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IRRI
INTERNATIONAL RICE RESEARCH INSTITUTE

Enhancing Farmers' Income and Livelihoods through Integrated Crop and Resource Management in the Rice-Wheat System in South Asia

(IRRI Ref. No.: DPPC 2004-02 / RETA 6208)

Terminal Project Report

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Rice Science for a Better World

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Executive Summary

Rice and wheat grown in sequence on the same field constitute the most productive rice-wheat (RW) system, which occupies an area of 13.5 million hectares in the four Indo-Gangetic Plains (IGP) countries—Bangladesh, India, Nepal, and Pakistan. The RW system represents 32% of the total rice area and 42% of the wheat area in these countries. This system feeds and provides employment to hundreds of millions of people in South Asia. However, the productivity and sustainability of the RW system are threatened because of (1) inefficient use of inputs (fertilizer, water, labor), (2) increasing scarcity of resources, especially water and labor, (3) adverse changes in climatic conditions, (4) changes in land use (cropping practices and cropping systems) driven by a shortage of water and labor, and (5) socioeconomic changes (urbanization, labor migration, changing attitude to shun away from farm work, concerns about farm-related pollution, etc.). Important among these threats are the short turnaround time between the rice harvest and wheat planting and the excessive preparatory tillage practiced by farmers, which delay wheat planting resulting to yield losses of 35 kg day^{-1} ha^{-1} in the northwest and up to 60 kg day^{-1} ha^{-1} in the eastern parts of the IGP. Inefficient production also increases the cost of the world's most important food staples—rice and wheat—for poor consumers. Therefore, the conventional cultivation practices followed in the RW system need to be improved or replaced by appropriate resource-conserving technologies (RCTs). RCTs developed during the past 15 years in earlier projects aim to enhance crop productivity and input-use efficiency on a sustainable basis, improve farmers' income and livelihood, and conserve the resource base and protect the environment in the IGP. To achieve these objectives, this ADB project (RETA 6208) was designed and implemented from 2005 to 2008.

In terms of project accomplishments, farmers evaluated different RCTs in 7,922 rice and wheat plots/fields at six sites of four IGP countries during 2005 - 2008 (Table 2). They refined, validated, and selected the most suitable RCTs for their regions by using their own criteria for selection. Farmers were supported in technology adoption by establishing 115 village seed banks to provide good-quality seed to local farmers, organizing 175 machinery pools and custom-hire service providers to help farmers too poor to purchase their own farm machines, lining of 16 irrigation canals (length=4,362 m) to improve irrigation efficiency at a systems level and use of water-saving RCTs at the field level, and analyzing 1,260 soil and water samples to make location-specific nutrient and crop management recommendations. Various types of training and education programs were organized for different stakeholders of the project—farmers, extension staff, researchers, local university student interns, service providers, private machine manufacturers, and policymakers. A total of 131 training and education events were organized in all four countries during the project period (2005-2008) with estimated total participants of 5,284. The categorized training activities involved 48 training sessions to train 1,703 research and extension staff, 8 internship training sessions with 52 student interns, 11 practical training events with 133 private machine manufacturers and service providers, 33 hands-on training events on RCTs for 1,385 farmers, 19 traveling seminars with 246 participants, and 12 household socioeconomic surveys with 1,765 participants. Appropriate dissemination and promotion activities were undertaken and related extension/promotional materials produced to effectively disseminate the proven RCTs to farmers. Twenty-eight field workshops/seminars with 780 participants, 36 farmers' field days with 1,160 participants, 114 TV programs on

RCTs, and 26 visits to project sites of 402 policymakers and scientists were organized in IGP countries during 2005-08. A total of 4,400 brochures/banners/posters/wall chalkings (billboards) were distributed to farmers to popularize the RCTs.

The project had great success in extending the RCTs to about half a million farmers in the project area. As of 2005-06, approximately 4.0 million ha of the area are under various RCTs in rice and wheat in the IGP countries. Specifically, the expert estimated area under zero-till, reduced-till, surface seeding, and bed planting of wheat is 1.94 million ha; direct-seeded rice, 0.19 million ha; laser land leveling, 0.07 million ha; crop diversification, 1.80 million ha; leaf color chart, 0.06 million ha; and nonpuddled transplanted rice, 0.01 million ha.

The widespread adoption of RCTs had pronounced direct effects on crop productivity and profitability. Assuming mean values of 0.30 t ha^{-1} for an increase in wheat yields and US$138 ha^{-1} for additional income and extrapolating these estimates over an area of 1.94 million ha, where zero- or reduced-till and bed-planted wheat are practiced, additional wheat production works out to 582,000 t and additional income accrued to farmers is $267.72 million. The extra wheat production and income will help improve local food security and farmers' livelihoods in all four IGP countries. The use of zero-tillage to overcome *Phalaris minor* weed problems is a boon to wheat farmers.

