FEATURE

At what scale does water saving really save water?

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Groundwater from surface water recharge being repumped. Water savings looks different depending on the scale.

Lessons from the use of resource conservation technologies in Pakistan

Water scarcity is a growing concern around the world. Opportunities to develop new water supplies are declining while new demands for industrial and urban uses and the environment are growing.

Globally, agriculture accounts for some 70% of global water diversions, and the agricultural sector is the single largest consumer of water in most countries. In addition, water used in agriculture is typically considered to have lower economic value than when applied for "new" uses. As a result, the agricultural sector is often the loser when pressures for reallocation occur, both because it has the most to give and because reallocation away from agriculture can increase overall water productivity. Agriculture's share of total water use is already falling and in some countries even absolute use is dropping.

Even as its allocations fall, the agricultural sector must continue to provide food to feed the world's still-growing and increasingly wealthy populations. In addition, farmers must continue to find ways to maintain incomes and meet their livelihood needs. To meet the challenge of decreasing agricultural allocations on the one hand and increasing demand for agricultural outputs on the other, governments and research organizations around the world are encouraging the use of resource conservation technologies (RCTs). RCTs include zero tillage, laser land leveling, and furrow bed planting.

The authors are all current or former employees of the International Water Management Institute (IWMI), a member of the Consultative Group on International Agricultural Research. Additional details on the work behind this article can be found in IWMI Research Report 108, *Water Saving Technologies: Myths and Realities Revealed in Pakistan's Rice-Wheat Systems* (www.iwmi.org).

Many studies have shown the effectiveness of RCTs in reducing water applications. However, very few studies have considered how reduced application at the field scale has translated into "real" water savings—that is, decreases in water depleted per unit of crop output. As we will see, whether or not decreased application translates into real water savings depends on the hydrologic interactions between the field, the farm, and the entire river basin. Furthermore, whether real water savings results in decreased water use—water that can be transferred to other users and purposes—depends on the response of farmers to the technologies and the physical and institutional environment in which they operate.

The experience of RCTs in Pakistan's Indus Basin highlights not only the water challenges facing agriculture globally but also the conditions under which RCT use results in real water savings.

Figure 1

Many farmers in Pakistan have shown an interest in implementing resource conservation technologies to achieve water savings at the field scale.

RESOURCE CONSERVATION TECHNOLOGIES IN PAKISTAN

Pakistan has a population of around 160 million people, making it the sixth most populous country in the world. In just the last 10 years, its population has increased by over 25% and continues to expand faster than global averages. While Pakistan has almost 18 million hectares of irrigated land, a key issue in efforts to keep food production rising with population is the lack of additional sources of water for agricultural use. In response to the water challenge, as well as other concerns including low farm income, various RCTs are being developed and promoted, in particular for rice and wheat, which together make up 90% of the country's total food grain production (PARC-RWC 2003).

Both zero tillage and laser leveling are perceived by farmers to result in substantial savings in water use.

The perceived value to farmers in Pakistan of some RCTs is demonstrated by their adoption. It has been estimated that zero tillage is now used on about 0.4 million hectares and laser leveling on about 0.2 million hectares in Pakistan (Ahmed and Gill 2004). Similar and growing adoption of RCTs has been seen in nearby Indian Punjab and Haryana (Hobbs and Gupta 2003). Figure 1 shows one farmer who uses RCTs.

Numerous studies have demonstrated that RCT use in the region results in water savings. For example, Kahlown et al. (2006) showed that the use of RCTs, including zero tillage, laser leveling, and bed and furrow planning, reduced water applications between 23% and 45% while increasing yield. Hobbs and Gupta (2003) showed water savings of 30% due to the adoption of zero tillage in rice-wheat systems. Gupta et al. (2002) showed 25% to 30% savings and Humphreys et al. (2005) a 20% to 35% savings in irrigation water under zero-tilled wheat compared to conventionally tilled wheat in the rice-wheat belt of the Indo-Gangetic plains. In wheat-corn systems, similar work conducted in China and Pakistan has also shown water savings of between 32% and 37% (Fahong et al. 2005; Hassan et al. 2005).

