15 Rice–Wheat Cropping Systems in the Indo-Gangetic Plains: Issues of Water Productivity in Relation to New Resource-conserving Technologies

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Abstract

The rice–wheat cropping system is found on 13.5 million ha in south Asia and is one of the most important cropping patterns for food self-security in the region. This system is found in the fertile, hot semi-arid to hot subhumid regions of the Indus and Gangetic alluvial plains of Bangladesh, India, Nepal and Pakistan. Irrigation is commonly used to stabilize the productivity of this system, using canal and tube-well water. Area and yield growth have been responsible for continued production growth for these cereals over the past 30 years and have matched the population growth and demand for food. This growth over the past 30 years was based on key inputs, such as variety, fertilizer and irrigation, with most of the investment coming from the public sector. Future growth required to meet population growth will be close to 2.5% $year^{-1}$ and must come from yield rather than from area growth, since the latter will decline as urbanization and industries spread to prime agricultural land. Competition for water will be a major challenge for agriculture and it is imperative that this scarce resource is used efficiently. This chapter describes various resource-conserving technologies that are being promoted by the rice–wheat consortium (one of seven Consultative Group on International Agricultural Research (CGIAR) ecoregional initiatives) to attain the goal of raising productivity in the region and meeting food-security needs while, at the same time, efficiently using natural resources, including water, providing environmental benefits, improving the rural livelihoods of farmers and helping to alleviate poverty. This technology of the post-green revolution will depend on farmer adoption and investment. Increasing and improving stakeholder participation in experimentation and fine-tuning of the technology will be a key to success.

Introduction

The rice–wheat (RW) cropping system is found on 13.5 million ha in south Asia and is one of the most important cropping patterns for food self-security in the region. Another 10 million ha are found in China, mostly in the central areas of the Yangtze River valley. This system is found in the fertile, alluvial Indo-Gangetic plains (IGP) of Bangladesh, India, Nepal and Pakistan of south Asia. In this system, rice is grown in the warm, sub-humid, monsoonal, summer months and wheat in the cooler, drier, winter season.

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Both crops are grown in one calendar year. Other crops, including pulses, oilseeds, potatoes, vegetables, fodder and sugarcane, are also grown, particularly in the winter. Irrigation is a common feature of this system, either from extensive surface-canal systems or from shallow wells and tube wells (shallow or deep). Rain-fed RW also exists, but most of the farmers apply at least one irrigation for wheat and many apply a full irrigation schedule.

The population growth rate in the IGP is still about 2% year^{-1} and will take a few decades to stabilize. It is estimated that about 2.5% growth in cereal production will be required to meet food demands in the next decade (Hobbs and Morris, 1996). During the past 30 years, agricultural production has been able to keep pace with population demand for food. This came about through significant area and yield growth. Area growth was a result of new lands being farmed and through increases in cropping intensity, from a single crop to double or even triple crops per calendar year. Area growth will be less important in its contribution to production growth in the future, as more land is used for urban areas and industry. Yield growth will have to be the mainstay for providing the means for meeting future food demands unless food imports start to play a major role in south Asia. Evidence from some long-term experiments, however, show that problems of stagnating yields at levels far below the potential productivity and even yield declines are occurring in some areas in the RW systems of south Asia (Hobbs and Morris, 1996; Dawe *et al.*, 2000; Duxbury *et al.*, 2000; Regmi *et al.*, 2002a,b). The total factor productivity is declining and farmers have to apply more fertilizer to obtain the same yields. Soil organic matter is declining; new weeds, pests and diseases are creating more problems; and paucity of irrigation water in the north-west is resulting in excessive pumping of groundwater. Farmers are complaining about high input costs and low prices for their produce. Marketing of excess production is a burden for farmers and storage is a problem for governments. There is, therefore, a huge challenge ahead in the region to sustainably meet future food demands without damaging the natural-resources base on which agriculture depends, producing food at a cost that is affordable by the poor, and with incentives to farmers that allow them to improve their livelihoods and ultimately alleviate poverty.

Water will become a major limiting factor for sustained production in the next decade in the IGP. Rapidly growing urban areas and industry will compete with agriculture for good-quality water. There are already reports of declining water tables in some areas (Harrington *et al.*, 1993), leading to more costly pumping of groundwater and increased costs of production. In several other canal command areas of the IGP, water tables are rising, leading to secondary soil salinization. The interbasin transfer of irrigation water to meet evapotranspiration demands of the RW system is a key feature of intensively cultivated irrigated agriculture in the IGP. The demands for water from the RW system exceed those available from rain and canal supplies. Farmers often rely on groundwater, which in places is low in quality, either due to excessive salt content or due to the presence of residual alkalinity, with detrimental effects to soil health. Long-term, regional hydrological salt and water balances, as influenced by existing and alternative management practices and as driven by policies (e.g. pricing, common-property management), are items of crucial information if we are to achieve sustainable agriculture in the region. Scientists are using crop-growth simulation and risk-analysis models to evaluate risk-efficient water-use strategies at the district level. Initial results suggest that improved water and energy pricing policies could reduce water use by 25%.

This chapter describes various resource-conserving technologies (RCTs) that are being promoted by the RW Consortium (RWC) to attain the goal of raising productivity in the region and meeting food-security needs while, at the same time, efficiently using natural resources, including water, providing environmental benefits and improving the rural livelihoods of farmers.