Successful RCTs for rice include laser-aided land leveling, alternate wetting and drying (AWD) irrigation, integrated crop and resource management (ICRM), and LCC-based precision N management. Precision land leveling increased mean rice yields by 0.44 t ha^{-1} and saved on average 100 mm of irrigation water in farmers' fields. A total of 21,030 leaf color charts (LCCs) have been distributed or sold to farmers after training them on the proper use of an LCC for precision N management in rice. The demand for LCCs is growing fast in Bangladesh, and it can be met only by its local manufacturer and sale to farmers.

Environmental impacts of RCTs include (1) a 30–40% savings in irrigation water use, (2) improved soil quality through the addition of biologically fixed N (BNF) and short-term soil carbon sequestration with the retention of crop residues and addition of organic manures, and (3) reduced emission of methane in nonflooded rice cropping systems. However, the emission of another greenhouse gas, nitrous oxide (N_2O), is increased by the adoption of certain RCTs.

The indirect impact of the project is exemplified by the training and empowerment of about 65 farm machine manufacturers who made, adapted, and refined the required farm machines, including seed drills. More than 13,000 seed drills have been produced and marketed by different manufacturers in India and Pakistan. Similarly, more than 60 laser leveling units in India and 170 in Pakistan are being rented to tractor operators for land leveling. In addition, 175 private entrepreneurs were trained and equipped to provide custom-hiring services for farm machines to farmers. Some rural youth were trained to repair and maintain these machines. Other farmers were encouraged to earn additional income through seed production to meet local needs.

The project has been adjudged as a model for scientific leadership on multidisciplinary, multicommodity, farmer participatory systems research through a multistakeholder partnership involving researchers, extension staff, farm machinery manufacturers, input retailers and service providers, and farmers to effectively solve problems of RW system productivity, profitability, and sustainability. The project has also built a strong base for long-term sustainability of the RW system through conservation agriculture with the use of RCTs. This exemplary and successful model was recognized by the receipt of the CGIAR's King Baudouin Award in 2004.

Diffusion of proven RCTs to deprived farming communities outside project areas is critical to realize the full impact on food security and farmers livelihood in South Asia. For this to happen, we need to sensitize agricultural policymakers and encourage them to allocate more resources for wider dissemination of successful RCTs in the region. The national governments must institutionalize the promotion of RCTs as a regular feature of program planning and implementation of agricultural development initiatives in each of the IGP countries.

List of abbreviations and acronyms

ACIAR	Australian Centre for International Agricultural Research
ADB	Asian Development Bank
AIT	Asian Institute of Technology
AVRDC	Asian Vegetable Research and Development Center
AWD	Alternate wetting and drying
BARI	Bangladesh Agricultural Research Institute
BCW	Broadcast-seeded wheat
BNF	Biological N fixation
BRRI	Bangladesh Rice Research Institute
CA	Conservation agriculture
CGIAR	Consultative Group on International Agricultural Research
CHT	Chinese hand tractor
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
CT	Conventional tillage
DFID	Department for International Development (UK)
DrumR	Drum-seeded rice on wet puddled soil
DSR	Direct drill-seeded rice
DSS	Decision support system
DSW	Drill-seeded wheat
DZT	Double zero-till
EU	European Union
FAO	Food and Agriculture Organization (of the United Nations)
FFC	Fauji Fertilizer Company (Pakistan)
FU	Facilitation Unit (of the RWC)
FYM	Farmyard manure
GHG	Greenhouse gas
GIS	Geographic information system
GR	Green Revolution
GWP	Global warming potential
HAU	Haryana Agricultural University
IAC	International Agriculture Center (Wageningen, Netherlands)
IAEA	International Atomic Energy Agency
IARC	International agricultural research center
ICAR	Indian Council for Agricultural Research
ICRISAT	International Center for Research in the Semi-Arid Tropics
ICRM	Integrated crop and resource management
IDRC	International Development Research Council
IFAD	International Fund for Agricultural Development
IGP	Indo-Gangetic Plains
InfRCT	Information on use of resource conservation technologies in agriculture
IPM	Integrated pest management
IRRI	International Rice Research Institute