However, whether the field-scale savings translates into real water savings at other scales and to reductions in overall agricultural water use has not been well documented in Pakistan or elsewhere. To better understand these issues, a team of researchers working from the International Water Management Institute's Pakistan office evaluated reasons for RCT adoption, farmer response to RCT use, and the resulting water use impacts in the Rechna Doab (a doab is the area between two rivers, in this case the Ravi and Chenab tributaries of the Indus), at the center of the rice-wheat zone in Pakistan's Indus Basin (figure 2). The study was based on both farmer surveys and detailed hydrologic study.

Impact at the Field Scale. Survey results showed that zero tillage and laser leveling are the two most used RCTs in the Rechna Doab. Farmers indicated that their primary reasons for adopting the two technologies were to (1) to increase profitability (97% of adopters' respondents) and (2) to cope with water scarcity (87% of respondents). Coping with water scarcity is itself related to profitability, because it is strongly linked with productivity and the

Figure 2

Overview map of the study area—Rechna Doab, Indus Basin, Pakistan.

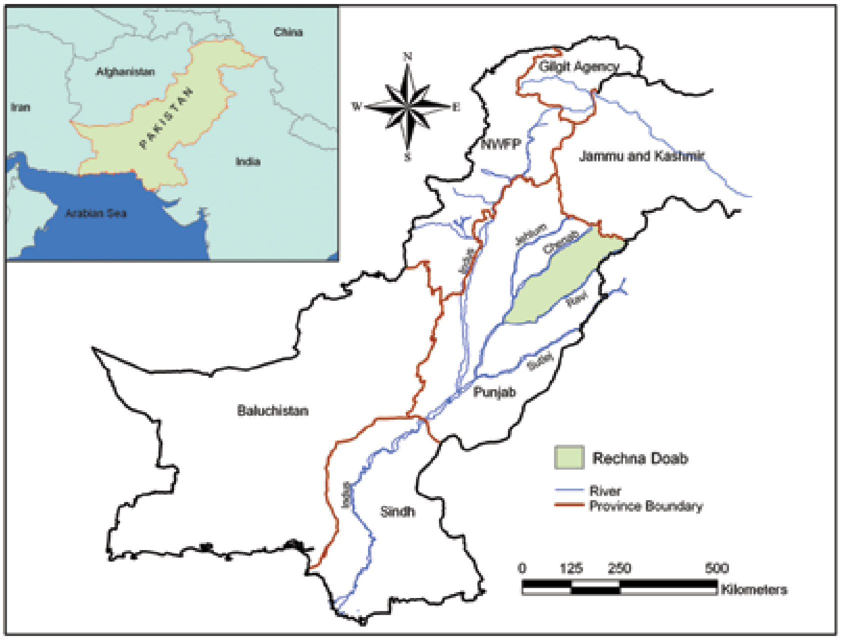


Figure 3

Zero-till drill in Pakistan.

Source: Photo by Riaz Ahmad Mann, Pakistan Agricultural Research Council (PARC), Islamabad.

cost of groundwater pumping. Farmers also reported increasing labor shortage due to migration as a major reason for adopting zero tillage. Figure 3 shows an example of zero tillage adoption in Pakistan.