RWC and the IGP

The RWC was established in 1994 as a CGIAR ecoregional initiative. A CGIAR ecoregional programme is a combination of natural-resources management and production (extension) in a defined geographical area with site-specific socio-economic and policy environments (Fig. 15.1). The RWC for the IGP is a successful partnership between national programmes (Bangladesh, India, Nepal and Pakistan) in south Asia, several international centres of the CGIAR (the International Maize and Wheat Improvement Center (CIMMYT), the International Rice Research Institute (IRRI), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), the International Potato Center (CIP) and the International Water Management Institute (IWMI)) and various advanced international institutions (Cornell University; International Agricultural Centre (IAC), Wageningen; Institute of Arable Crops Research (IACR), Rothamsted; CAB International (UK) and Melbourne University). The RWC focuses on issues of raising the productivity and sustainability of RW systems of south Asia in an efficient way and by conserving natural resources, leading to improved livelihoods and reduction of poverty.

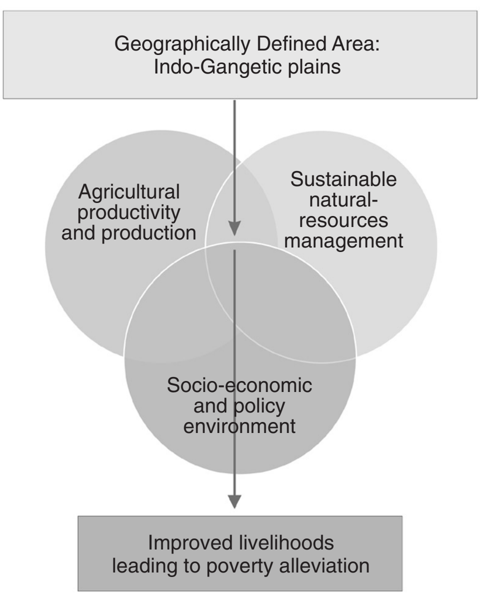

Fig. 15.1. Conceptual diagram of a CGIAR ecoregional project.

The major success of the RWC in the last few years has been the development and deployment of RCTs with farmers in the RW systems of south Asia (Hobbs, 2001; Hobbs *et al.*, 2002). RCTs range from simple surface seeding, where wheat seed is broadcast on the non-ploughed soil, and zero tillage with a special opener for placing seed in the soil, also without ploughing, to reduced tillage and bed planting. In 2000, 100,000 ha of zero-tillage wheat were planted in Pakistan and India in the RW areas. This has benefited farmers through less cost, more yield and more income.

One major hurdle to acceptance was changing the mind-sets of all partners concerned since the phrase 'the more you till, the more the yield' was stubbornly adhered to and difficult to overcome. In this chapter, RCTs are defined as any practice that will result in improvement of the efficiency of natural resources. Water is the major natural resource described in this chapter. Another term for RCTs – used by the Food and Agriculture Organization (FAO) – is Conservation Agriculture. Globally, these technologies are rapidly gaining popularity among farmers, as they result in higher production at less cost, with significant benefits to the environment and more efficient use of natural resources. Ultimately, these result in higher profits, cheaper food and improved farmer livelihoods. Crop diversification is also easier as less land is needed to produce staple cereals, freeing land for other crops. Interestingly, farmers are bearing the capital cost of this new technology, as opposed to the public sector.

Another major challenge in the region is how the knowledge-intensive technologies are transferred to the farmers, especially in areas where extension services are weak. This has been accomplished by the RWC through the promotion of participatory approaches and expanded partnerships with stakeholders.

Various RCTs

A basket of RCT options are being developed and made available to farmers for experimentation and adoption. Some are based on reduced tillage for wheat, including zero tillage. Bed-planting systems are being promoted to increase water productivity and, when combined with reduced tillage in a permanent bed system, they provide even more savings. Laser levelling, combined with these tillage systems, provides additional benefits. Many of the benefits of the tillage options for wheat are lost when rice soils are traditionally puddled (ploughed while wet). System-based technologies are now being promoted that do away with puddling so that total system productivity is raised. The use of groundwater to obtain early rice planting and efficient use of rainwater is another technology. The various technologies are briefly described in the following paragraphs.

Surface seeding

Surface seeding is the simplest zero-tillage system being promoted. In this tillage option, wheat seed is placed on to a saturated soil surface without any land preparation. This is a traditional farmer practice for wheat, legume and other crops in parts of eastern India and Bangladesh. Wheat seed is broadcast either before (relay planting) or after the rice crop is harvested.

Promotion of surface seeding for planting wheat has been done for several years in areas where the soils are fine-textured and drain poorly and where land preparation is difficult and often results in a cloddy tilth. The key to success with this system is having the correct soil moisture at seeding. Too little moisture results in poor germination and too much moisture can cause seed to rot. A saturated soil is best. The roots corkscrew into the moist soil and follow the saturation fringe as it drains down the soil profile. The high soil moisture reduces soil strength and thus eliminates the need for tillage. Additional irrigation may not be needed if the roots can penetrate the surface layers while it is still moist. In this case the roots penetrate the soil before the surface soil dries and soil strength increases so the roots can then follow the water table down the profile. In drier soils, the roots cannot penetrate the soil surface because of the higher soil strength and miss the opportunity to follow the water table as it drains down the profile.