IWMI	International Water Management Institute
LCC	Leaf color chart
LTSFE	Long-term soil fertility experiments
LTE	Long-term experiments
NARC	National Agricultural Research Council (Nepal)
NARES	National agricultural research and extension systems
NATP	National Agricultural Technology Project (India)
NGO	Nongovernment organization
NZODA	New Zealand Office for Development Assistance
OFWM	On-Farm Water Management (Lahore, Pakistan)
PARC	Pakistan Agricultural Research Council
PRISM	Project Information and Management System
PTOS	Power tiller–operated seeder
RCTs	Resource-conserving technologies
RSC	Regional Steering Committee (of the RWC)
RT	Reduced-till or reduced-tillage
RTCC	Regional Technical Coordination Committee (of the RWC)
RWC	Rice-Wheat Consortium for the Indo-Gangetic Plains
RW system	Rice-wheat system
TAC	Technical Advisory Committee (of the CGIAR)
TCE	Tillage and crop establishment
TPR	Transplanted rice on wet puddled soil
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
ZT	Zero-till or zero-tillage

ENHANCING FARMERS' INCOME AND LIVELIHOODS THROUGH INTEGRATED CROP AND RESOURCE MANAGEMENT IN THE RICE-WHEAT SYSTEM IN SOUTH ASIA

1. Project background

Rice and wheat grown in sequence in the same field constitute the productive rice-wheat (RW) system in South Asia. The intensively cultivated irrigated RW system is crucial to employment, income, and livelihoods for hundreds of millions of rural and urban people in the region (Ladha et al 2003a). The productivity and sustainability of the RW system are threatened, however, because of (1) inefficient use of inputs (fertilizer, water, labor), (2) increasing scarcity of resources, especially water and labor, (3) adverse changes in climatic conditions, (4) changes in land use (cropping practices and cropping systems) driven by a shortage of water and labor, and (5) socioeconomic changes (urbanization, labor migration, changing attitude to shun away from farm work, concerns about farm-related pollution, etc.). The RW production system in South Asia is thus characterized by increasing conflicts in economic, social, climatic, ecological, and production-related objectives (RWC 2006). The conventional cultivation practices followed in the RW system need to be improved or replaced by resource-conserving technologies (RCTs) not only adapt to emerging changes but also to enhance system productivity, input-use efficiency, and farm profitability on a sustainable basis (Gupta and Seth 2006).

1.1. Evolution of the RW system in the Indo-Gangetic Plains (IGP)

Harrington and Hobbs (2008) have summarized the history and development of the RW system in South Asia with details of support from donors—the Asian Development Bank (ADB); international agricultural research centers (IARCs), including the International Rice Research Institute (IRRI) and International Maize and Wheat Improvement center (CIMMYT) with rice and wheat as their mandate crops; and the national agricultural research and extension systems (NARES) of the IGP countries (Bangladesh, India, Nepal, and Pakistan). Early work concentrated on tillage and crop establishment (TCE) with a systems perspective (1984-89); later focus was on systems research on management of degraded resources, crop improvement, crop management, and productivity and sustainability of the RW system with ADB support—RETA 5414 (1990-93). Research focus then shifted to strategic, applied, and on-farm research on TCE, water productivity, soil fertility status and site-specific nutrient management, integrated pest management (IPM), and policy issues with multidonor and NARES support (1994-99). Later, multidisciplinary integrated RW systems research began on TCE, water, fertility, and IPM to develop RCTs, cost-benefit analysis, and policy and market analysis during 2000-03 with ADB support—RETA 5945. Finally RCTs were integrated through an integrated crop and resource management (ICRM) approach for on-farm evaluation and promotion to farmers in the IGP with ADB support—RETA 6208 (IRRI 2005). The milestones in the history and development of the RW system are indicated in Annex 1.

1.2. Introduction and rationale

The recent triple global crises—food, financial, and economic—have adversely affected the livelihoods and threatened the existence of poor producers and consumers of developing countries. This is due to the increasing prices of farm inputs in relation to outputs, stagnant or decreasing yields and productivity, less off-farm work opportunities for supplementing farm income, reduced remittances from relatives working outside villages, and declining income and purchasing power of poor consumers. In addition to the mismanaged global financial systems, continued neglect of and reduced public investment in the rural and farming sectors for 15–20 years, decreasing support to farmers in production and inadequate support for processing, storage, value addition, and marketing, undue emphasis on industrial and commercial crops vis-à-vis food crops, and increasing diversion of crop land to other uses have all contributed to growing food scarcity and economic crises. The immediate consequence is the extreme suffering of the poor, leading to civil unrest and disturbances, especially in South Asia, where the largest proportion of the global poor lives (Ahmed et al 2008).