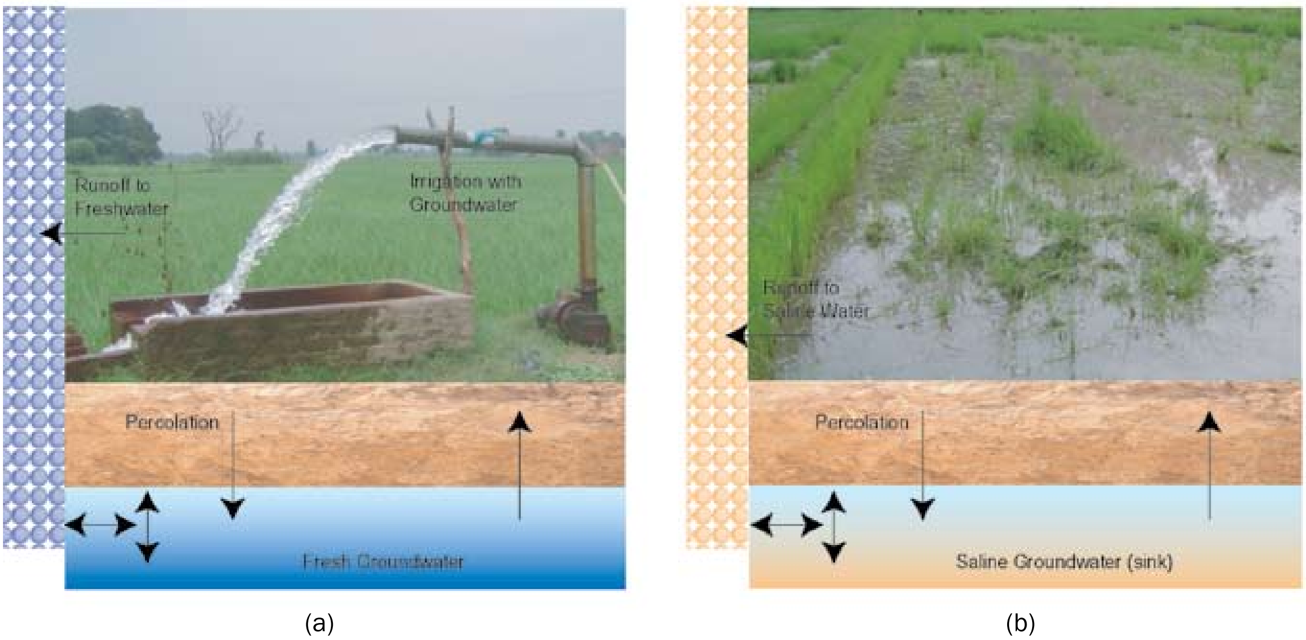
Both zero tillage and laser leveling are perceived by farmers to result in substantial savings in water application (24% for zero tillage and 32% for laser leveling), fuel (52% and 16%), and labor (52% and 14%). Impacts on fertilizer and herbicide use were relatively small. Because of the decrease in input use, almost all adopters (87% for zero tillage and 88% for laser leveling) reported a decrease in production costs.

The impacts of RCTs on wheat yields were varied, with about 54% of farmers reporting an increase, 30% a decline and 16% no change for zero tillage. The comparative numbers for laser leveling were 96%, 0%, and 4%, respectively. With generally increased yields and decreased costs, net crop income on fields using the two RCTs rose for the majority of farmers, providing an obvious explanation for the increasing adoption and popularity of the two technologies, a finding consistent with the results of Kahlown et al. (2006), Gupta and Seth (2007), and Jehangir et al. (2007) for similar areas.

Impact at the Field to Farm Scale. Reductions in field-level water applications such as those reported resulting from RCT use have often been equated with water savings. However, it remains an open question whether water is in fact saved at larger scales. To answer this question requires an understanding of the various components of the water balance as the scale of analysis expands. Cropped fields in Pakistan's rice-wheat zone can receive water from rainfall, irrigation with canal and ground water, and in some cases from the capillary rise from high groundwater tables. For a farmer, the water received in the field would ideally be used as transpiration to support crop growth, since other uses such as evaporation from bare soils and ponded water, transpiration by weeds, percolation to the groundwater table, and runoff to surface drains do not

Figure 4

Differential water outcomes of excess field-scale applications: (a) fresh and (b) saline areas.



contribute to food and fodder production. From the field perspective, it is clear that water savings can occur by reducing any of these sources of loss, though water also plays important nontranspiration roles in maintaining anaerobic conditions and suppressing weeds in rice production.