In China, where surface seeding is also practised, farmers apply cut straw to mulch the soil, to reduce evaporative losses of moisture and to control weeds. The standing stubble also protects the young seedlings from birds. However, relay planting can be done only if the soil moisture is correct for planting.

One of the major pluses of surface seeding is that no costly equipment is needed and any farmer can easily adopt this practice. The use of a drum or simple seeder for line sowing is found to be advantageous. This system is being monitored in farmer fields to determine if continuous surface seeding is possible or whether a rotation of tillage systems may be needed to control future weed problems.

Zero tillage with inverted-T openers

This is another RCT, where the seed is placed into the soil by a seed drill without prior land preparation. This technology, which has been tested in Pakistan (Aslam *et al.*, 1993; Sheikh *et al.*, 1993), is currently being tested in other areas of the Indo-Gangetic floodplains, including India and Nepal. This technology is more relevant in the higher-yielding, more mechanized areas of north-western India and Pakistan, where most land preparation is now done with four-wheel tractors. However, to extend the technology in eastern parts of the IGP in Bangladesh, equipment is being modified for two-wheel hand tractors and bullocks.

The basis for this technology is the inverted-T openers (Fig. 15.2), which were developed in and imported from New Zealand. This coulter and seeding system places the seed into a narrow slot made by the inverted-T opener as it is drawn through the soil by the four-wheel tractor. The coulters can be rigid or spring-loaded, depending on the design and cost of the machine. This type of seed drill works very well in sit-

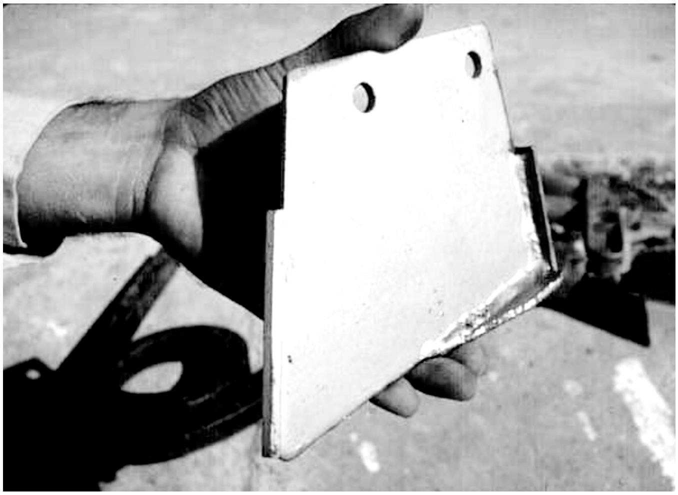

Fig. 15.2. A photograph of the inverted-T coulter used for zero tillage in the IGP.

uations where there is little surface residue after harvesting of rice. This usually occurs after manual harvesting.

Where combine harvesting is becoming popular, loose straw and residue create a problem for the inverted-T opener. Farmers currently burn residues to overcome this problem of loose stubble, whether they use zero tillage or the traditional system. Since the RWC wants to discourage this practice, which has major environmental and air-pollution implications, future strategies will look at alternative machinery and techniques to overcome this problem. Leaving the straw as mulch on the soil surface has not been given much thought in Asian agriculture. However, results from rain-fed systems and some preliminary results in Asia suggest that this may be very beneficial to the early establishment and vigour of crops planted this way (Sayre, 2000) and for soil moisture conservation, water infiltration and erosion. Studies are needed to explore the regional-scale benefits and longer-term consequences of this practice, already being adopted in some way in the zero-tillage wheat system.

Interestingly, significantly fewer weeds were found under zero tillage compared with conventional tillage (Verma and Srivastava, 1989, 1994; Singh, 1995), which is the opposite of the experience with zero-tillage systems in developed countries (Christian and Bacon, 1990; Kuipers, 1991). This observation has been confirmed in many other locations. Results from 336 on-farm trials in Haryana are shown in Fig. 15.3. Fields with both zero tillage and normal tillage were sprayed with weedicide, but significantly lower weed counts were found in fields with zero tillage both before and after herbicide application. This difference can be explained by the nature of the weeds found in the RW cropping system. Most of the weeds affecting the wheat crop germinate during the crop season and, since the soil is disturbed less under zero tillage, fewer weeds are exposed and fewer germinate. Also, before the weeds are able to grow and compete, the main crop is able to cover up the surface and significantly reduce the weed biomass. Weed problems are typically more severe under conventional tillage than under zero tillage, at least in the short term. Longer-term research is needed to anticipate future consequences of tillage changes for weed populations (e.g. to quantify likely shifts in weed species and the effects of those shifts on yield stability).