Another factor contributing to emerging food scarcity is the stagnation of cereal productivity in the IGP countries, aggravated by the mining and inefficient use of natural resources, the grim prospects of climate change, and the looming freshwater crisis (Ladha et al 2003b, 2007). Despite the tremendous gains obtained in RW productivity during the past 40 years, the continued growth in population and the resultant decreases in per capita availability of land and water resources have placed a severe stress on the RW production system, raising serious concerns about the region's food security (Harrington L. 2001). Additional gains in productivity, profit, and product quality are becoming increasingly difficult to achieve by using the single-technology-centric approach. Therefore, a systems approach is needed to increase the productivity of both rice and wheat crops grown in sequence. We need to build on the recent scientific and technological gains made by various national and international partners and move forward with the integration, evaluation, and promotion of promising RCTs to farmers in the IGP countries (Balasubramanian et al 2003, Hobbs and Gupta 2003).

Earlier projects on the RW system helped develop and disseminate several RCTs to farmers in the region (Gupta and Seth 2006, Hazell and Wood 2008). Examples of popular RCTs include laser-assisted land leveling and zero-/reduced-tillage practices that increase overall system efficiency such as savings in time and energy and improving crop and water productivity. Despite the remarkable progress made so far, the varying technological performance, adoption rates, and impacts require our urgent and focused attention to realize the full socioeconomic and environmental benefits of RCTs. The current project on *Enhancing Farmers' Income and Livelihoods through Integrated Crop and Resource Management in the Rice-Wheat System in South Asia* (RETA 6208) was built on the progress and achievements of previous projects. This project was designed to integrate all available rice and wheat production technologies, evaluate them in farmers' fields, and promote the successful ones to farmers at large in close collaboration with key national and international partners (Annex 2).

1.3. Project's goal and objectives

The overall goal of the project was to reduce rural poverty and improve farmers' livelihoods by promoting RCTs in rice-based cropping systems in the IGP countries—Bangladesh, India, Nepal, and Pakistan. The specific objectives of the project were to

- Integrate, validate, and refine available RCTs for the rice-wheat ecosystem by applying the integrated crop and resource management (ICRM) approach.
- Disseminate and promote promising RCTs as components of ICRM for the rice-wheat system with the help of extension staff to attain food and nutritional security for the poor.
- Improve farmers' income through reduced costs of cultivation, increased productivity, and efficient use of resources.
- Promote crop diversification to reduce risks, add value, and improve marketing opportunities.
- Encourage the participation of private entrepreneurs in production and postproduction management.
- Improve the quality of the environment in rice-wheat ecologies through judicious use of agro-chemicals.
- Build the capacity of rice-wheat stakeholders (farmers, extension staff, farm machine manufacturers and service providers, processors, retailers, and researchers).

Later, ADB extended the project until 2008 to assess the contribution and impact of its support to the RWC over the years, with the following specific objectives:

- Review and document the history and impact of ADB support to the RWC and synthesize the salient findings from the work of projects RETA 5945 and 6208.
- Assess the socioeconomic impact of RETA 5945 through a survey of a sample of farmers/villages and other stakeholders.
- Strengthen the assessment of socioeconomic and environmental impact of various resource-conserving technologies.
- Produce an IRRI/RWC/ADB publication documenting the above outputs.

2. What are resource-conserving technologies (RCTs)?

Resource-conserving technologies are those that enhance farmers' productivity and profitability by making more efficient use of production resources and inputs (thereby reducing input costs) and by increasing yield per unit of scarce resources and inputs. RCTs form key components of conservation agriculture (CA)—an approach to conserve, improve, and make more efficient use of natural resources through integrated management of soil, water, crop, and other biological resources together with carefully selected external inputs. In the long run, CA contributes to both enhanced productivity and environmental conservation on a sustainable basis. Elements of CA include minimum soil tillage (minimum tillage, direct drill seeding), retention of soil cover (crop residues), and appropriate and economic crop rotations to sustain high yields and prevent disease and pest problems.

Popular RCTs either solve one or more farmers' problems or exploit opportunities to improve farmers' income and livelihoods (Harrington and Hobbs 2008). The name, abbreviation, brief description, benefits, and limitations of selected RCTs and conventional technologies are presented in Table 1a for rice and Table 1b for wheat.

Table 1a. Name, abbreviation, brief description, main benefits, and limitations of conventional technologies and RCTs for rice.