To understand water savings beyond the field scale, it is essential to understand the flow paths and final destinations of percolation and surface runoff, often considered as "losses" from a field-scale perspective. Deep percolation and surface runoff can take two paths: one is into fresh groundwater aquifers or surface water bodies, the other is into nonreclaimable sinks—bodies of water so saline or degraded that further use is not possible without treatment. The extent to which "true" water savings can be gained from reduced field-scale applications depends on whether percolation and surface runoff flow (1) to sources where they can be pumped or otherwise reused by the same or "downstream" farmers, as shown in figure 4a, or (2) to degraded sinks, as shown in figure 4b.

In the Rechna Doab, a large amount of applied irrigation water percolates to the groundwater aquifer. Aquifer quality is good in the upper parts of the Rechna Doab and along the flood plains of the Chenab and Ravi Rivers. While aquifers are saline in the lower and central parts (Khan et al. 2003), there is substantial reuse through pumping throughout the doab. Therefore, excess applications tend to follow the path shown in figure 4a and cannot generally be considered as losses (Ahmad 2002).

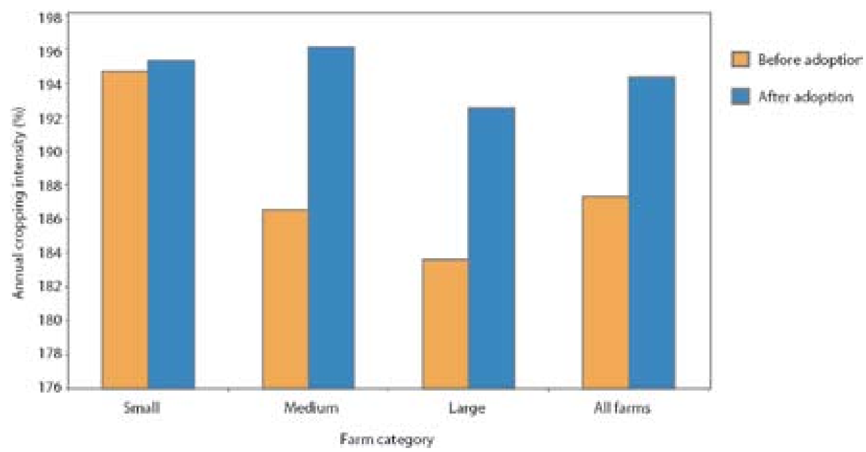
A second essential component in understanding water savings when moving beyond the field scale is the response of farmers in the face of new technologies and the impact of those technologies on water productivity. Two aspects of this component are especially important for consideration here. First, when scarcity of an input is a constraint to production, it can be expected that production will increase if the constraint is relaxed. The reduction in water applications made possible by RCTs is due to an increase in field-scale water productivity and thus constitutes an increase in effective supply. If water has been a constraint to production, then we would generally expect to see farmers use their saved water to expand production, either through intensification on existing fields or by expanding area. Second, simple economics also teaches us that when, *ceteris paribus*, the productivity of an input increases, producers will use relatively more of it.

Water is a constraint to agricultural production for most farmers in the Rechna Doab. The majority of the farmers (about 75%) in fact report that they do not receive their allocated share of canal water. Farmers have responded to canal water scarcity by pumping more and more groundwater, and virtually all now use groundwater solely or in conjunction with surface supplies. The major share of all irrigation water in fact now comes from groundwater sources.

In addition, many farmers have opportunities to expand production if the water constraint is relaxed. Approximately 15% of the farmers reported that they have at least half a hectare of "culturable waste" area—agricultural land that has not been cultivated for the last three years. This in a context where the mean size of surveyed farms is 17 ha and the median 10 ha. The two main reasons for not cultivating this land were given as scarcity of irrigation water (50% of responses) and soil salinity (35% of responses), a water-scarcity related issue.

Figure 5

Percentage change in annual cropping (area and cropping intensity index combined) before and after adoption of resource conservation technologies by farm size.