Earlier planting is the main reason for the additional yields obtained under zero tillage (Table 15.1). Zero-tilled plots were planted as close as possible to 14–20 November, the optimum date for planting wheat in India and Pakistan. The results of many trials suggest that the longer the farmer delays planting, the lower the yield. This finding has

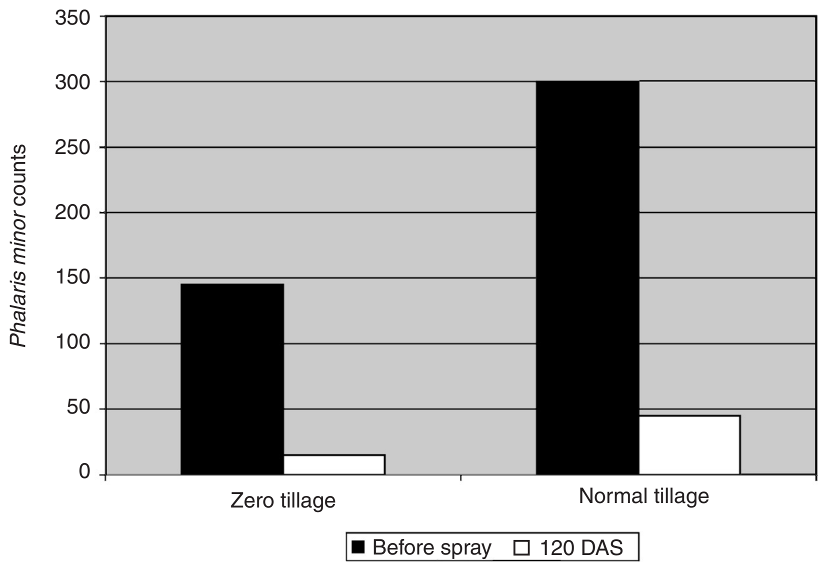

Fig. 15.3. *Phalaris minor* population before herbicide spray and 120 days after seeding (DAS) in zero-till and normal-tilled plots in 1998/99, Haryana Agricultural University, Hisar, India.

Table 15.1. Comparison of zero tillage and farmers' practice for establishing wheat after rice in Punjab, Pakistan, at locations where planting dates for the two methods differ (from Aslam *et al.*, 1993).

	Wheat yield (kg ha^{-1})		
Location	Zero tillage	Farmers' practice	Difference in the no. of days
Daska, site 2	3143	3209	10
Daska, site 1	3842	2735	13
Ahmed Nagar	4308	3526	20
Maujianwala	2689	2198	22
Mundir Sharif	4245	2660	33
Daska, site 3	3838	3420	44
Mean	3677a	2598b	24

Means followed by the same letter do not differ significantly at the 5% level using Duncan's multiple range test.

been confirmed in trials throughout the IGP in the past few years. In Haryana, surveys and crop cuts have shown that zero tillage produces 400–500 kg ha^{-1} more grain than traditional systems. This is attributed to earlier, timely planting, fewer weeds, better plant stands and improved fertilizer efficiency because of placement with the seed drill. Some farmers are now in their fourth year of adoption of zero tillage and find no deleterious effects that would make them revert to the traditional system.

Reduced tillage

The Chinese have developed a seeder for their 12 hp, two-wheel diesel tractor, which prepares the soil and plants the seed in one operation. This system consists of a shallow rotovator, followed by a six-row seeding system and a roller for compaction of the soil. Several tractors and implements were imported from Nanjing, China, into Nepal, Pakistan and India, where they have been tested over the past few years with positive results. In Bangladesh, farmers are using more than 200,000 hand tractors imported from China. Soil moisture was found to be critical in this reduced-tillage system. The rotovator fluffs up the soil, which then dries out faster than with normal land preparation. The seeding coulter does not place the seed very deep, so soil moisture must be high during seeding to ensure germination and root extension before the soil dries appreciably. Modification of the seed coulter to place the seed a little deeper would help correct this problem.

The main drawback of this technology is that the tractor and the various implements are not easily available and spare parts and maintenance are major issues. It would help if the private or public sector in south Asian countries could import this machinery or develop a local manufacturing capability. As it becomes more costly to keep and feed a pair of bullocks for a year, more farmers in the region are turning to significantly cheaper mechanized options of land preparation. One of the benefits of this tractor is that it comes with many options for other farm operations; it includes a reaper, rotary tiller and a mouldboard plough, and it can also drive a mechanical thresher, winnowing fan or power source for pumping water. However, most farmers are attracted to the tractor because it can be hitched to a trailer and used for transportation. For smaller-scale farmers who cannot afford their own tractors, custom hiring is a common alternative.

The Chinese tractor can also be used with a rotovator (Bangladesh) to quickly prepare the soil and incorporate the seed after a second pass. This speeds up the planting and results in better stands with less cost than traditional methods. However, the Chinese seeder attachment does a better job, because the seeds are placed at a uniform depth in the single pass. Engineers are experimenting with removing some of the blades that rototill the soil. In this way, a strip of soil is cultivated rather than the whole area. This reduces the power needs and costs and makes it easier for farmers to manage the tractor. In India, a four-wheel tractor version of this ‘strip-tillage’ machinery is available.

Bed-planting systems

In bed-planting systems, wheat or other crops are planted on raised beds. This practice has increased dramatically in the last decade or so in the high-yielding, irrigated, wheat-growing area of north-western Mexico (Meisner *et al.*, 1992; Sayre and Moreno Ramos, 1997). Bed planting in Mexico rose from 6% of farmers surveyed in 1981 to 75% in 1994, and farmers have given the following reasons for adopting the new system:

- Management of irrigation water is improved.
- Bed planting facilitates irrigation before seeding and thus provides an opportunity for weed control prior to planting.
- Plant stands are better.
- Weeds can be controlled mechanically, between the beds, early in the crop cycle.
- Wheat seed rates are lower.
- After wheat is harvested and straw is burnt, the beds are reshaped for planting the succeeding soybean crop. Burning can also be eliminated.
- Herbicide dependence is reduced, and hand-weeding and roguing are easier.
- Less lodging occurs.