Name	Abbreviation	Brief description	Benefits	Limitations
Conventional-till (puddled) transplanted rice	CT-TPR	Land is plowed, puddled, and leveled; 21–30-d-old seedlings are transplanted at random or in rows.	Good water retention due to plow pan; fewer weeds; sustainable.	Time-consuming; labor-intensive; delays wheat seeding in RW system; destroys soil structure.
Conventional-till (puddled) broadcast-seeded rice	CT-BCR	Land is plowed, puddled, and leveled; sprouted seeds are broadcast 0–2 days after puddling.	Faster crop establishment; less planting labor; most suited to rainfed wetlands.	Perfect land leveling and good early water control needed; variable crop stand; more weeds; lodging due to poor anchorage.
Conventional-till (puddled) TPR with alternate wetting and drying (AWD) irrigation	CT-TPR-AWD	In CT-TPR, AWD irrigation is practiced.	Water savings.	Variable or reduced yield; more weeds.
Conventional-till (puddled) drum-seeded rice	CT-DrumR	Sprouted seeds are sown in rows on wet soil by using a drum seeder instead of broadcasting in a conventionally tilled and puddled field.	Faster crop establishment; less planting labor; good crop stand; easy weeding between rows.	Perfect land leveling needed; good water control for 7–10 days after seeding is critical.
Reduced-till (non-puddled) transplanted rice	RT-TPR	2–3 dry tillages followed by planking/leveling and ponding water but without puddling; 21–30-d-old seedlings are transplanted at random or in rows.	Reduced tillage; good soil structure due to no puddling.	Time-consuming; labor-intensive; difficult to plant manually; weed pressure.
Reduced-till (non-puddled) dry drill-seeded rice	RT-DSR	Dry seeds are drilled in rows by a zero-till ferti-seed-drill at 2–3-cm depth in a well-prepared moist soil and leveled, followed by one light irrigation	Reduced tillage; faster crop establishment; allows timely planting; less	Heavy weed infestation requiring chemical weed control.

		applied for good germination.	labor; easy to weed between rows; good soil structure due to no puddling.	
Reduced-till drill-seeded rice with a power tiller–operated seeder (PTOS)	RT-DSR (PTOS)	The PTOS is a tiller with an attached seeder and a soil-compacting roller. The PTOS is used to till shallow (4–5-cm depth), sow seeds in rows at adjustable distance, and cover seed and compact the soil at the same time in a single pass.	Reduced tillage; faster crop establishment; less labor; easy to weed between rows; good soil structure due to no puddling.	Heavy weed infestation requiring chemical weed control; may delay wheat seeding in too wet soils.
Reduced-till (non-puddled) dry drill-seeded rice + *Sesbania*	RT-DSR+Ses	Rice is drill-seeded; *Sesbania* seeds either drill-seeded or broadcast in reduced-till plots followed by *Sesbania* knocked down at 25–30 DAS with 2-4,D.	Faster crop establishment; less labor; partial weed suppression and enhanced soil fertility by *Sesbania*; good soil structure due to no puddling.	May reduce rice yields due to intercrop competition; additional cost of *Sesbania* seeds and herbicide to control *Sesbania*.
Raised-bed transplanted rice	Bed-TPR	A bed former-cum-drill seeder is used to form 37-cm-wide raised beds and 30-cm-wide furrows in well-prepared, pulverized soil. Then, 21-d-old seedlings are planted on both sides of moist beds. Furrows are kept flooded for up to 21 DAT.	Good crop stand; good drainage; savings in water; facilitates mechanical weeding.	More weeds; micronutrient deficiency; termite problems; labor-intensive.
Raised-bed drill-seeded rice	Bed-DSR	A bed former-cum-zero-till drill is used to form 37-cm-wide raised beds and 30-cm-wide furrows in well-prepared and pulverized soil, and dry rice seeds are sown in rows on both sides of moist beds. Furrows are kept flooded for up to 21 DAS. Frequent light irrigations are applied for quick germination and crop establishment.	Good drainage; savings in water; facilitates mechanical weeding.	Poor crop stand; heavy weed infestation requiring chemical weed control; micronutrient deficiency; termite problems; soil compaction with time.
Permanent (double) bed-	Bed (permanent)-	Drill seeding on raised beds is practiced for both rice	Good drainage; savings in	Variable crop stand; heavy

