons for wheat). The results show that the potential crop-water demand for rice varied from 537 mm to 627 mm, with average value of 573 mm. Rice was transplanted during the months of June and July, and in some cases delayed until August, resulting in lower crop water requirement, but at the cost of yield losses. Farmers transplanting in the later half of June used more water compared to those who transplanted later. The study indicates that the most of the rice was transplanted during first–fourth week of July. The farm-level average irrigation supply, rainfall and gross inflow were 1,224 mm, 192 mm and 1,417 mm, respectively. The sample farm F1-21TF had better water management with the lowest amount of gross inflow (1,209 mm) compared to other sample farms. Laser land leveling was one of the main factors in reducing the total irrigation input at F1-21TF, F1-28L and F1-74R. These sample farms also produced good rice harvests of 3.8 t/ha for F1-21TF and 3.2 t/ha for F1-28L and F1-74R. The average gross value of production for rice was 38, 910 Rs/ha with highest value of 48, 328 Rs/ha for F1-21TF and lowest value of 33,148 Rs/ha for F2-21TF.

The farm-level average water productivities of rice in terms of $WP_{-GI}$ and $WP_{-I}$ were 0.25 $Kg/m^3$ and 0.29 $Kg/m^3$, respectively. The farm-level variations in $WP_{-I}$ ranged from 0.19-0.32 $Kg/m^3$. The economic water productivity of rice was 2.93 $Rs/m^3$ and 3.50 $Rs/m^3$ per unit of irrigation and gross inflow, respectively. Higher physical and economic water productivity was observed for F1-21TF, F1-28L and F1-74R, which could be attributed to better water management practices and the adoption of laser land leveling in these farms.

Water application on wheat was considerably lower than that of rice. The average gross inflow varied from 251 mm to 368 mm across the sample farms, whereas potential crop water requirement ranged from 392 mm to 459 mm. The results show that irrigation input and gross inflow were lower than the potential crop-water requirement at all the sample farms. This shortfall was 122 mm (gross inflow: 299 mm and crop-water requirement: 411 mm) for F1-21TF and 66 mm for F1-32L (gross inflow: 333 mm and crop-water requirement: 399 mm). The results indicated that wheat was under-irrigated and may have faced a bit of water stress, though the deficit could be partially met from the moisture left in the root zone after the rice harvest. The farm-wise analysis shows better performance of residual moisture utilization where zero tillage was adopted (F1-21TF, F1-28L, F1-74 R) compared to farms under conventional practices (F1-32L, F2-74R, F2-21TF).

The physical water productivity measured in terms of yield per unit of gross inflow ($WP_{-GI}$) of wheat ranged from 0.93 $Kg/m^3$ to 1.39 $Kg/m^3$ across the sample farms, with a farm-level average of 1.15 $Kg/m^3$. The irrigation water productivity was higher than that of gross inflow and, was mainly influenced by the proportion of rainfall in gross inflow. The economic water productivity of wheat, $WP_{-GI}$ and $WP_{-I}$ was 8.42 Rs/$m^3$ and 13.57 Rs/$m^3$, respectively. The results indicate that economic productivity of water is higher for wheat compared to rice, but the opposite is true in terms of land productivity. Rice, being a cash crop, produces more farm revenue (Rice GVP/ha: 38,910 Rs/ha) than wheat (Wheat GVP/ha: 25,246 Rs/ha). The farmers are more concerned in maximizing the yields from their land resources than water productivity increases, as they could pump good-quality groundwater. However, increasing pumping costs and declining groundwater tables call for improved water management practices in rice cultivation.

### *3.1.3 Watercourse Level Water Balance and Water Productivity*

Estimation of water productivity becomes complex when moving from micro level to system level, which involves various crops and multiple uses of water. Within a watercourse command area in addition to crop cultivation, water is used for multiple purposes such as livestock, poultry, fishery, trees, drinking and other domestic uses. All these uses have social and economic value, and it becomes extremely intricate to study the overall productivity of water for larger irrigated domains. The analysis is further constrained by accurate measurement of water used for all these purposes and estimating the value of production per unit of water (Renwick 2001; Meinzen-Dick and van der Hoek 2001). To keep the analysis simple, the focus was on the gross inflow available at the watercourse command level and the gross value of production obtained by the crop sector. The water availability from canals, groundwater and rainfall was estimated and compared with the crop-water requirement for all the crops grown in the sample watercourse commands. The economic water productivity was estimated, in order to provide good indicator for comparison across the range crops grown in an irrigation system, that have differing yield ceilings, components and values.

*3.1.3.1 Comparing Water Availability and Crop Water Requirement:* The cropping pattern indicates that farmers are intensively growing high-water-loving cash crops. The seasonal crop-water requirement and the availability of water at the watercourse level are shown in figures 3a and 3b. The canal water supply was much less than the crop-water requirement in the study area. Quantitatively, it could not meet more than 35 percent and 25 percent of the crop demand in Kharif and Rabi seasons, respectively. The variation in daily discharge data shows that reliability was also low due to variations in actual flows, occasional breeching and canal closures. Rainfall events were sporadic and mostly concentrated over the Kharif season (July to August). This scenario led the farmers to pump more groundwater in order to sustain their crops. Groundwater has acquired a central role as it supplies about three-fourths of the gross inflow. However, seasonal groundwater withdrawals were higher than the crop water demand. The groundwater reservoir was subjected to immense 'pumpage'. Almost every farmer of the sample watercourses owned a tubewell. The average density of tubewells was one tubewell per 13 ha of cultivable land.

The average balance between gross inflow and crop-water demand was estimated to be 893 ± 304 mm and 176 ± 78 mm during Kharif and Rabi seasons, respectively. This balance amount is divided into evaporation, conveyance losses from main and branch watercourses, evapotranspiration from banks of watercourses and fields (grasses and trees), irrigation application losses due to seepage and percolation and nonagricultural uses. The disparity between water availability and demand was quite significant during the Kharif season compared to the Rabi season. On an average, gross inflow was 60 ± 9 percent and 31 ±9 percent higher than the crop demand during Kharif and Rabi seasons, respectively. This was due to the fact that besides conveyance and other inefficiencies, a large amount of water was needed to offset the seepage and percolation losses to maintain continuous flooding

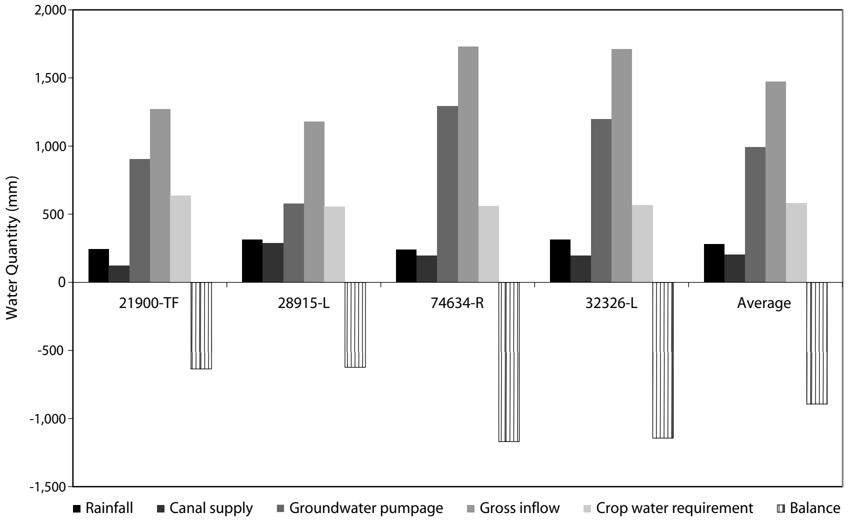
*Table 4. Farm-wise variation in water balance and water productivity of rice and wheat.*

| Indicators | Sample Farms | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | F1-21TF | F2-21TF | F1-28L | F2-28L | F1-74R | F2-74R | F1-32L | Farm average |
| Farm area ($m^2$) | 133,844 | 101,223 | 83,991 | 96,161 | 111,782 | 102,233 | 76,929 | 100,880 |
| Results for Rice crop | | | | | | | | |
| Rice area ($m^2$) | 94,701 | 99,199 | 72,520 | 74,567 | 51,712 | 66,478 | 58,030 | 73,887 |
| Irrigation (mm) | 1,042 | 1,259 | 1,095 | 1,511 | 1,109 | 1,374 | 1,181 | 1,224 |
| Rainfall (mm) | 167 | 163 | 214 | 210 | 187 | 189 | 217 | 192 |
| Gross inflow (mm) | 1,209 | 1,422 | 1,309 | 1,720 | 1,296 | 1,563 | 1,398 | 1,417 |
| Crop water requirement (ETc) (mm) | 627 | 553 | 608 | 573 | 563 | 549 | 537 | 573 |
| Rice yield (Kg/ha) | 3,788 | 2,997 | 3,260 | 3,260 | 3,227 | 3,326 | 3,030 | 3,270 |
| Gross value of production (Rs/ha) | 48,328 | 33,148 | 39,046 | 39,046 | 39,766 | 38,263 | 34,778 | 38,910 |
| Physical Water productivity (Kg/$m^3$) | | | | | | | | |
| $WP_{-GI}$ | 0.32 | 0.24 | 0.25 | 0.19 | 0.25 | 0.23 | 0.23 | 0.25 |
| $WP_{-I}$ | 0.38 | 0.30 | 0.30 | 0.22 | 0.29 | 0.28 | 0.29 | 0.29 |
| Economic Water productivity (Rs/$m^3$) | | | | | | | | |
| $WP_{-GI}$ | 4.05 | 2.63 | 2.98 | 2.34 | 3.09 | 2.79 | 2.59 | 2.93 |
| $WP_{-I}$ | 4.78 | 3.27 | 3.57 | 2.69 | 3.62 | 3.35 | 3.26 | 3.50 |
| Results for Wheat crop | | | | | | | | |
| Wheat area ($m^2$) | 74,955 | 101,198 | 84,035 | 76,908 | 55,537 | 69,521 | 66,792 | 75,564 |
| Irrigation (mm) | 195 | 209 | 177 | 257 | 153 | 217 | 229 | 205 |
| Rainfall (mm) | 104 | 104 | 111 | 111 | 98 | 97 | 104 | 104 |
| Gross inflow (mm) | 299 | 313 | 288 | 368 | 251 | 314 | 333 | 309 |
| Crop water requirement (ETc) (mm) | 411 | 414 | 392 | 403 | 459 | 450 | 399 | 418 |
| Wheat yield (Kg/ha) | 4,150 | 3,260 | 3,359 | 3,359 | 3,112 | 3,409 | 3,508 | 3,451 |
| Gross value of production (Rs/ha) | 31,902 | 23,320 | 24,206 | 24,206 | 23,340 | 24,776 | 24,972 | 25,246 |
| Physical Water productivity (Kg/$m^3$) | | | | | | | | |
| $WP_{-GI}$ | 1.39 | 1.07 | 1.17 | 0.93 | 1.35 | 1.085 | 1.06 | 1.15 |
| $WP_{-I}$ | 2.60 | 1.56 | 2.07 | 1.30 | 2.04 | 1.699 | 1.58 | 1.84 |
| Economic Water productivity (Kg/$m^3$) | | | | | | | | |
| $WP_{-GI}$ | 10.69 | 7.55 | 8.44 | 6.71 | 10.10 | 7.87 | 8.41 | 8.42 |
| $WP_{-I}$ | 20.19 | 11.14 | 15.12 | 9.45 | 15.27 | 12.45 | 3.57 | 13.57 |