As RCTs have been adopted, the water-scarcity constraint has been relaxed and allowed farmers to increase both area and intensity (figure 5). However, it is critical to note that farmer response varied by land holding size. There has been a significant increase on medium and large farms following the adoption of zero tillage and laser leveling, but only a marginal increase by small farmers. The reason for this differential outcome is believed to be that small farmers generally already cultivate all available area and it is land, rather than water or labor availability, that constrains production. In contrast, water and to a lesser extent labor limit the area sown by medium and larger farmers.

As explained above, much of the water used for increased production would have recharged to groundwater from where it would have been pumped to the surface and used again for crop production. In fact, more than half of all farmers (54%) reported a decrease in groundwater use after the adoption of RCTs, while only 13% reported an increase and 33% no change. However, consistent with figure 5, it was primarily large farmers who reported increases in groundwater use as well as in annual cropping intensity. Large farmers, though a minority of all farmers, control about half of the farmland in the Rechna Doab. In contrast, most small farmers reported a decrease in groundwater pumpage. While the survey results could not get at the exact reasons for the reduced use of groundwater by smaller farmers, it is likely attributable to the increased productivity, relative to groundwater, of cheaper canal water supplies and the inability to reuse any canal water savings because of land constraints.

While it was not possible to accurately determine overall volumetric changes in total irrigation water use based on the study results, we can estimate the implications of the farmer responses based on potential crop evapotranspiration. The results show a small but significant increase (8% for large farmers, 5% for medium farmers, and less than 1% for small farmers) in net water use. Since surface supplies are already fully utilized, this increase can only come from an increase in groundwater exploitation. Unfortunately, increased groundwater use has already negatively impacted the system level water balance, with 70% of farmers reporting a declining trend in groundwater tables while only 1% report rises.

Impact at the Farm to Farming System and Basin Scales. For the entire rice-wheat zone, the net effect of irrigation water savings in wheat by some smaller farmers and the counterbalancing increase of groundwater by medium and larger farmers depends on the differential adoption rates of the technologies, and the relative proportions of land area in each category. At the moment, adoption rates of zero tillage and laser leveling are highest by medium and larger scale farmers who have better access to the required machinery, more to gain from increased efficiency and better management, and who occupy, overall, about 50% of the cultivated area. Therefore, the net increase in water use from the medium- and large-scale farmers will outweigh the net savings on small farms and result in further net increases in groundwater use.

The estimated net increase in annual crop water depletion at the doab level is shown in table 1 under a range of adoption rates, assumed ceilings on adoption, and estimates of incremental land area that can be sown. It is important to note that most of the increases in evapotranspiration shown would be achieved by a reduction in groundwater recharge and that this may aggravate the decline of the groundwater table in rice-wheat systems and also reduce groundwater availability to "downstream" users. Without increases in surface supplies or other institutional arrangements to limit water use in the near future, this may result in a negative water balance at a system scale and pose a serious threat to the sustainability of irrigated agriculture.

This conclusion on the impact of RCTs is limited to the Rechna Daob and the hydrology of the rice-wheat system, in particular the generally reasonable quality groundwater and groundwater recycling opportunities. The situation in the lower Indus basin, in Sindh Province, provides a stark contrast. There, widespread high and saline water tables prevail due to overapplication of canal water and ineffective drainage on the one hand and very low land surface gradients to the sea on the other. The use of RCTs there would reduce excess irrigation applications, applications that could not have been reclaimed through pumping for reuse do to quality degradation. To date, adoption rates of RCTs in the Sindh have not been surveyed and assessed in the detail.

Table 1

Anticipated changes in the volume of crop water use in Pakistan's Rechna Doab as a result of increased adoption of resource conservation technologies.