planted rice	DSR	and wheat in a sequence.	irrigation water; facilitates mechanical weeding.	weed infestation requiring chemical weed control; micronutrient deficiency; termite problems in rice.
Zero-till (non-puddled) transplanted rice	ZT-TPR	Transplanting rice seedlings in flooded field at optimum soil moisture without tillage and seedbed preparation.	No tillage cost; good soil structure due to no puddling.	Difficult to plant manually; more weeds; labor-intensive.
Zero-till drill-seeded rice	ZT-DSR	Fields are flush-irrigated to moisten the soil and allow weeds to germinate. After 5–7 days, glyphosate/paraquat is applied to kill all weeds. Then, a zero-till drill seeder is used to drill rice seeds at shallow depth, followed by a light irrigation to have a quick and uniform germination.	Uniform crop stand; savings on tillage cost; good soil structure for winter wheat.	Heavy weed infestation requiring chemical weed control; micronutrient deficiency; termite problems.
Zero-till drill-seeded rice with traffic control	ZT-DSR-TC	A version of ZT-DSR in which a 4-wheel tractor with narrow wheels and a zero-till drill is used for seeding after need-based preplant herbicide weed control. The tractor enters the field from fixed points and operates in the same tracks each time—behaving like traffic control (TC). The tire track area is not seeded and it serves as irrigation-cum-drainage channels. If needed, the tractor can be used for inter-cultivation to control weeds.	In this version, border-effect compensates for the missing rows, saves costly seeds, facilitates irrigation/drain-age, and does not reduce crop yield.	Experienced operator needed to maintain controlled tire traffic; heavy weed infestation requiring chemical weed control; micronutrient deficiency; termite problems.
Zero-till drill-seeded rice and *Sesbania*	ZT-DSR+Ses	Rice is drill-seeded; *Sesbania* seeds either drill-seeded or broadcast in zero-till plots. *Sesbania* knocked down at 25–30 DAS with 2-4,D.	No tillage; faster seeding; less labor; weed suppression by *Sesbania*.	May reduce rice yields due to intercrop competition; additional cost of *Sesbania* seeds.
Zero-till drill-seeded rice and *Sesbania* with	ZT-DSR-TC +Ses	Rice is drill-seeded; *Sesbania* seeds either drill-seeded or broadcast in zero-till plots	No tillage; faster seeding; less labor;	May reduce rice yields due to intercrop

traffic control		with controlled traffic. *Sesbania* knocked down at 25–30 DAS with 2-4,D.	weed suppression by *Sesbania*.	competition; additional cost of *Sesbania* seeds.
Double zero-till drill-seeded rice (followed by wheat)	DZT-DSR	Rice is zero-till drill-seeded at optimum moisture in the presence of residues, along with need-based preplant herbicide weed control. In winter, wheat is similarly zero-till drill-seeded in the same field.	Savings on tillage cost for both rice and wheat; good soil structure; improved soil carbon status.	Variable crop stand; soil hardening with time.
CT-TPR with leaf color chart (LCC) for improved N management	CT-TPR-LCC	Use of LCC to determine plant N status at periodic intervals and apply N fertilizer as per crop demand.	Higher N-use efficiency; reduced fert. cost; less or no pesticide use; reduced air and water pollution.	Additional labor for monitoring plant N status and N application.
CT-TPR with integrated crop and resource management	CT-TPR-ICRM	Land is plowed, puddled, and leveled; young seedlings at 3- to 4-leaf stage are transplanted at an optimal spacing with 1 to 2 seedlings per hill and improved soil, water, nutrient, and weed management.	Reduced inputs, increased yields, and higher resource-use efficiency.	Time-consuming; need for skilled labor; difficult to follow wetting and drying irrigation.
Laser-assisted land leveling	LASER-level	A laser-attached tractor is used to level the field dry or wet. A proper tillage or zero-tillage is needed to maintain the level for 3–4 years.	Uniform irrigation and water savings; good crop stand; fewer weeds; high yield.	Experienced operator needed; initial additional cost for leveling.

Table 1b. Name, abbreviation, brief description, benefits, and limitations of conventional technologies and RCTs for wheat.

Name	Abbreviation	Brief description	Benefits	Limitations
Conventional-till broadcast-seeded wheat	CT-BCW	Seeds are broadcast manually in thoroughly prepared fields with 4–5 plowings/harrowings by a tractor or a power tiller. After sowing, laddering is practiced to cover seeds.	Traditional; easy crop establishment.	High energy and tillage cost; high seed rate; late wheat seeding; low yield.
Reduced-till (with a rotovator)	RT-BCW (rotovator)	A single-pass tillage is done by a tractor or a power tiller	Savings on tillage cost;	High seed rate; variable crop