*Note*: Data generated by the project research

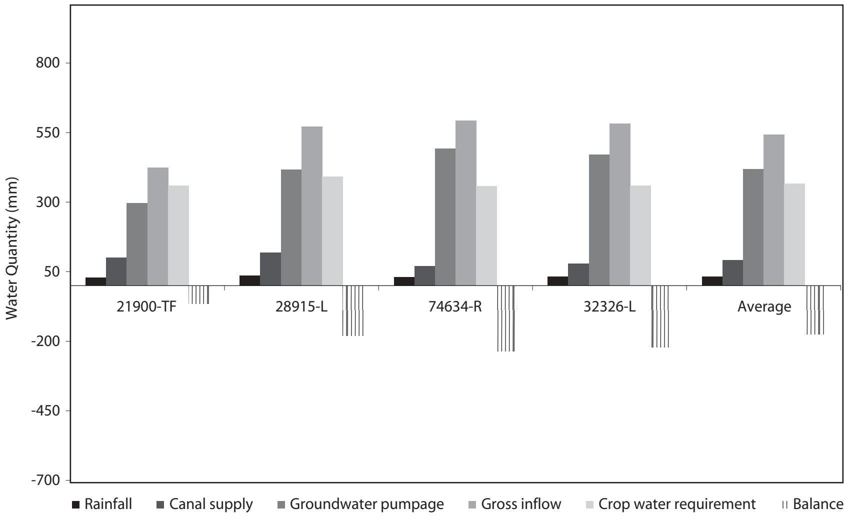
conditions for traditional rice cultivation. The availability of a high volume of water compared to the crop-water requirement at the watercourse level during the Rabi season appears to be contradictory to the opposite situation at field and farm levels described earlier. This spatial difference could be mainly attributed to the seepage and percolation from the watercourses before reaching the field. Various studies reported a conveyance loss of 25–50 percent from the watercourses (Corey and Clyma 1974; IWASRI 1988; WAPDA 1996).

*Figure 3a. Comparison of water balance components (Kharif 2001).*



*Note*: Data generated by the project research

*Figure 3b. Comparison of water balance components (Rabi 2001-2002).*



*Note*: Data generated by the project research

*3.1.3.2 Crop Water Productivity at the Watercourse Level:* The seasonal and annual gross value of production for sample watercourse is summarized in table 5. The watercourse-wise details of gross value of production, inflow values and water productivity are given in annex 3A. The average water productivity at the watercourse level during the Kharif season was estimated as 1.75 Rs/m$^3$ and 2.11 Rs/m$^3$ on the basis of gross and irrigation inflow, respectively. The corresponding values of $WP_{-GI}$ and $WP_{-Irrigation}$ for the Rabi season were estimated as 4.43 Rs/m$^3$ and 4.70 Rs/m$^3$. The annual GVP was skewed towards the Kharif value and estimated as 2.50 Rs/m$^3$ and 2.91 Rs/m$^3$ for gross and irrigation inflows, respectively.

The variations among watercourses show that 21-TF had the highest crop-water productivity followed by 28-L, 32-L and 74-R. It was observed that the areas, where farmers had diversified the cropping pattern by introducing orchards, sugarcane and Rabi vegetables obtained higher gross income per unit of land and a higher level of crop-water productivity. As shown in annexes 3B and 3C, the crop-wise analysis of land and water productivity indicates that:

- Rice gave the maximum gross income per unit of land using maximum water (maximum land return outweighs the water productivity concern from a farmer's perspective)
- Orchards gave high gross income per unit of land using less water (optimal land return with a higher level water productivity)
- Sugarcane gave a high gross income per unit of land, using a large volume of water (optimal land return with a higher level of water productivity)
- Sorghum (Kharif fodder) and oil seeds gave the least gross income per ha using the least amount of water.

Also, the watercourses with higher levels of adoption of laser–land-leveling and zero tillage technologies (21-TF and 28-L) had higher land and water productivity compared to the control watercourse (32-L) with no adoption and 74-R with a comparatively low level of RCT adoption.

*Table 5. Gross value of production per unit of water at the watercourse level.*

| Watercourse | Crop Water Productivity (Rs/m$^3$) | Kharif 2001 | Rabi 2001/2002 | Annual 2001/2002 |
|---|---|---|---|---|
| 21900/TF | $WP_{-GI}$ | 2.56 | 5.52 | 3.28 |
| | $WP_{-I}$ | 3.17 | 5.91 | 3.91 |
| 28915/L | $WP_{-GI}$ | 1.93 | 4.07 | 2.66 |
| | $WP_{-I}$ | 2.64 | 4.34 | 3.32 |
| 74634/R | $WP_{-GI}$ | 1.35 | 3.96 | 2.08 |
| | $WP_{-I}$ | 1.57 | 4.17 | 2.35 |
| 32326/L | $WP_{-GI}$ | 1.28 | 4.40 | 2.25 |
| | $WP_{-I}$ | 1.57 | 4.66 | 2.63 |
| Overall average | $WP_{-GI}$ | 1.75 | 4.43 | 2.50 |
| | $WP_{-I}$ | 2.11 | 4.70 | 2.91 |

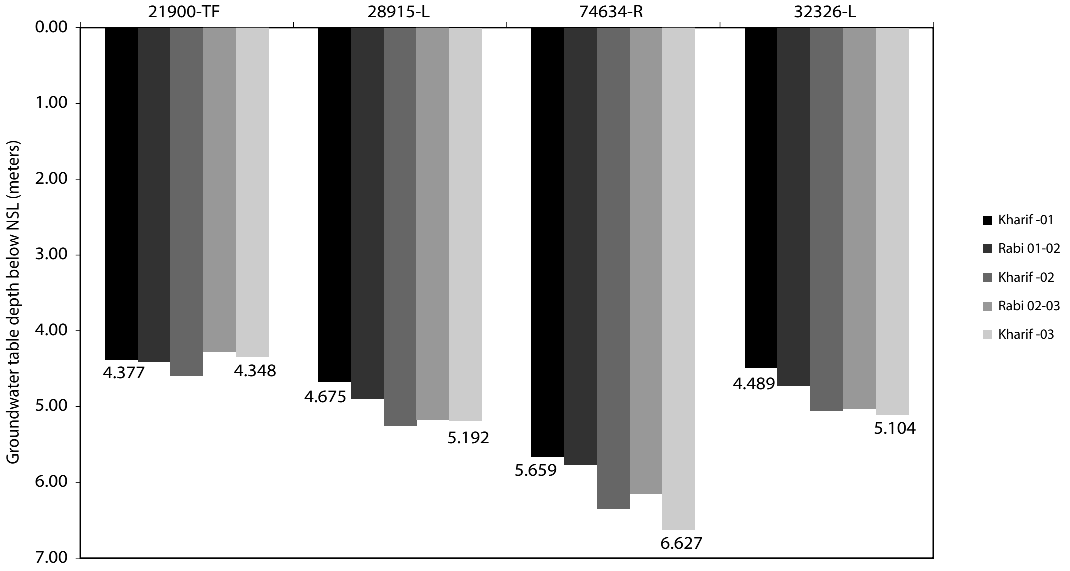
*Note*: Data generated by the project research

### *3.1.4 Change in Source Groundwater Table Depth*

Figure 4 shows the seasonal groundwater table depth measured with reference to natural soil surface. In 2001, the groundwater depth at different sample watercourses during the Kharif cropping season varied between 4.38 m and 5.66 m. The seasonal observations show a declining trend at three watercourses (74634-R, 28915-L and 32326-L), whereas the water table was almost stable at 21900-TF. The groundwater observations show that during Kharif 2003 the groundwater table depth varied from 4.35 m to 6.63 m in the study area. The watercourse-wise analyses over the study period show a decline of 0.97 m in the groundwater table's depth at the watercourse command of 74634-R (Kharif 2001: 5.66 m vs. Kharif 2003: 6.63 m). The other two watercourses showed a similar trend with 0.52 m and 0.62 m decline in the groundwater table's depth at watercourse commands of 28915-L and 32326-L, respectively, for the period Kharif 2001 to Kharif 2003. However, a slight rise of 0.03 m in the groundwater table was observed for the command area of 21900-TF (Kharif 2001: 4.35 m vs. Kharif 2003: 4.38 m). It could be attributed to the location of the watercourse (near the bank of two main canals i.e., Qadar Abad Baloki [Q.B.] the location of this Link canal and Upper Gugera Branch canal), also because the groundwater table was mainly influenced by the seepage from the aforesaid two canals.