Scenario	Domain of analysis	Farm area (1,000 ha)	Adoption rate (percent)	Net increase in crop water use	
				(10^6 m^3)	(percent)
Base scenario: Increased crop water use under current level of RCT adoption.	Rice-wheat zone	1,440	28%	252	1.8%
	Rechna Doab	2,594	18%	291	1.2%
Scenario 1: Maximum increase in RCT adoption of 20%, assuming similar trends in differential adoption rates (57% on large farms), changes in cropping pattern, and an increase in cropping intensity of 7%.	Rice-wheat zone	1,440	48%	431	3.2%
	Rechna Doab	2,594	38%	615	2.5%
Scenario 2: Maximum increase in RCT adoption of 40%; otherwise, as scenario 1.	Rice-wheat zone	1,440	68%	611	4.5%
	Rechna Doab	2,594	58%	939	3.8%
Scenario 3: Maximum increase in RCT adoption of 60%; otherwise, as scenario 1.	Rice-wheat zone	1,440	88%	791	5.8%
	Rechna Doab	2,594	78%	1,262	5.1%

Note: Adoption rate includes zero-tillage and laser-leveling RCTs only.

SUMMARY AND CONCLUSIONS

In the example of Pakistan's Indus Basin, the successful uptake of RCTs and the small realizable water savings they generate at the field scale allow expansion by large and medium farmers of the winter wheat area and cropping intensity, requiring net increases in abstraction of groundwater to support the additional crop through to harvest. Depending on final levels of adoption, there could potentially be greater groundwater abstraction in winter on up to 50% of the rice-wheat area in the Rechna Doab, with implications for the long-term sustainability of groundwater supplies in the region and further downstream.

Thus, this example has shown that, counterintuitively, field-level water savings in the upper Indus due to the adoption of "water saving" technologies have contributed to increased net water use at the farming system scale. Without doubt, net basin level water use has also increased, though probably not at levels significant in terms of the total water balance. If similar technology adoption took place in downstream areas of the Indus where saline groundwater prevents water reuse, reductions in excess field scale applications could directly translate into increased supplies for other uses—in other words, real water savings.

The overriding message of this research is that water savings on the farm that leads to more productive enterprises will tend to be reused and may even stimulate greater total water use. The main factor governing this in Pakistan appears to be farm size; in situations where small farmers are the majority, small net water savings may not be able to be reused on the farm, and the cumulative savings may result in system-level water savings. Alternatively, the savings could allow better placed large farmers or other downstream users a more secure and generous water supply.

Nonetheless, opportunities for increasing overall economic benefits, maintaining equity, and achieving real water savings are possible in the Indus Basin of Pakistan. Here are some recommendations for accomplishing this goal:

- Provide incentives to small farmers for technology adoption while limiting new groundwater use by medium- and large-scale farmers.
- Improve the performance of canal water supply systems and manage these systems in high water availability years to sustain good quality groundwater resources.
- Promote water evaporation reducing technologies on a priority basis in rice-wheat zones located in upper parts of the Indus Basin where groundwater quality is fresh and drainage is reused by downstream users.
- Target technologies that reduce accessions to saline groundwater and also minimize evaporation losses at the rice-wheat zones in the lower part of the basin (Sindh).

- Invest more in data collection, monitoring, and case studies for detailed agro-hydrological, salinity, and water productivity assessment for resource conservation technologies at different scales, from field, to farm, to system, and to basin.

LESSONS FOR OTHER CONTEXTS

The particular hydrologic, socio-economic, and technological conditions of Pakistan that determined the study outcomes here are of course in some senses unique. However, the general finding, that "water savings" at the field scale is not necessarily equivalent to water savings at broader scales and may even result in an increase in overall water depletion, is instructive in many contexts and for many technologies promoted for their water savings value including drip irrigation, sprinkler systems, and canal and watercourse lining.

Generalizing from the Pakistani case, strategies for developing and promoting water savings technologies should focus on reductions in water depletion, rather than application, for productive uses; an understanding of the interrelationship between the new technologies and management of the overall irrigation system; and the appropriateness to overall farming systems and hydrologic outcomes at the basin level.

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All key considerations require an understanding of water balances and water productivity across scales, from field to basin. The results presented here highlight that technologically positive innovation is not socially neutral. Technological change without corresponding institutional change can increase inequity even in the face of productivity improvement. This is an especially important point in the ongoing global debates on water infrastructure investments for poverty alleviation.