broadcast-seeded wheat		with an attached rotovator; here, the entire swath of soil is rotovated. Then, wheat is sown by broadcasting.	timely wheat seeding; high yield.	stand; weed problems.
Reduced-till drill-seeded wheat	RT-DSW (rotovator)	A single-pass tillage is done by a tractor with an attached rotovator or tiller; then, wheat is drill-seeded.	Faster tillage and seeding; savings on tillage cost; timely wheat seeding; high yield.	Tendency to increase tillage frequency; no soil structure maintenance.
Reduced-till drill-seeded wheat with a power tiller–operated seeder (PTOS)	RT-DSW (PTOS)	The PTOS is a tiller with an attached seeder and a soil-compacting roller. The PTOS is used to till shallow (4–5-cm depth), sow seeds in rows at adjustable distance, and cover seed and compact the soil at the same time in a single pass. PTOS can also be used to sow other crops.	Faster tillage and seeding; savings on tillage cost; timely wheat seeding; high yield.	Variable crop stand; weed problems.
Raised-bed drill-seeded wheat	Bed-DSW	Here, a bed former-cum-zero-till drill is used to form 37-cm-wide raised beds and 30-cm-wide furrows in well-prepared, pulverized soil and wheat is sown in rows on both sides of moist beds.	Good drainage; savings in irrigation water; facilitates mechanical weed control.	Variable crop stand; weed pressure.
Permanent (double) bed-planted wheat	DBed-DSW	Drill seeding on raised beds is practiced for both wheat and rice in a sequence.	Good drainage; savings in irrigation water; facilitates mechanical weed control.	Variable crop stand; weed pressure.
Zero-till broadcast wheat: surface seeding	ZT-BCW	Seeds are simply broadcast on a well-moistened soil without any land preparation and in the presence of crop residues or, alternatively, on fallow land.	Reduced cost; faster and timely wheat seeding; most suited to heavy soils with excessive soil moisture in the eastern IGP.	Variable crop stand; lower yield.
Zero-till drill-seeded wheat	ZT-DSW	Glyphosate/paraquat is applied to kill all weeds and wheat seed is drilled at 4–5 cm in moist soil by a	Uniform crop stand; savings in tillage cost; timely wheat	Chemical weed control.

		zero-till fertilizer-cum-seed drill, without any tillage and in the presence of anchored crop residues.	planting.	
Zero-till drill-seeded wheat under surface mulch or crop residues	ZT-DSW-Residue	The surface mulch seeder cuts stubbles, picks up combined loose straw, chops into small pieces, and spreads uniformly in the field, followed by drill seeding of wheat in rows.	Reduced cost; faster and timely wheat seeding; partial weed control due to mulch.	Variable yield.
Zero-till drill-seeded wheat with traffic control	ZT-DSW-TC	A version of ZT-DSR in which a 4-wheel tractor with narrow wheels and a zero-till drill is used for wheat seeding after need-based preplant herbicide weed control. The tractor enters the field from fixed points and operates in the same tracks each time—behaving like traffic control (TC). The tire track area is not seeded and it serves as irrigation-cum-drainage channels.	In this version, border effect compensates for the missing rows, saves costly seeds, facilitates irrigation/drainage and does not reduce crop yield.	Experienced operator needed to maintain controlled tire traffic; chemical weed control.
Double zero-till drill-seeded wheat (followed by rice)	DZT-DSW	Seeds are drilled by a zero-till drill at optimum moisture in the presence of residues, along with need-based preplant herbicide weed control. In monsoon season, rice is similarly zero-till drill-seeded in the same field.	Savings in tillage cost for both rice and wheat; good soil structure; improved soil carbon status.	Variable crop stand; soil hardening with time.
Bed-planted wheat with intercropped sugarcane	Bed-DSW-Sugar	Sugarcane is interplanted in furrows with wheat planted on raised beds.	Good drainage; savings in irrigation water.	Competition; reduced wheat yield.

2.1. Crop diversification

In RW, farmers keep their land fallow after harvest of wheat for about 70–80 days in premonsoon (prekharif) season, especially in the eastern IGP. Short-season pulses such as mungbean and pigeonpea, green manure crops, vegetables, and other high-value crops can be cultivated prior to the monsoon rice crop to intensify and diversify the RW cropping system, improve soil quality, and increase farmers' income (Dahiya et al 2002, Khan et al 2008). Wherever possible, suitable crop-livestock systems can also be developed and promoted to enhance farm diversification and increase farmers' income.