Groundwater withdrawals from the aquifer were greater than the recharge rate during the three Kharif seasons and the Rabi 2001-2002 cropping season. However, in all the watercourse commands, a rise in the groundwater table was observed for Rabi 2002-2003 cropping season, indicating a net recharge to the aquifer. This is attributed to the intense rainfall during this season, which contributed to higher recharge and lower abstractions from tubewells.

*Figure 4. Seasonal groundwater table depth in the sample watercourses (Kharif 2001-2003).*



*Note:* Data generated by the project research

### 3.1.5 Change in Groundwater Quality

Groundwater quality of tubewells was measured by using an electrical conductivity meter (EC meter), and the results are summarized in table 6. The groundwater quality at 21900-TF varied from 0.580 to 1.20 dS/m, with an average of 0.843 dS/m. Two tubewells supplied groundwater to the command of 28915-L, with an average quality of 1.045 dS/m. At watercourse 32326-L, 17 tubewells were monitored and they showed large variations in pumped groundwater quality ranging from 0.890 to 1.690 dS/m. There were two tubewells in this watercourse command area having groundwater quality poorer than 1.5 dS/m, and they were categorized as pumping marginal[*] quality groundwater. At 74634/R, 38 tubewells had water quality in the range of 0.610 to 1.140 dS/m and an average value of 0.829 dS/m. The overall groundwater quality was acceptable for irrigation (i.e., < 1.5 dS/m).

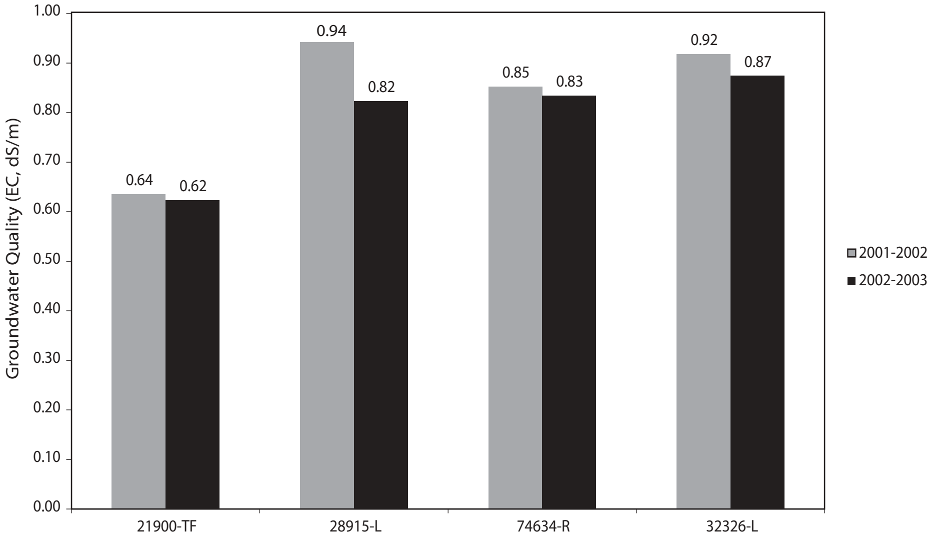
Figure 5 indicates the temporal variation in groundwater quality measured at piezometers within the watercourses, which shows similar trends in the four watercourses with lower values for 21900-TF and 74634-R compared to 28915-L and 32326-L. The average groundwater quality ranged from 0.64 dS/m to 0.94 dS/m during the year 2001-2003. A slight variation of 2-13 percent was observed over the study period.

*Table 6. Tubewell water quality in the study area.*

| Watercourse | Tubewells monitored (#) | Groundwater quality (EC, dS/m) | |
|---|---|---|---|
| | | Range | Average |
| 21900-TF | 23 | 0.580 to 1.20 | 0.843 |
| 28915-L | 2 | 1.010 to 1.080 | 1.045 |
| 74634-R | 38 | 0.610 to 1.140 | 0.829 |
| 32326-L | 17 | 0.890 to 1.690 | 1.244 |

*Note:* Data generated by the project research

*Figure 5. Variation in groundwater quality measured at piezometers during 2001-2003.*



*Note*: Data generated by the project research

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[*] Following criteria of Water and Power Development Authority for the study area, groundwater of EC < 1.5 dS/m was considered as fresh, 1.5 to 2.7 dS/m as marginal and > 2.7 dS/m as saline (Beg and Lone 1992).

## 3.2 Field Level Testing and Development of Rice-Wheat Crop Establishment Methods

### *3.2.1 Agronomic Evaluation of Rice-Wheat Crop Establishment Methods*

Direct seeded rice was established about one month earlier than the transplanted rice. During the first year, both direct seeding and transplanting were done in July, but the direct seeded crop was sown only one week earlier than transplanted rice. In the following two seasons, the crop was direct seeded in mid-June and transplanted in July. In some fields at F1-74R (Dogar Farm), rice transplanting was delayed up to the first week of August. The harvesting of rice was done at the same time for all the treatments during November. The wheat sowing was completed within 1–2 weeks after the rice harvest, and it was harvested during April and May.

*3.2.1.1 Agronomic Performance of Rice:* The plant height for four rice treatments ranged from 93 cm to 116 cm, with a lower height attained by the direct seeded rice when compared to that of the transplanted rice. The panicle length for DSRF and DSRB was 25.32 cm and 24.08 cm, whereas the corresponding values for TPRB and TPRF were 27.57 cm and 28.31 cm, respectively. Rice may be attacked by 70 species of insect pests in Pakistan, which can cause 25–30 percent yield losses annually. Of these, stem borers, leaf folder, white backed plant hopper and grasshoppers are the chief destroyers. However, in our experimental plots the population of these insects was too small to damage the crop and the successful pesticide applications too contributed in checking this pest menace.

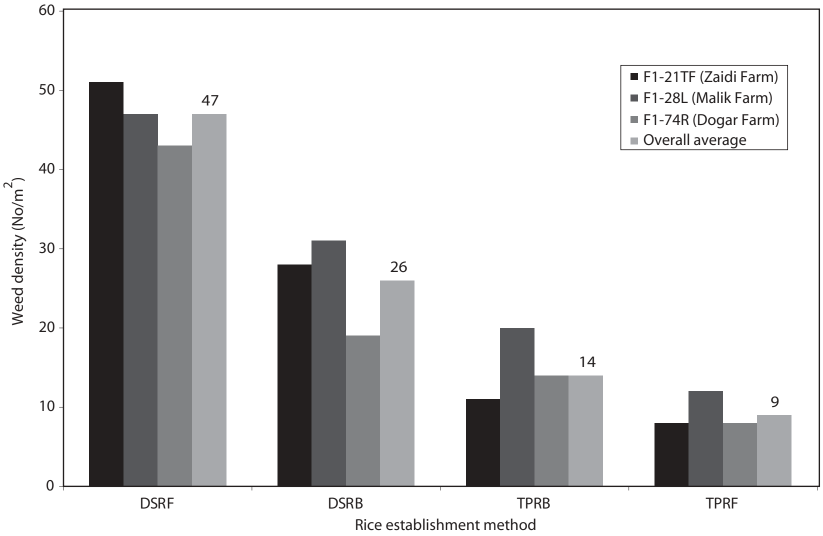
Weed type and the degree of infestation in rice fields are often determined by the type of rice culture (irrigated, rain-fed lowland, deepwater or tidal wetlands); stand establishment method (transplanted, direct seeded); moisture regime (irrigated, rain-fed) land preparation and cultural practices (De Datta 1981; Baltazar and De Datta 1992). Out of the more than 1,000 weed species reported to grow in rice fields, the grass family Poaceae is the most common, followed by Cyperaceae (sedge) family. Other important weed families are: Alismataceae, Asteraceae, Fabaceae, Lythraceae and Scrophulariaceae (Smith 1983). The number of weed species that make up the major portion of weed flora in any rice field is usually less than ten; in most cases only three or four species are important (Ahmed and Moody 1982; Kim and Moody 1980). Similar findings were observed in our sample sites. Higher weed infestations were observed in direct seeded rice (DSRF: 47 weeds/$m^2$; DSRB: 26 weeds/$m^2$) when compared with transplanted rice (TPRB: 14 weeds/$m^2$; TPRF: 9 weeds/$m^2$) (figure 6). The main weeds were Cyprus rotundus, Echinochloa crassgali and Cyprus iria. Due to high weed infestation in direct seeded rice, more weed control measures were taken in terms of manual weeding and herbicide application compared to those in transplanted rice. Better weed control was achieved at F1-21TF (Zaidi Farm) compared to the other two farms, with least success at F1-74R (Dogar Farm). The interaction between water, tillage and weeds is complex and difficult to manage on farm, where effective herbicides are not available and water reliability is a constraint. Bhagat et al. (1996), after comprehensive study of such interactions, suggested further research was still required.

Figure 7 summarizes the rice yields obtained in the field trials. The yield of all treatments was better at F1-21TF (Zaidi Farm) compared to F1-28L (Malik Farm) and F1-74R (Dogar Farm). The 3-year average paddy yield for DSRF ranged from 1,391 Kg/ha, at F1-74R (Dogar Farm), to 4,185 Kg/ha, at F1-21TF (Zaidi Farm). The corresponding values for TPRB and TPRF were in the range of 1,868 Kg/ha to 3,762 Kg/ha, and 2,809 Kg/ha to 4,551 Kg/ha, respectively. The performance of all treatments at 21-TF (Zaidi Farm) was better than the other six sample farms. The paddy yield under DSRF, DSRB and TPRB was around 4 t/ha at F1-21TF (Zaidi Farm), which was higher than the paddy rice yield obtained by conventional methods at other sample farms (3 t/ha) (see table 4). Overall, DSRF (2,878 Kg/ha) and DSRB (2,850 Kg/ha) produced 26 percent and 27 percent, lower yields when compared to TPRF (3,910 Kg/ha). Whereas, TPRB (3,124 Kg/ha) yielded 20 percent lower as compared to TPRF. The following major yield-reducing factors were identified:

- With DSRF, DSRB and TPRB, weeds are the major constraint and severely affected yield at F1-74R and F1-28L.
- The poor seed germination resulted in poor stand uniformity and density. Better depth precision is required from direct seeders, which now place the seed deep for successful germination.
- Lack of experience in agronomy and irrigation management with the alternative technologies in farm settings, particularly in relation to managing water supplies.
- Poor canal water availability particularly affected the direct seeded rice on beds and on the flat. The lack of water control resulted in poor weed management under direct seeded and bed planted rice, which contributed to high yield loss at F1-74R (Dogar Farm).