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REFERENCES

Ahmad, M.D. 2002. Estimation of Net Groundwater Use in Irrigated River Basins Using Geo-information Techniques: A Case Study in Rechna Doab, Pakistan. Dissertation. The Netherlands: Wageningen University.

Ahmed, M., and M.A. Gill. 2004. Sustaining crop and water productivity in the irrigated rice-wheat systems of the Pakistan's Punjab through promotion of resource conservation technologies. *In* Sustaining Crop and Water Productivity in the Irrigated Rice-Wheat Cropping Systems: Proceedings of the Project End Workshop, April 29, 2004, ed. W.A. Jehangir and H. Turral. Lahore, Pakistan: International Water Management Institute (unpublished).

Fahong, W., W. Xuqing, F. Bo, S. Jisheng, L. Shengdong, and M. Zhongming. 2005. Raised bed planting for wheat in China. *In* Evaluation and Performance of Permanent Raised Bed Cropping Systems in Asia, Australia and Mexico: Proceedings No. 121, ed. C.H. Roth, R.A. Fischer, and C.A. Meisner. Canberra, Australia: Australian Centre for International Agricultural Research (ACIAR).

Gupta, R.K., R.K. Naresh, P.R. Hobbs, and J.K. Ladha. 2002. Adopting conservation agriculture in the rice-wheat system of the Indo-Gangetic Plains: New opportunities for saving water. *In* Water Wise Rice Production: Proceedings of the International Workshop on Water Wise Rice Production, April 8-11, 2002, Los Banos, Philippines, ed. B.A.M. Bouman, H. Hengsdijk, B. Hardy, P.S. Bindraban, T.P. Tuong, and J.K. Ladha. Los Banos, Philippines: International Rice Research Institute.

Gupta, R., and A. Seth. 2007. A review of resource conserving technologies for sustainable management of the rice-wheat cropping systems of the Indo-Gangetic plains (IGP). Crop Protection 26(3):436-447.

Hassan, I., Z. Hussain, and G. Akbar. 2005. Effect of permanent raised beds on water productivity for irrigated maize–wheat cropping system. *In* Evaluation and Performance of Permanent Raised Bed Cropping Systems in Asia, Australia, and Mexico: ACIAR Proceedings No. 121, ed. C.H. Roth, R.A. Fischer, and C.A. Meisner. Canberra, Australia: Australian Centre for International Agricultural Research (ACIAR).

Hobbs, P.R., and R.K. Gupta. 2003. Rice-wheat cropping systems in the Indo-Gangetic Plains: Issues of water productivity in relation to new resource conserving technologies. *In* Water Productivity in Agriculture: Limits and Opportunity for Improvement, ed. J.W. Kijne, R. Barker, and D. Molden. CABI Publishing in association with the International Water Management Institute.

Humphreys, E., A. van der Lely, W.A. Muirhead, and D. Hoey. 1994. The development of on-farm restrictions for minimising recharge from rice in New South Wales. Australian Journal of Soil and Water Conservation 7(2):11-20.

Jehangir, W.A., I. Masih, S. Ahmed, M.A. Gill, M. Ahmad, R.A. Mann, M.R. Chaudhary, A.S. Qureshi and H. Turral, H. 2007. Sustaining Crop Water Productivity in Rice-Wheat Systems of South Asia: A Case Study from Punjab Pakistan. IWMI Working Paper 115. Colombo, Sri Lanka: International Water Management Institute.

Kahlown, M.A., M. Azam, and W.D. Kemper. 2006. Soil management strategies for rice-wheat rotations in Pakistan's Punjab. Journal of Soil and Water Conservation 61(1):40-44.

Khan, S., T. Rana, K. Ullah, E. Christen, and M. Nafees. 2003. Investigating Conjunctive Water Management Options Using a Dynamic Surface-Groundwater Modelling Approach: A Case Study of Rechna Doab. Technical Report 35/03. Australia: CSIRO Land and Water.

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