This system is now being assessed for suitability in the Asian subcontinent. At the Punjab Agricultural University, two bed widths and two or three rows of wheat planted per bed were compared with conventional flat-bed planting. Two rows on 70 cm beds were best. Two of the major constraints on higher yields in north-western India and Pakistan are weeds and lodging. Both can be reduced in bed-planting systems. The major weed species affecting wheat, *Phalaris minor,* is normally controlled using the herbicide Isoproturon, which is not always effective. Farmers do not always apply Isoproturon either well or on time; in addition, recent reports have confirmed that *P. minor* has developed Isoproturon resistance (Malik and Singh, 1995; Malik, 1996; Malik *et al.*, 1998). Alternative integrated weed strategies must be developed to overcome this problem. Preliminary observations indicate that *P. minor* is less prolific on dry tops of raised beds than on the wetter soil found in conventional flat-bed planting. Cultivating between the beds can also reduce weeds. Thus bed planting provides farmers with additional options for controlling weeds.

Lodging is also less of a problem on raised beds. Additional light enters the canopy and strengthens the straw, and the soil around the base of the plant is drier. Reduced lodging can have a significant effect on yield, since many farmers in the Punjab do not irrigate after heading precisely because they want to avoid lodging. As a result, water can become limiting during grain filling, resulting in lower yields. On raised beds, this irrigation need not be avoided, for the reasons stated.

Results show that there is no significant difference in yield between flat- and bed-planted systems, which means that yield was not sacrificed by moving to a bed system (Table 15.2). The data in Table 15.2 were obtained in a 1 year on-station experiment. Further studies are needed to investigate possible significant interactions between bed planting and variety, with more spreading varieties yielding better in this system than upright ones. Figure 15.4, although based on

Table 15.2. Effects of bed size and configuration on wheat yield, Punjab Agricultural University, Ludhiana, India, 1994/95 (from unpublished data from S.S. Dhillon, wheat agronomist, Punjab Agricultural University).

	Sowing Method					
	On the flat	75 cm beds		90 cm beds		
Variety	25 cm row	2 rows per bed	2 +1 rows	3 rows per bed	3 +1 rows	Mean
			Wheat yield (kg ha^{-1})			
PBW 226	5740	6170	6390	6160	6320	6160a
WH 542	6290	5830	6360	6000	6040	6110a
CPAN 3004	6020	5530	6140	5630	5600	5780b
PBW 154	5460	5110	6000	5930	5880	5680b
HD 2329	5770	4660	6190	5580	5810	5600b
PBW 34	5650	5610	5800	5580	5630	5650b
Mean	5820	5490	6150	5810	5880	

Means followed by the same letter do not differ significantly at the 5% level using Duncan's multiple range test.

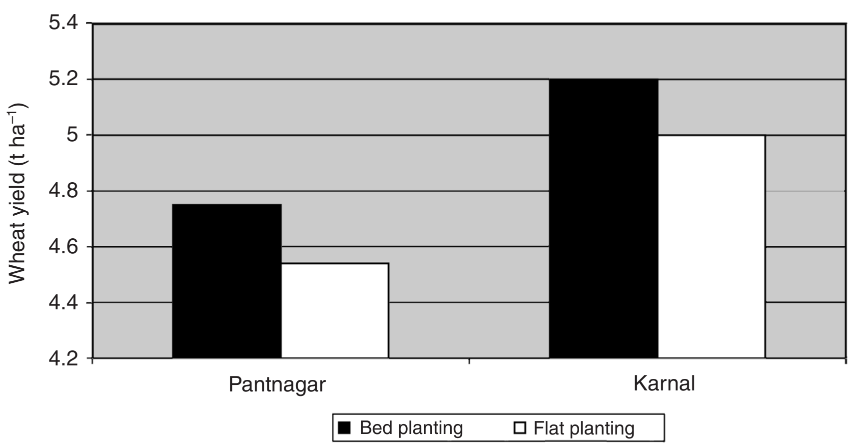

Fig. 15.4. Comparison of bed versus flat planting of wheat in farmers' fields in Pantnagar (n = 3) and Karnal (n = 8), India, in 1998/99.

trials in only a few farmers' fields in Haryana in 1998/99, shows a significant difference in wheat yield resulting from the planting method. Similar results have been found since then and the planting of wheat on beds is gaining popularity in Haryana and the Punjab of India and in the Punjab of Pakistan. Farmers are particularly pleased with the water savings they obtain from bed systems.

An additional advantage of bed planting becomes apparent when beds are 'permanent' – that is, when they are maintained over the medium term and not broken down and re-formed for every crop. In this system, wheat is harvested and straw is left or burnt. Passing a shovel down the furrows reshapes the beds. The next crop (soybean, maize, sunflower, cotton, etc.) can then be planted into the stubble in the same bed. Research in farmers' fields has also shown that rice can be grown on beds, making this system feasible in the RW pattern. Rice can be grown on beds by either transplanting seedlings or direct seeding. At the moment, transplanting on beds is best since normal herbicides used for transplanted rice can be used to control weeds. As dry-seeded herbicides become available and weeds can be managed, dry-seeded rice on beds will become more attractive. One farmer in the Punjab obtained 9 t ha^{-1} of rice transplanted on beds and saved more than 50% of the water he normally applied on flat, transplanted rice. This was confirmed through monitoring water use in bed-planted plots in 2002.