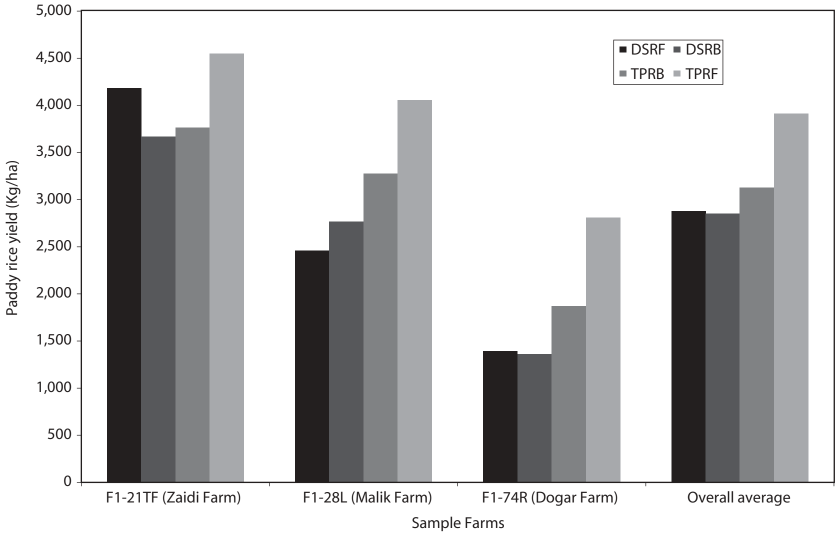
There could be many other reasons for lower yields under alternately wet and dry rice cultivation (DSRF, DSRB and TPRB), which have not been monitored during this study. For instance, Sharma et al. (2002) and Singh et al. (2002) reported lower rice yields under aerobic conditions, which have often occurred in these trials without being an explicit treatment. The major yield reducing factors were reported to be iron and zinc deficiency, higher nematode populations causing root galling, excessive infestation of weeds and lack of availability of suitable rice cultivars.

*Figure 6. Incidence of weeds in various rice establishment methods.*



*Note:* Data generated by the project research

*Figure 7. Rice yield under various establishment methods at sample farms.*

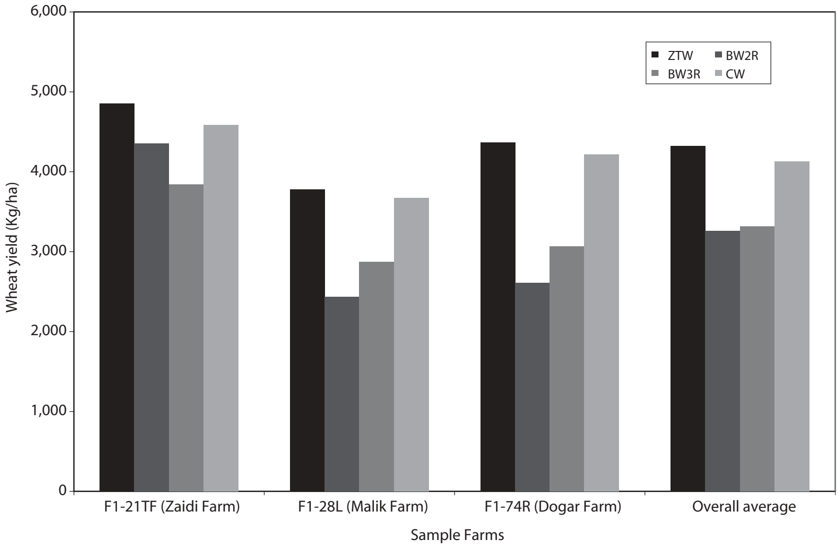


*Note*: Data generated by the project research

*3.2.1.2 Agronomic Performance of Wheat:* The plant height for four wheat treatments ranged from 93-95 cm, at F1-21TF (Zaidi Farm), 91-95 cm at F1-28L (Malik Farm) and 97-100 cm at F1-74R (Dogar Farm). The spike length also showed minor variations across the sample farms and ranged from 10-12 cm. The incidence of insects and weeds remained normal in all the studied methods and suitable agronomic and chemical control measures were used as and when required. Compared to rice, lower spatial variations were observed among the sample sites (figure 8). The wheat yield under zero tillage was higher than the other three methods at all three sites. The wheat yield for zero tillage ranged from 3.8 t/ha, at F1-28L (Malik Farm), to 4.9 t/ha at 21-TF (Zaidi Farm), whereas, the corresponding values under conventional tillage ranged from 3.7 t/ha at F1-28L (Malik Farm) to 4.6 t/ha at F1-21TF (Zaidi Farm). Bed planted wheat had lower yield than zero tillage and conventional ploughing, averaging 3.3 t/ha (WB2R and WB3R) and 4.1 t/ha (conventional). The wheat yield on beds was significantly lower (2.6 t/ha) during the first year of experiment.

The rice crop residue obstructed the smooth sowing and germination of wheat seed. Based on this experience, during the second year beds were re-constructed after the harvesting of rice crop. Wheat seed was sown on these new beds, which resulted in better crop germination. Therefore, during the second year wheat yields increased to 3.9 t/ha, although it was still slightly lower than the wheat yield obtained under conventional (4.1 t/ha) and zero tillage method (4.3 t/ha). The results indicate that the introduction of suitable machinery for proper management of crop residue management could help in improving wheat yields under zero tillage and beds planting methods.

*Figure 8. Wheat yield under various establishment methods at the sample sites.*

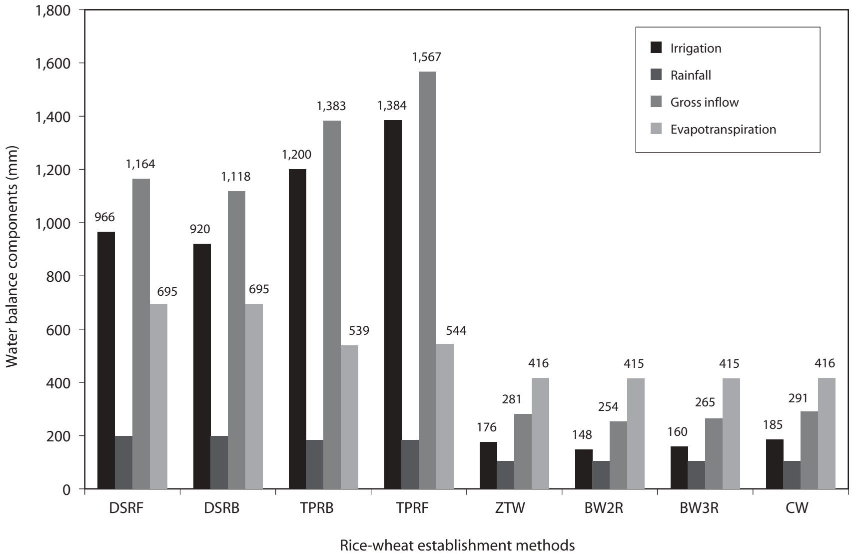


*Note:* Data generated by the project research

### *3.2.2 Water Balances of Rice-Wheat Treatments*

Figure 9 shows the water balance components for rice-wheat establishment methods. Crop water demand and water supply were higher in rice than in wheat, indicating higher dependence of rice on irrigation compared to wheat. Irrigation for direct seeded rice was lower than in the conventional transplanting methods. The irrigation depths on DSRB and DSRF were 920 mm and 966 mm, respectively, some 34 percent and 30 percent lower than the 1,384 mm applied with conventional transplanting. The transplanting rice on beds (TPRB) also used 13 percent less water than transplanting on the flat. The rainfall share in gross inflow for rice was less than 25 percent of supply at 198 mm for direct seeded and 183 mm for transplanted rice, making for a slightly higher rainfall contribution to the earlier planted direct seeded rice. The comparison of total water input (gross inflow) and crop-water requirements show a greater excess with conventional practices (1,567 mm supplied for $Et_p$ = 544 mm). Hence, about 65 percent of the water supplied to conventionally transplanted rice leaves the field as seepage and percolation, and in turn recharging the groundwater aquifer. This water is recycled through groundwater pumping in the same/adjoining areas or downstream of the study areas. The gross inflow to DSRF and DSRB was 1,164 mm, and 1,118 mm, against the potential crop-water requirement of 695 mm: direct seeded rice used about 60 percent of gross inflow beneficially as evapotranspiration and 40 percent water goes to seepage and percolation. More efficient water management occurred at F1-21TF (Zaidi Farm) compared to other two sample farmers' farms.

*Figure 9. Comparison of water balance components for rice-wheat treatments.*



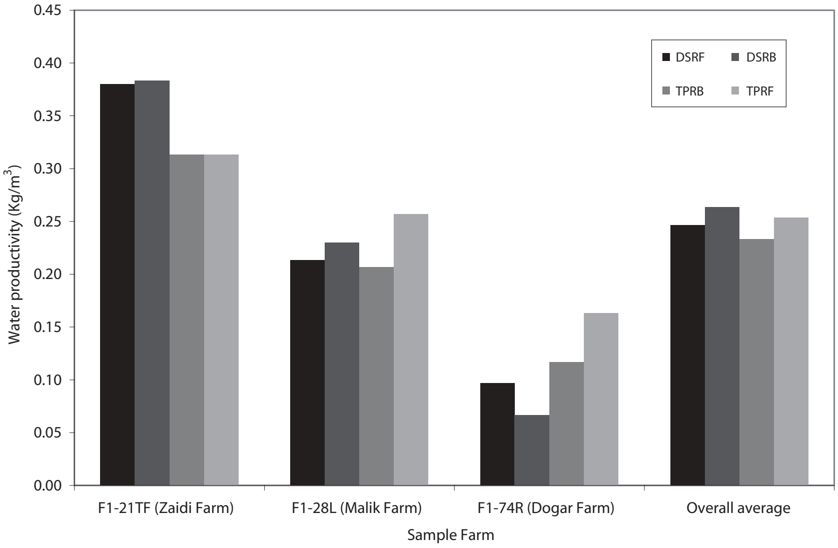
*Note*: Data generated by the project research

Irrigation applications on wheat ranged from 148 mm to 185 mm, and the corresponding gross inflow from 254 mm to 291 mm against the potential crop-water requirement of 415 mm. All treatments received less potential crop-water requirement. This potential water stress was mitigated by the water stored in the root zone after the rice harvest, although it was not measured in this study. The practice of under-irrigating wheat was observed throughout the study area, as farmers tend to maximize the benefit of rainwater. Bed-planted wheat received 17 percent less irrigation than the conventional treatment. In the case of on Zero-tilled wheat, 176 mm were applied, which is, only 5 percent lower than what is used in conventional wheat (185 mm). Normally greater water savings are attributed to zero tillage as more root zone moisture is available than after conventional ploughing. The fact that the sowing dates for ZT and conventional treatments were the same has probably contributed to masking this commonly observed difference. The reduction in water needed for bed planting is due to more rapid watering, and more limited 'ponding'.

### *3.2.3 Comparing Water Productivity of Rice Treatments*

Water productivity of rice establishment methods showed large variations with respect to site. The water productivity of the four establishment methods was higher at F1-21TF (Zaidi Farm) compared to F1-28L (Malik Farm) and F1-74R (Dogar Farm), as shown by figure 10. The average $WP_{-GI}$ ranged for 0.31 $Kg/m^3$ to 0.38 $Kg/m^3$ for the four rice treatments at F1-21TF, indicating about 23 percent higher $WP_{-G1}$ for direct seeded rice (DSRF and DSRB) over transplanted rice (TPRB and TPRF). At this farm, irrigation water productivity of direct seeded rice was about 33 percent higher (DSRF: 0.47 $Kg/m^3$ and DSRB: 0.48 $Kg/m^3$) compared to transplanted rice on beds (TPRB: 0.36 $Kg/m^3$) and flat 'puddled' fields (TPRF: 0.35 $Kg/m^3$).

*Figure 10. Water productivity (WP$_{\text{–GI}}$) of rice establishment methods.*



*Note:* Data generated by the project research

At F1-28L (Malik Farm), WP$_{\text{–GI}}$ was 0.26 Kg/m$^3$ and 0.21 Kg/m$^3$ for transplanted rice on flat and beds, respectively. The corresponding values for direct seeded rice on flat and beds were 0.21 Kg/m$^3$ and 0.23 Kg/m$^3$, respectively. The lowest water productivity for all four rice establishment methods was observed at F1-74R ranging from 0.07 Kg/m$^3$ for DSRB and 0.16 Kg/m$^3$ for TPRF. Consistent with F1-21TF, WP$_{\text{–I}}$ was higher than WP$_{\text{–GI}}$ and was in the range 0.25-0.30 Kg/m$^3$ and 0.08-0.19 Kg/m$^3$ at F1-28L and F1-74 R respectively. The results show that, despite of lower water input to direct seeded rice and bed planting rice, the water productivity remained lower than for the conventional method at these two sites. The gains in water productivity were restricted due to the fact that water savings were outweighed by reduced yields for direct seeded and bed planted rice compared to the conventional method at F1-28L (Malik Farm) and F1-74R (Dogar Farm).

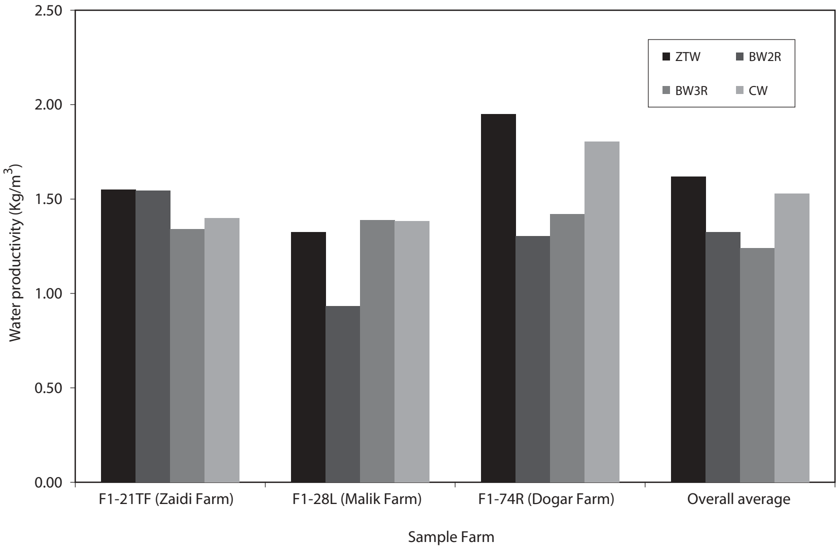
Combining the results of the entire three-sample sites, WP$_{\text{–GI}}$ of direct seeded rice on flat and conventional transplanted methods was similar (0.25 Kg/m$^3$). The DSRB and TPRB were also not markedly different with overall average of 0.26 Kg/m$^3$ and 0.23 Kg/m$^3$, respectively. Research conducted in the Burdekin River Irrigation Area in Queensland, Australia, also showed similar evidence (Borrell et al. 1997; Thompson 2002). The 4-year comparison showed 10 percent water savings under bed planted rice over the traditional flat planting method. A similar reduction in grain yield (11.6 t/ha for flat sowing and 10.2 t/ha for bed sowing) resulted in no net improvement in water productivity. This study shows that to obtain a sustainable increase in the water productivity of rice (through direct seeded and bed planting methods) requires reliable mechanisms to cope with the yield-reducing factors.

### *3.2.4 Comparing Water Productivity of Wheat Treatments*

Figure 11 shows the average water productivity of wheat establishment methods at the three sample farms. Compared to rice, wheat did not show a markedly different behavior across the sites. The WP$_{\text{–GI}}$ of conventional wheat ranged from 1.39-1.81 Kg/m$^3$, with an average of 1.53 Kg/m$^3$. The average WP$_{\text{–GI}}$ for zero tillage was 1.62 Kg/m$^3$, ranging from 1.33-1.95 Kg/m$^3$. ZT wheat had an

8 percent and an 11 percent higher $WP_{-GI}$ compared to those of the conventional methods i.e., at F1-74R and F1-21TF. However, at F1-28L, $WP_{-GI}$ was 4 percent less than the conventional method. The irrigation water productivity of zero tillage wheat was 11–25 percent higher than with the conventional establishment at the three sample farms.

*Figure 11. Average water productivity ($WP_{-GI}$) of wheat establishment methods.*



*Note*: Data generated by the project research

Overall, $WP_{-I}$ for zero tillage wheat was 3.00 Kg/m$^3$ and was higher than that for conventional (WC: 2.51 Kg/m3) and bed planted wheat (BW2R: 2.98 Kg/m$^3$ and BW3R: 2.57 Kg/m$^3$). The average water productivity of bed planted wheat was consistently lower than conventional and zero tillage methods. This was due to the considerably lower yields, which is attributed to the difficulty in sowing through rice residue on permanent beds resulting in poor seed germination. During Rabi 2001-2002 $WP_{-GI}$ was 1.2 Kg/m$^3$ and 1.12 Kg/m3 for BW2R and BW3R, compared to 1.78 Kg/m$^3$ for conventional wheat and 1.70 Kg/m$^3$ for zero tillage wheat. However, during Rabi 2002-2003 new beds were formed and $WP_{-GI}$ was higher (BW2R: 1.45 Kg/m$^3$ and BW3R: 1.36 Kg/m$^3$) than for conventional (CW: 1.28 Kg/m$^3$) but lower than that for zero tillage wheat (1.54 Kg/m$^3$).

## 3.3 Promotion of Resource Conservation Technologies

### *3.3.1 Adoption of Resource Conservation Technologies*

The promotion of RCTs for wheat generated a more encouraging response than the adoption of other new methods for rice cultivation. Rice growers benefited by the laser leveling of their undulating fields, but farmers were well aware of the poor performance of direct seeding and bed planting of rice. Table 7 summarizes the adoption of the various resource conservation technologies in the project area over the span of the project.

*Table 7. Adoption of resource conservation technologies in the project areas.*

| RCTs adopted | Sample watercourses | | | Total |
|---|---|---|---|---|
| | 21900-TF | 28915-L | 74634-R | |
| Laser land leveling (ha) | | | | |
| *Baseline 2001-2002* | 57 | 6 | 4 | 68 |
| *Project end 2003-2004* | 115 | 42 | 50 | 208 |
| Zero tillage drills (#) | | | | |
| *Baseline 2001-2002* | 4 | 1 | 1 | 6 |
| *Project end 2003-2004* | 10 | 2 | 7 | 19 |
| Wheat area under zero tillage (ha) | | | | |
| *Baseline 2001-2002* | 39 | 24 | 40 | 104 |
| *Project end 2003-2004* | 158 | 29 | 125 | 312 |
| Wheat residue management (ha) | | | | |
| *Baseline 2001-2002* | 2 | 0 | 0 | 2 |
| *Project end 2002-2003* | 51 | 6 | 2 | 59 |
| Rice residue management (ha) | | | | |
| *Baseline 2001-2002* | 0 | 0 | 0 | 0 |
| *Project end 2003-2004* | 17 | 4 | 2 | 23 |

*Note*: Data generated by the project research

The area under laser leveling for the three sample villages increased from 68 ha during 2000-2001 to 208 ha during 2003-2004. The area laser leveled in sample villages increased from 57 to 115 ha, 6 to 42 ha, and 4 to 50 ha, during 2001-2004, at 21900-TF, 28915-L and 74634-R, respectively. Although the window available to complete 'Laser Land Leveling' is limited due to the importance of timely wheat planting following rice, many farmers still made a big effort to level their fields.