The use of beds also provides a way for improving fertilizer-use efficiency. This is achieved by placing a band of fertilizer in the bed at planting or as a top-dressing. Using slow-release formulations and experimenting with urea supergranules can make further improvements. Both can be applied in the bed at the time of planting with the seed-cum-fertilizer drill.

Multiuse of Low-quality Water

Low-quality water is often used in a cyclic mode in the IGP. At times, it is blended with canal water in watercourses to improve the total water supply and also the flow rates. Blending of low- and good-quality water has previously been discouraged because of its adverse effect on crop productivity. However, if the resultant electrical conductivity of the blended water supplies is less than the threshold conductivity, they can be used safely. In combination with new RCTs, blending of multiquality water supplies in on-farm water-storage reservoirs improves the quality of water having residual sodium carbonates and overcomes problems associated with this water. It can also improve the use of rainwater and the water productivity and yields of a bed-planted wheat crop. Preliminary results of a trial conducted in Pakistan have been very encouraging. The bed-planting system also offers scope for use of even saline water. When saline water is applied in a raised-bed–furrow land configuration, it permits salt movement to the top of the raised beds, keeping the root zone relatively free of salts below the furrow. This improves the ability of the plants to avoid early salt injury at seedling stage and subsequently improves the salt tolerance of the crop due to crop ontogeny. When combined with mulching or residue retention, bed planting has the potential to reduce evaporation losses from the soil surface and salinization and to further improve crop productivity in saline environments.

Non-puddling for rice

The benefits of the new resource-conserving tillage options listed above are lost when rice soils are puddled (ploughed when wet). Therefore, the RWC is encouraging research on station and with farmers to find ways to eliminate this soil-degrading process. Most rice farmers in south Asia traditionally puddle their soils to help pond water, reduce percolation losses and control weeds. Initial data indicate that rice-fields do not need to be flooded after the first few weeks and that puddled soils have more cracking and need more water once the fields dry. Initial flooding, though, is important to promote tillering and to more effectively control weeds. Studies are also being initiated to determine the exact water balance for the puddled and non-puddled conditions at the field, watercourse and command level. This is being done for fields where bed planting is practised and in fields with flat planting, with and without tillage. As mentioned above, farmers feel that bed-planted rice saves water over the traditional system. Quantitative data will be available soon to confirm this.

Data presented in Fig. 15.5 show that wheat yields are significantly better when wheat is planted with zero tillage after non-puddled rice than after puddled rice. The data also show that rice yields are similar between puddled and non-puddled situations if weeds can be controlled. This shows that RCTs need to be assessed on a systems basis and not on a single commodity.

Laser levelling

All the above technologies can benefit from levelled fields. This is being promoted in Pakistan as a means of improving water efficiency. However, when this is combined with zero tillage, bed planting and non-puddled rice culture, plant stands are better, growth is more uniform and yields are higher. The use of permanent-bed systems and zero tillage results in less soil disturbance and reduces the need for future levelling. India is also starting work on this and promoting levelling in farmers' fields in Haryana and western Uttar Pradesh (UP).

Supplemental water use in eastern India

The winter season following the long rainy season is short in eastern India. Long-term analysis of the rainfall data clearly indicates that there are three distinct periods of moisture availability. The early moist period (evaporation exceeds rainfall) extends over 12–18 days, followed by 93–139 days of a humid moist period, wherein precipitation exceeds potential evapotranspiration. This is followed by a moist period of 17–22 days, where once again rainfall is less than evapotranspiration. If the rice seedlings and crop can be established early in the first moist period, before the humid period, the rice crop can benefit from the monsoonal rain and grow without the need for irrigation. Timely transplanting of rice also results in earlier harvests and allows timely planting of the next wheat crop. The results of farmer-participatory field trials showed that the strategy of timely transplanting of rice improves wheat yields. The productivity of the RW system was nearly 12–13 t ha^{-1} when

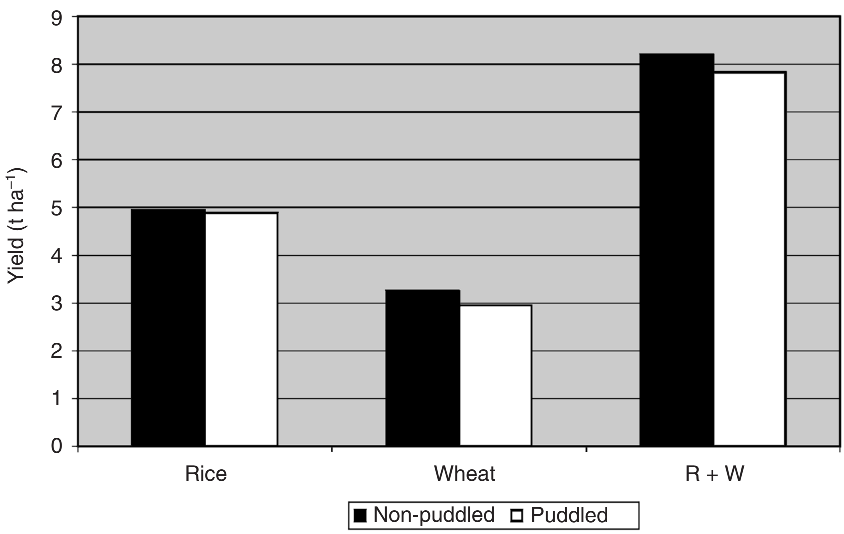

Fig. 15.5. Rice and wheat yields with and without puddling the rice soil in Nepal. R + W, rice plus wheat.

rice was transplanted before 28 June. This was reduced by more than 40% when fields were planted after 15 August (to 6–7 t ha^{-1}).

It was also reported that peripheral bunds with a height of 18–20 cm around fields could store nearly 90% of the total rainwater *in situ* for improved growth and production of rice.

Benefits of the RCTs in Terms of Water Use

Farmers are adopting the new RCTs quickly. Figure 15.6 shows the rapid adoption of zero tillage in the region. More than 100,000 ha of wheat were grown that way last year and this is expected to increase to a million in the next few years. There is no evidence from farmers' interviews and other surveys that farmers are going back to the old system. On the contrary, adoption of RCTs could be even faster if it were possible to have sufficient machinery available from small-scale manufacturers. Farmer feedback on water savings with these new technologies essentially says that they save water. For zero tillage, farmers report about 25–30% savings. This comes in several ways. First, zero tillage is possible just after rice harvest and any residual moisture is available for wheat germination. In many instances, where wheat planting is delayed after rice harvest, farmers have to pre-irrigate their fields before planting. Zero tillage saves this irrigation. Savings in water also come from the fact that an untilled soil has less infiltration than a tilled soil and so water flows faster over the field. That means farmers can apply irrigation much faster. Because zero tillage takes immediate advantage of residual moisture from the previous rice crop, as well as cutting down on subsequent irrigation, water use is reduced by about 10 cm-ha, or approximately 1 million l ha^{-1}. One additional benefit is less waterlogging and yellowing of the wheat plants after the first irrigation, which are common occurrences on normal ploughed land. In zero tillage, less water is applied in the first irrigation and this yellowing is not seen.

Farmers also report water savings in bed planting. Farmers commonly mention 30–50% savings in this system. Farmers also indicate that it is easier to irrigate with bed planting. Obviously, half the space is used for water and so less water is used. The question is whether farmers need to apply more frequent turns of irrigation with this system. This is being studied in a newly started RWC Asian Development Bank (ADB)

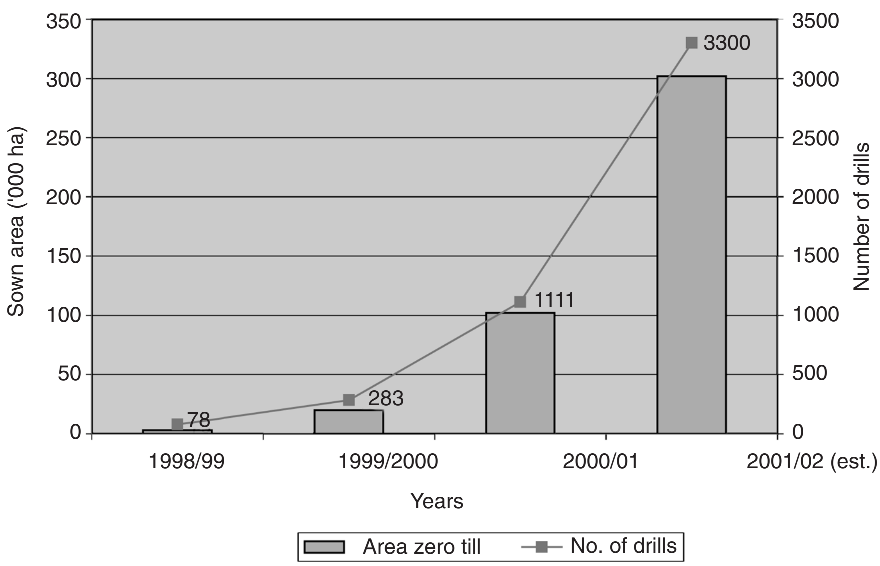

Fig. 15.6. Trends in wheat zero-tillage area in rice–wheat systems in India and Pakistan.

project in Pakistan and India. In the initial year of planting rice on beds, farmers estimated that they used 50–65% less water than on the flat. They kept the beds flooded for the first week, but were then able to cut down on irrigation frequency later. This also needs to be confirmed with good quantitative data.

Members of the On-Farm Water-Management staff of Pakistan's Punjab comparing RCT farms have collected data on water productivity (Gill *et al.*, 2000). This is presented in Table 15.3 for one location. All the systems provided better water productivity compared with traditional systems. The average water saved with laser levelling, zero tillage and bed planting over the traditional was 715, 689 and 1329 m^3 ha^{-1}, with a value of Rs 522, 503 and 970 ha^{-1} based on a water rate of Rs 900 per acre-foot for private tube wells for the year 1999/2000.