The number of zero tillage drills in the project area increased from 7 units to 19 units from baseline year 2000-2001 to 2003-2004. Owners provided a rental service of ZT drills, which was a major factor in technology transfer to small farmers. The promotion of zero tillage technology to adjacent areas resulted in an increase zero tillage drills from 2 to 33 units over the same period of time. Consequently, the area under zero tillage wheat in sample villages was increased from 104 ha (32% of area) during 2000-2001 to 312 ha (90% of area) during 2003-2004. The bed planting of rice-wheat received little attention from farmers. The farmers experimented with 16 ha of wheat on beds in 2002-2003 but they were not impressed. A lack of bed planting equipment and difficulty in crop residue management may have contributed to negate any farmer enthusiasm.  However, key factor restricting adoption was attributed to yield impacts.

The management of crop residue was identified as the key issue in improving the adoption of RCTs in rice-wheat system. Innovative techniques for residue incorporation and management were demonstrated in each crop season and appropriate machinery was made available by OFWM. Similar demonstrations were made at Farmers' Days. The area under wheat residue management increased from 2 to 59 ha during the project period. A few farmers also started incorporating rice residue into their soils increasing area under rice residue management from 0 to 23 ha. Farmers normally burn rice-wheat residues left after a combine harvesting. Efforts were made to link local manufacturers and the Farm Machinery Institute (FMI) of PARC to rectify technical problems and modify the existing equipment available for residue management. These modifications will lead to development of a new machine capable of performing both operations in one and at the same time.

### *3.3.2 Farmers' Views About Resource Conservation Technologies*

The farmers' views about the advantages and problems of laser land leveling, zero tillage and bed planting are summarized in table 8. The socioeconomic profile of the sample farmers is given in annex 4. The survey results showed that 57 to 100 percent of the sample farmers in the four watercourses were aware of laser leveling. With respect to zero tillage technology, 71 percent of respondents at 74634/R, 100 percent at 28915/L and 21900/TF and 75 percent at 32326/L were aware of this technology. Furrow-bed technology was known to 40 to 60 percent of the respondents at different watercourse commands. The majority of farmers received information about these technologies from fellow farmers who had adopted these technologies and from the 'On Farm Water Management Department'.

The majority of the farmers indicated that these technologies are useful in water saving and enhancing crop yields. They identified several benefits and constraints of laser leveling, zero tillage and bed planting as enlisted in table 8. The results indicated that farmers are more convinced about the advantages of these technologies. Though they were not able to quantify these benefits, they still considered laser leveling, zero tillage and bed planting as means of saving water, increasing yield, reducing cost and increasing farm incomes. More efforts are needed to devise suitable policies to provide greater number of this equipment, and demonstrating how to use them in farmers' fields with a view to enhance their adoption prospects. Farmer's opinions about the effectiveness of bed planting are not consistent with the results obtained in field trials, where performance (of bed planting) was considerably poorer than in conventional methods. Since adoption rates thus far are also low, this is hard to explain, but farmers are anecdotally aware of the success of this method with crops such as maize grown beds in Punjab and North West Frontier Province NWFP, in association with ACIAR sponsored research.

### *3.3.3 Constraints and Opportunities in Adoption of Resource Conservation Technologies*

The socioeconomic and adoption survey was conducted in the four sample watercourses, for which 41 respondent farmers from where the adoption of Resource Conservation Technologies had been promoted (i.e., 21900/TF, 28915/L and 74634/R), and 16 farmers from the control watercourse 32326/L, where no intervention was carried out were selected. The rapid adoption of the zero tillage technology was observed among the sample farmers, while other technologies failed to make much of an impression. This was because they were not either readily accessible to farmers (e.g., laser land leveling, residue chopper and bed planter) or they required further improvement to generate acceptable crop yields (e.g., direct seeding and bed planting of rice). Therefore, the discussion of survey results regarding the adoption of Resource Conservation Technologies will, hereafter, refer to zero tillage only. Laser leveling has not been widely adopted in the rice-wheat area where this research was conducted. However, it is being more extensively used in the sugarcane-wheat zone, where groundwater salinity is higher and canal water supplies are erratic.

*Table 8. Farmers' views about the advantages and constraints regarding resource conservation technologies.*

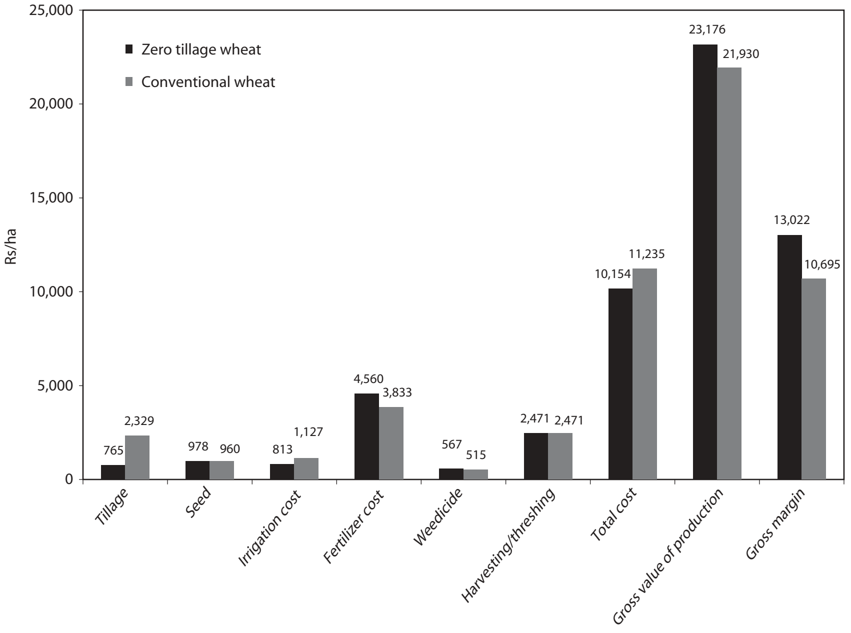
| Laser leveling | Zero tillage | Bed planting |
|---|---|---|
| Advantages | | |
| • Water saving<br>• Bigger plot sizing making cultivation and harvesting easier<br>• Smooth fields and uniform water distribution<br>• Better crop stand and yield<br>• Reduced field dikes/bunds<br>• Earlier field preparation | • Cheaper source of water saving<br>• Saves time and energy<br>• Increases yield<br>• No waste of fertilizer and seed<br>• Covers more area per unit of time<br>• Better seed germination<br>• Reduce land preparation cost | • Efficient irrigation requiring less amount of water and saves time<br>• Better crop stand<br>• Good technology for poor/saline soils<br>• Saving of puddling cost in rice production<br>• Fertilizer saving |
| Disadvantages | | |
| • Shortage of laser equipments anecdotally<br>• Difficult access particularly for small farmers | • Lack of zero tillage machines<br>• Continuous use may cause soil compaction and reduce yields<br>• More farm management efforts about weed control | • Unavailability of bed planter<br>• Difficulty in harvesting operation<br>• More weed management and labor requirements |

*Note*: Data generated by the project research

The main reasons for not adopting these technologies were financial, unavailability of RCT machinery, small landholdings and preference for traditional practices. The four farmers who adopted the zero tillage and later abandoned the practice reported unavailability of zero tillage drill on time, lack of financial resources and adequate advice and difficulty in weed control as the major reasons for doing so. However, 95 percent of the adopters intended to continue using zero tillage technology for wheat cultivation.

Figure 12 indicates the relative costs of production against income from zero tillage and conventional wheat in the study area. Zero tillage reduces costs for tillage and irrigation practices. Zero tillage adopters use more fertilizer, resulting in higher costs compared to the conventional method. The survey responses indicate lower labor requirements for zero tillage, but these have not been estimated here. Adopters of zero tillage obtained higher gross margins by 2,327 Rs/ha (gross margins: 13,022 Rs/ha) than those using conventional practices (gross margin: 10,695 Rs/ha). The higher economic returns from adopting zero tillage technology were attributed to lower cost of production (Zero tillage: 10,154 Rs/ha vs. Conventional: 11,235 Rs/ha) and a slightly higher yield (Zero tillage: 3,143 Kg/ha vs. Conventional: 2,965 Kg/ha), which is reflected as higher GVP in Figure 12.

*Figure 12. Comparison of zero tillage and conventional wheat production costs and income (Rabi 2002-2003).*



*Note:* Data generated by the project research

## 4 CONCLUSIONS AND RECOMMENDATIONS

- There is a considerable over-supply of irrigation water to rice cultivated through conventional practices at field, farm and watercourse levels. While much of it is lost as percolation to groundwater, which can be recycled where water quality is good. Higher irrigation efficiency will contribute to reduce pumping costs, help diminish un-productive evaporation and minimize long-term mixing of saline and freshwater aquifers. In scaling from field and farm to watercourse levels, crop-water productivity shows a large spatial and temporal variation. The adoption of two resource conservation technologies (laser land leveling and zero tillage) contributes to higher land and water productivity at field and farm scale, for wheat only. None of the technologies promoted for rice cultivation are yet to show profitability on the farm and, thereby creating a need to further develop these technologies. It is not possible to assess the impact of water savings at the system scale with the available data, and in addition to that there are methodological difficulties concerning measurement. These can be addressed by a carefully targeted and quantified survey of adopters' assessments of water savings and what they do with that water.
- Direct seeded rice lowered total water input by 30 percent, whereas conventional transplanted rice on beds had a 15 percent reduction in the total water input. The average water productivity of rice ranged from 0.29 to 0.32 Kg/m$^3$ among the treatments, with direct seeding giving higher water productivity than conventional transplanting. However, rice yields were considerably lower under direct seeding, mainly due to :a) poor seed germination and crop establishment; b) causing high weed infestation; and, c) machinery problems and

lack of on-farm experience regarding water management and agronomic practices for new rice establishment methods.