We still need to collect data for water use under puddled and non-puddled rice cultivation. Definitely, water percolation will be higher in non-puddled situations, but the total water use may be less, since no water is needed for seedling raising or puddling the main field. Also, when puddled soils dry – and many farmers cannot keep their fields continuously flooded – soils crack and so the field needs more water to fill the profile when water is next added. Less cracking occurs in non-puddled soils. Balasubramanian and Hill (2002) reported from Bhagat *et al.* (1999) that maintaining saturated soil conditions throughout the crop growth period (of puddled, transplanted rice) saved more than 40% of irrigation water compared with continuous shallow flooding when weeds were controlled with herbicides in the Philippines. This suggests that standing water is needed early to help tillering and control weeds but is not essential after that.

Importance of Participatory Technology Development

Adoption of RCTs in south Asia has been rapid over the past few years, especially for zero tillage with the inverted-T planter. Figure 15.6 shows that more than 100,000 ha were grown in 2001. This success was possible because of the application of participatory approaches for accelerating adoption. The traditional extension system, which was so effective in the early years of the Green Revolution, was based on the development of recommendations and packages and then having the extension service demonstrate the technology to farmers. Seed and fertilizer were easily packaged and it was possible to lay out many trials at low cost. When this traditional extension system was used for extending RCTs, problems arose. The first problem was the availability of the machinery to conduct the demonstrations. However, the main constraint was convincing farmers, extension workers and, at times, scientists that this technology had any benefit. Success came once partners were allowed to work together and experiment with the technology. Local manufacturers had to be involved in the development and manufacture of the equipment. Machinery had to be of high quality and yet at a cost within the budgets of farmers. Farmers had to be shown how the drill worked and then allowed to experiment with the equipment before they could be persuaded to accept this radical technology. Stories abound of how the farmers who first tried the technology were ridiculed by their neighbours for trying something so alien. But, once the seed germinated, farmers begged the innovators to help them sow their fields. It is now felt that zero-tillage wheat is an acceptable technology and will

Table 15.3. Effect of sowing on irrigation water productivity (WP) in wheat production in Mona Project, Pakistan (from Gill *et al.*, 2000).

	Laser levelling	Zero tillage	Bed planting	Normal planting
Water applied (m^3 ha^{-1})	2849	2933	2281	3610
Yield (t ha^{-1})	4764	4188	4134	3968
WP (kg m^{-3})	1.67	1.43	1.81	1.10

be part of the recommendations for planting wheat. Similarly, other RCTs, such as bed planting, will become accepted practices as machinery is made available and more farmers experiment with the system.

One question that is often asked is 'who can benefit from this technology and is it just for the large, commercial farmer?' The answer appears to indicate that this technology is scale-neutral and that farmers from all social classes can benefit from the many advantages that this system brings to wheat cultivation. A survey, conducted in 2000 in Haryana, of 20 villages and 91 farmers showed that 24% of the zero-tillage adopters owned a tractor, while the rest used service providers. The average farm size of adopters ranged from 0.8 to 20.2 ha. Twenty-two per cent had less than 2 ha each and 37% had farms of 2–4 ha each. All but one farmer agreed that zero tillage was highly profitable and data show that zero tillage resulted in US\$75 ha^{-1} more than with conventional practices. Yields from zero tillage were 5.4 t ha^{-1} while for conventional tillage they were 5.1 t ha^{-1}. Resource-poor farmers and farmers without tractors are using contract services to plough their fields at the moment. It is becoming too expensive to keep a pair of bullocks just for land preparation and so using a service provider is more economical. When this is applied to zero tillage or bed planting, the benefits are even more pronounced. In this case, the farmer has only to rent the service once and his/her fields are planted. This saves him/her money and provides time to do other activities. Data from socio-economic and impact-assessment surveys in India and Pakistan show this to be true. The first innovators are larger, better-endowed tractor owners. Later less well-endowed farmers adopt the technology as they see the benefits and obtain the services for this technology.

Farmer responses to the RCTs, especially zero tillage, provide valuable feedback for scientists in the RWC for improving the technology. At the same time, scientists have been monitoring the fields where these technologies are being adopted and collecting data on soil, biotic and resource use.

Conclusions

This chapter has described various RCTs available for testing the RW systems of the IGP. It describes the benefits to the farmers of the region adopting various RCTs in terms of improved production at lower cost, improving the efficiency of natural resources, benefits to the environment and improved livelihoods of farmers, all of which ultimately help in alleviating poverty. Water is particularly highlighted, since farmers indicate that all the technologies result in water savings. There is a research need to more accurately measure these savings and a recent ADB project will do just that. It is also important to look at water balances at different scales to determine if water savings at the field level will also give savings at the watercourse, command and basin levels.

The success of resource-conserving technologies is dependent on rapid adoption by farmers. Accelerated adoption was mainly the result of the change in the paradigm for extending the technology. Instead of the linear approach to extension commonly found in the Green Revolution era, the importance of partnerships, expanded stakeholders and participatory approaches, where farmers could experiment and feed back information, soon became apparent. RCTs are a key to ensuring sustainable food production in south Asia in the next decade. Overcoming mind-sets that hold traditional beliefs about excessive tillage and providing the enabling factors that allow exposure of the technology to all those involved in agriculture will be key factors for future success. This technological revolution is seen as one way to sustainably increase food production to meet future demands while conserving natural resources, improving farmer livelihoods and reducing the negative effects on the environment. Water is placed high on the list of natural resources and its use and productivity can definitely be improved with these new technologies. Of course, all of these benefits will be of little use unless nations in south Asia control their population growth.

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