- Zero tillaged wheat provided better land and water productivity compared to conventional ploughing and seeding. And in the case of bed planted wheat, further refinement in planting machinery is needed to achieve uniform germination and in the improvement of land and water productivities.
- Farmers are convinced of the benefits of laser leveling and zero tillage, but adoption is constrained, particularly for small farmers by access, cost and time availability. Farmers would benefit from further training on the selection and use of resource conservation technologies.
- Further research and development is needed to secure acceptable yields of rice under direct seeding and bed planting, before educating the farmers on the advantages of adopting these technologies. Further work needs to be done to understand the extent of real water savings at the system level, which might justify further development and promotion of water saving technologies for rice in Pakistan’s Punjab.

## 5 FUTURE DIRECTION AND THE WAY FORWARD

The socioeconomic conditions of farmers in the Rice-Wheat Zone of Pakistan’s Punjab and most parts of South Asia compel them to concentrate more on increasing the economic returns from rice production by diverting large amounts of fresh water. They are more keen on increasing land productivity in order to improve their incomes and food security than improving water use efficiency. Adoption of resource conserving technologies, particularly ones that save water, depend primarily on their economic attractiveness to farmers (if they save production costs and increase profitability, then there is little standing in the way of adoption in the long run). If significant costs are imposed, but the benefits are still greater, the element of risk will play a major role in determining the degree of attractiveness to different farmers.

Policies that encourage the adoption of resource conserving technologies to save water need to ensure that the expected real water savings will accrue. The policymakers should have a clear understanding of the types of incentives required to put the policy into practice, ranging from enabling local market activity to outright subsidy. Although at the field scale, these technologies look promising water saving options, whether they really save water at irrigation system/river basin level is not yet known and requires further study. The application of an integrated modeling approach at field, irrigation system and basin levels can provide answers under scenarios of accelerated adoption of resource conservation.

The long-term impact of these new crop establishment methods on soil-health and productivity needs to be explored, particularly in areas where excessive irrigation plays a significant role in leaching salts below the root zone.

Further promotion of the resource conservation technologies in Pakistan’s rice-wheat system requires a multi-dimensional and integrated effort. Three simultaneous activities are implied below:

1. A suitable policy framework and action program to promote well-developed water conservation technologies. At present, laser leveling and zero tillage methods receive more attention from farmers. Improving farmers’ access to these technologies may be the first step in improving land and water productivity at the system level. Encouraging rental markets

and provision of lower cost machinery appropriate for small farms would address these issues. The history of machinery pools and state provided equipment is not encouraging and more self-sustaining solutions are needed.

2. Further research is needed to perfect technologies that minimize yield penalties compared to conventional practice: these should allow better seeding depth control and crop establishment through crop residues for rice, both on the flat and on beds; and for wheat on beds. Further work is required to optimize the sizing and irrigation management of permanent beds, and an economic analysis of the cost benefit of laser leveling and temporary and permanent bed cultivation. The reductions in yield compared to conventional methods of rice cultivation on beds in Australia are marginal compared to those experienced in Punjab, although they probably have a significant effect on gross margin, since most of the profit generated is derived from the final ton or so of production (i.e. the fifth ton of production in a 5t/ha crop).

3. Further research is needed to justify the economic and regional case that water savings generated by RCT adoption justify policy and technological development. This means assessing and modeling adoption rates, impacts and understanding what farmers do with ‘saved’ water. Where do real savings accrue and to whom? Long-term justification for minimizing groundwater use relates to the likelihood and risk of the mixing between saline and fresh groundwater through continuous pumping and recycling, especially in rice producing areas. This can also be modeled in order to develop better long term strategies for conjunctive use that minimize water quality degradation of the aquifer.

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# ANNEX 1

## Data Collection and Analysis at Field, Farm and Watercourse Levels

| Sr. # | Level | Component | Sub-component | Unit | Frequency | Method |
|---|---|---|---|---|---|---|
| 1 | Field | Inflow | Canal water | cm | Whenever irrigated | measured by cutthroat flume |
| | | | Tubewell water | cm | Whenever irrigated | recorded discharge rate and operation hours |
| | | | Rainfall | mm | Daily | measured by rain gauge near the field |
| | | | Imported water from other field | cm | Whenever imported | measured by cutthroat flume |
| | | Storage change | | mm | Each crop season | inflow minus outflow |
| | | Outflow | Evapotranspiration | mm/d | Daily | Hargreaves method |
| | | | Deep percolation | mm/d | Once for rice | estimated using basic infiltration rate |
| | | | ET + DP | mm/d | Daily | measured by daily depletion data using scales |
| | | | Exported water to other fields | cm | per event | measured by cutthroat flume |
| 2 | Farm | Inflow | Canal water | cm | Daily | measured by current meter/cutthroat flume |
| | | | Tubewell water | cm | Daily tubewell operating hours | recorded discharge rate and operation hours for all tubewells |
| | | | Rainfall | mm | Daily | measured by rain gauge |
| | | Storage change | | mm | Each crop season | inflow minus outflow |
| | | Outflow | Evapotranspiration | mm/d | Daily | total ET by multiplying ET of each crop by respective area |
| | | | Deep percolation | mm/d | Once for rice | estimated using steady state infiltration rate |
| | | | Surface drainage | cm | per event | measured by cutthroat flume |

(continued)

# ANNEX 1 (Continued)

## Data Collection and Analysis at Field, Farm and Watercourse Levels

| | | | | | | |
|---|---|---|---|---|---|---|
| 3 | Watercourse | Inflow | Canal water | cm | Daily | measured by head after calibration of the outlet and cutthroat flume |
| | | | Tubewell water | cm | Daily tubewell operating hours | recorded discharge rate and operation hours for all tubewells |
| | | | Rainfall | mm | Daily | measured by rain gauge |
| | | | Subsurface inflow | cm | from measured water table gradients | by monitoring groundwater fluctuation through piezometers |
| | | Storage change | | cm | Each crop season | Inflow minus outflow |
| | | Outflow | Evapotranspiration | mm/d | Daily | Total ET by multiplying ET of each crop by respective area |
| | | | Deep percolation | mm/d | Once for rice | estimated using basic infiltration rate |
| | | | Surface drainage | cm | per event | by measuring flow through surface drains |
| | | | Subsurface outflow | cm | On monthly/seasonal basis | by monitoring groundwater fluctuation by piezometers |
| 4 | Other Data | | Water table depth | m | On weekly basis | piezometer monitoring on weekly basis |
| | | | Electrical conductivity | ds/m | On monthly basis | electrical conductivity through EC meter |
| | | | Distributary discharge | cumecs | Daily | measured discharge at head of the distributary |
| | | | Crop data | | For whole cropping season | recorded type of the crop and acreage sown |
| | | | Agricultural practices | | For whole cropping season | recorded agronomic practices |
| | | | Other related data | | | from primary and secondary sources |

*Note*: Data generated by the project research

## ANNEX 2

### Seasonal Water Balance and Water Productivity Analysis for Conventional Rice-Wheat Cultivation at Farmer’s Fields, Watercourse 32326/L, Ghour Dour Distributary, Punjab, Pakistan

| Performance Indicators | Conventional Rice | | | | Conventional Wheat | | |
|---|---|---|---|---|---|---|---|
| | Kharif 2001 | Kharif 2002 | Kharif 2003 | Average 2001/2/3 | Rabi 2001/2 | Rabi 2002/3 | Average 2001/2/3 |
| Field area ($m^2$) | 4,192 | 4,049 | 4,238 | 4,160 | 4,049 | 4,049 | 4,049 |
| Inflow components (mm) | | | | | | | |
| *Irrigation* | 826 | 2,010 | 896 | 1,244 | 302 | 204 | 253 |
| *Rainfall* | 315 | 89 | 239 | 214 | 32 | 175 | 103 |
| *Gross inflow* | 1,141 | 2,099 | 1,135 | 1,458 | 334 | 379 | 357 |
| Outflow components (mm) | | | | | | | |
| *Evapotranspiration* | 503 | 587 | 505 | 532 | 426 | 367 | 396 |
| *Seepage and percolation* | 638 | 1,512 | 1,456 | 1,202 | - 92 | 12 | - 40 |
| Performance | | | | | | | |
| *Gross depleted fraction (-)* | 0.44 | 0.28 | 0.45 | 0.39 | 1.28 | 0.97 | 1.12 |
| *Grain yield (Kg/ha)* | 3,031 | 4,084 | 2,616 | 3,243 | 5,351 | 5,140 | 5,245 |
| *Water productivity (Kg/$m^3$)* | | | | | | | |
| $WP_{-GI}$ | 0.27 | 0.20 | 0.23 | 0.23 | 1.61 | 1.36 | 1.48 |
| $WP_{-I}$ | 0.37 | 0.20 | 0.30 | 0.29 | 1.78 | 2.52 | 2.15 |
| $WP_{-Evapotranspiration}$ | 0.60 | 0.7 | 0.52 | 0.61 | 1.26 | 1.40 | 1.33 |

*Notes:* Data generated by the project research
The values represent average of three fields extensively monitored during 2001-2003

# ANNEX 3A

## Gross Value of Production Per Unit of Water at the Watercourse Level

| Watercourse | Season | Area (ha) | Gross Income (Million Rs) | Irrigation Inflow (Million m$^3$) | Gross Inflow (Million m$^3$) | GVP_I (Rs/m$^3$) | GVP_GI (Rs/m$^3$) |
|---|---|---|---|---|---|---|---|
| 21-TF | Kharif 2001 | 197 | 6.41 | 2.02 | 2.50 | 3.17 | 2.56 |
| | Rabi 2001/2002 | 188 | 4.41 | 0.75 | 0.80 | 5.91 | 5.52 |
| | Annual | 385 | 10.81 | 2.77 | 3.30 | 3.91 | 3.28 |
| 28-L | Kharif 2001 | 63 | 1.45 | 0.55 | 0.75 | 2.64 | 1.93 |
| | Rabi 2001/2002 | 68 | 1.59 | 0.37 | 0.39 | 4.34 | 4.07 |
| | Annual | 132 | 3.04 | 0.92 | 1.14 | 3.32 | 2.66 |
| 74-R | Kharif 2001 | 222 | 5.24 | 3.34 | 3.88 | 1.57 | 1.35 |
| | Rabi 2001/2002 | 253 | 5.99 | 1.44 | 1.51 | 4.17 | 3.96 |
| | Annual | 475 | 11.23 | 4.77 | 5.39 | 2.35 | 2.08 |
| 32-L | Kharif 2001 | 80 | 1.74 | 1.11 | 1.36 | 1.57 | 1.28 |
| | Rabi 2001/2002 | 106 | 2.70 | 0.58 | 0.61 | 4.66 | 4.40 |
| | Annual | 185 | 4.45 | 1.69 | 1.98 | 2.63 | 2.25 |
| Overall Watercourse | Kharif 2001 | 140 | 3.71 | 1.75 | 2.12 | 2.11 | 1.75 |
| | Rabi 2001/2002 | 154 | 3.67 | 0.78 | 0.83 | 4.70 | 4.43 |
| | Annual | 294 | 7.38 | 2.54 | 2.95 | 2.91 | 2.50 |

*Notes:* Data generated by the project research

Sugarcane and orchards are the annual crops and their gross value of production was equally divided into Kharif and Rabi seasons

## ANNEX 3B

### Crop-wise Value of Production at the Watercourse Scale During Kharif 2001

| | | Area | | Yield/ha | GVP | |
|---|---|---|---|---|---|---|
| Watercourse | Crop | ha | percent of CA | Kg/ha | Rs/ha | Total Rs |
| 21900-TF | Rice | 172.66 | 87.86 | 3,385 | 33,444 | 5,774,450 |
| | Sugarcane | 12.15 | 6.18 | 59,280 | 29,640 | 360,138 |
| | Orchards | 9.81 | 4.99 | na | 24,700 | 242,312 |
| | Fodder | 1.49 | 0.76 | na | 9,880 | 14,703 |
| | Vegetable | 0.41 | 0.21 | na | 33,345 | 13,631 |
| Total | | 196.52 | 100.00 | | | 6,405,234 |
| 28915/L | Rice | 26.56 | 41.89 | 3,352 | 29,162 | 774,658 |
| | Orchards | 31.29 | 49.33 | na | 18,525 | 579,581 |
| | Vegetables | 1.21 | 1.91 | na | 22,230 | 26,967 |
| | Fodder | 2.93 | 4.62 | na | 9,880 | 28,931 |
| | Sugarcane | 0.82 | 1.29 | 69,160 | 34,580 | 28,241 |
| | Oil Seed | 0.61 | 0.96 | 593 | 13,634 | 8,339 |
| Total | | 63.42 | 100.00 | | | 1,446,717 |
| 74634/R | Rice | 135.17 | 60.86 | 3,069 | 288,486 | 3,899,364 |
| | Fodder | 36.38 | 16.38 | na | 9,880 | 359,432 |
| | Oil Seed | 37.13 | 16.72 | 593 | 13,634 | 506,260 |
| | Sugarcane | 12.61 | 5.68 | 74,100 | 37,050 | 467,071 |
| | Orchards | 0.81 | 0.36 | na | 14,820 | 11,995 |
| Total | | 222.10 | 100.00 | | | 5,244,122 |
| 32326/L | Rice | 52.16 | 65.48 | 2,848 | 26,031 | 1,357,729 |
| | Fodder | 15.35 | 19.28 | na | 9,880 | 151,699 |
| | Sugarcane | 2.98 | 3.74 | 69,160 | 34,580 | 103,080 |
| | Oil Seed | 8.35 | 10.48 | 593 | 13,634 | 113,872 |
| | Vegetable | 0.81 | 1.02 | na | 22,230 | 18,002 |
| Total | | 79.65 | 100.00 | | | 1,744,382 |

*Notes*: Data generated by the project research
na = not available

## ANNEX 3C

### Crop-wise Value of Production at the Watercourse Scale During Rabi 2001

| | | Area | | Yield/ha | GVP | |
|---|---|---|---|---|---|---|
| Watercourse | Crop | ha | percent of CA | Kg/ha | Rs/ha | Total Rs |
| 21900/TF | Wheat | 147 | 77.91 | 3,395 | 23,290 | 3,415,509 |
| | Orchard | 18 | 9.34 | na | 24,700 | 242,312 |
| | Sugarcane | 12 | 6.24 | 59,280 | 29,640 | 360,138 |
| | Fodder | 5 | 2.61 | na | 34,580 | 169,618 |
| | Vegetable | 7 | 3.91 | na | 29,640 | 218,094 |
| Total | | 189 | 100.00 | | | 4,405,671 |
| 28915/L | Wheat | 31 | 45.01 | 3,855 | 26,831 | 826,544 |
| | Orchard | 31 | 45.71 | na | 18,525 | 579,581 |
| | Vegetable | 4 | 5.36 | na | 24,700 | 90,612 |
| | Fodder | 2 | 2.91 | na | 34,580 | 68,876 |
| | Sugarcane | 1 | 1.01 | 69,160 | 34,580 | 28,241 |
| Total | | 69 | 100.00 | | | 1,593,854 |
| 74634/R | Wheat | 184 | 72.91 | 3,157 | 216,57.02 | 3,994,546 |
| | Orchard | 1 | 0.32 | na | 14,820 | 11,995 |
| | Vegetable | 21 | 8.39 | na | 24,700 | 524,050 |
| | Fodder | 29 | 11.34 | na | 34,580 | 991,976 |
| | Sugarcane | 18 | 7.05 | 74,100 | 37,050 | 467,071 |
| Total | | 253 | 100.00 | | | 5,989,638 |
| 32326/L | Wheat | 86 | 81.14 | 3,321 | 23,812 | 2,039,542 |
| | Fodder | 12 | 11.58 | na | 34,580 | 422,862 |
| | Sugarcane | 2 | 2.06 | 69,160 | 34,580 | 103,080 |
| | Vegetable | 6 | 5.22 | na | 24,700 | 136,102 |
| Total | | 106 | 100.00 | | | 2,701,586 |

*Notes*: Data generated by the project research
na = not available

# ANNEX 4

## Socioeconomic Characteristics of Sample Farmers

| Description | Sample Watercourses | | | | Overall |
|---|---|---|---|---|---|
| | 21900/TF | 28915/L | 74634/R | 32326/L | Mean |
| Family size (#) | | | | | |
| Family members | 12 | 7 | 11 | 10 | 10 |
| Male | 7 | 3 | 6 | 6 | 6 |
| Female | 5 | 4 | 5 | 4 | 4 |
| Working at the farm | 3 | 2 | 3 | 2 | 2 |
| Profession (%) | | | | | |
| Agriculturist | 89 | 80 | 93 | 100 | 93 |
| Agri + Industrial | 11 | -- | 7 | -- | 5 |
| Agri + Employee | -- | 20 | -- | -- | 3 |
| Farming experience (Years) | 17 | 32 | 25 | 27 | 23 |
| Farm size (ha) | 8.93 | 71.00 | 8.31 | 5.01 | 8.66 |
| Tenancy status (%) | | | | | |
| Owner | 63 | 100 | 50 | 75 | 61 |
| Owner-cum-tenant | 25 | -- | 21 | 6 | 18 |
| Tenant | 13 | -- | 29 | 19 | 21 |
| Soil type | | | | | |
| Loam | 71 | -- | 33 | 31 | 43 |
| Clay loam | 18 | 100 | 21 | 31 | 25 |
| Sandy loam | 6 | -- | 29 | 31 | 22 |
| Other | 6 | -- | 17 | 7 | 12 |
| Soil salinity problem (%) | 59 | — | 38 | 44 | 45 |
| Education (%) | | | | | |
| Illiterate | 11 | -- | 50 | 50 | 35 |
| Read and write only | 11 | -- | 7 | -- | 5 |
| Primary | 33 | 20 | 14 | 8 | 17 |
| Middle | 22 | 80 | 7 | 25 | 25 |
| High school | 22 | -- | 7 | 8 | 10 |
| Intermediate | -- | -- | 7 | 8 | 5 |
| Graduate | -- | -- | 7 | -- | 3 |
| Household assets | | | | | |
| Television | 65 | 100 | 42 | 50 | 50 |
| Radio/tape recorder | 53 | 100 | 42 | 44 | 45 |
| Bicycle | 82 | 100 | 79 | 44 | 71 |
| Motorbike | 24 | 100 | 17 | 13 | 19 |
| Sewing machine | 77 | 100 | 83 | 63 | 74 |
| Brick house | 77 | 100 | 50 | 56 | 60 |
| Farm assets | | | | | |
| Tractor (%) | 59 | 100 | 50 | 25 | 47 |
| Trolley (%) | 47 | 100 | 7 | 6 | 29 |
| Seed drill (%) | 35 | 100 | 3 | 100 | 19 |
| Thresher (%) | 41 | 100 | 5 | -- | 22 |
| Cows (#/farm) | 1 | 5 | 3 | 3 | 3 |
| Buffalos (#/farm) | 4 | -- | 6 | 7 | 5 |
| Goats/sheep (#/farm) | 1 | -- | 2 | 2 | 2 |

*Notes:* Data generated by the project research

The results are based on 58 respondent farmers distributed to four watercourse; 21900TF (17), 28915/L (1), 74634/R (24) and 32326/L (16)

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