3. Summary of major activities: 2005-08

About 8,000 on-farm trials evaluated different RCTs in rice and wheat fields at various sites of the four IGP countries during 2005-2008 (Table 2, Fig. 1). Farmers refined, validated, and selected the most suitable RCTs for their regions by using their own criteria for selection. Additional activities undertaken to support farmers in technology adoption include establishment of 115 village seed banks, organization of 175 machinery pools and custom-hire service providers, lining of 16 canals (total length, 4,362 m), and analysis of 1,260 soil and water samples (Table 2). A third category of activities includes various types of training and education programs organized for different stakeholders of the project—farmers, extension staff, researchers, local university student interns, service providers, private machine manufacturers, and policymakers. A total of 131 training and education events were organized in all four countries during the project period (2005-08), with an estimated total of 5,284 participants (Table 2). The categorized training activities include 48 training sessions with 1,703 research and extension staff, 8 internship training sessions with 52 student interns, 11 practical training events with 133 private machine manufacturers and service providers, 33 hands-on training events on RCTs for 1,385 farmers, 19 traveling seminars with 246 participants, and 12 household socioeconomic surveys with 1,765 participants. Dissemination and promotion activities undertaken and related extension materials produced are included in the fourth group. Twenty-eight field workshops/seminars with 780 participants, 36 farmers' field days with 1,160 participants, 114 television programs on RCTs, and 26 visits to project sites of 402 policymakers and scientists were organized in the IGP countries during 2005-08 (Table 2). A total of 4,400 brochures/banners/posters/wall chalkings (billboards) were distributed to farmers to popularize the RCTs. Key activities are discussed briefly below.

Table 2. Major project activities and number of events and participants/beneficiaries at different sites, 2005-08.

Activity	No. of trials, events, and activities of participants						
	Bangladesh	India			Nepal	Pakistan	Total
		Ballia	Karnal	Modipuram			
1. Validation and dissemination of RCTs							
• Conventional-till wet transplanted rice (CT-TPR)	2,107	130	66	74	217	49	2,643
• Conventional-till broadcast-seeded rice (CT-BCR)	–	11	–	–	–	–	11
• Conventional-till wet drum-seeded rice (CTDrumR)	30	17	0	1	26	0	74
• Reduced-till unpuddled transplanted rice (RT-TPR)	0	6	93	2	0	0	101
• Zero-/reduced-till drill-seeded rice (ZT/RT-DSR)	0	111	56	101	23	18	309
• CT-TPR with integrated crop and resource management in rice (CT-TPR-ICRM)	950	0	0	0	189	0	1,139
• CT-TPR with leaf color chart for improved N management (CT-TPR-LCC)	1,127	0	0	0	0	16	1,143
• Zero-till/reduced-till drill-seeded wheat (ZT/RT-DSW)	18	256	77	117	100	89	657
• Zero-till surface seeding of wheat (ZT-BCW)	0	10	0	0	3	0	13
• Integrated crop management in wheat (CT-ICM-W)	50	–	–	–	6	–	56
• Zero-till (double) drill seeding of wheat and rice in presence of crop residues (DZT-DSR/DSW)	18	295	77	101	123	92	706
• Permanent bed planting of wheat and rice (DBed-DSR-DSW)	0	23	60	4	0	28	115
• Zero-tillage in other crops	0	13	–	–	0	0	13

• Bed planting of other crops	0	5	58	9	0	4	76
• Laser-assisted land leveling	–	–	163	–	–	571	734
• Crop diversification/intercropping	43	18	58	9	0	4	132
Total on-farm RCT evaluation plots	**4,393**	**895**	**708**	**418**	**687**	**871**	**7,922**
2. Support to farmers							
• Establishment of machinery pools	–	95	–	–	33	47	175
• Establishment of village seed banks	6	4	–	–	104	1	115
• Soil and water analyses	–	100	350	600	–	210	1,260
• Lining of no. of canals (length, m)	–	–	–	–	–	16 (4,362 meter)	16 (4,362 meter)
Total no. of items/samples	6	199	350	600	137	274	1,566
3. Training and capacity building							
• Training to research and extension staff: no. of events (no. trained)	25 (1,450)	5 (25)	5 (20)	4 (20)	3 (48)	6 (140)	48 (1,703)
• Internship training to students: no. of events (no. trained)	–	2 (7)	3 (15)	–	–	3 (30)	8 (52)
• Training to private entrepreneurs and service providers: no. of events (no. trained)	2 (25)	2 (15)	2 (15)	2 (15)	3 (63)	–	11 (133)
• Training of farmers: no. of events (no. trained)	10 (615)	5 (100)	5 (200)	2 (50)	6 (180)	5 (240)	33 (1,385)
• Traveling seminars and meetings: no. of events (no. of participants)	2 (80)	3 (15)	3 (15)	3 (15)	4 (70)	4 (51)	19 (246)
• Farmer surveys: no. of events (no. of participants)	2 (370)	2 (201)	2 (314)	2 (182)	2 (398)	2 (300)	12 (1,765)
Total no. of events (no. of participants)	**41 (2,540)**	**19 (363)**	**20 (579)**	**13 (282)**	**18 (789)**	**20 (761)**	**131 (5,284)**
4. Technology dissemination and promotion							
• Field workshops and seminars: no. of events	2 (50)	5 (100)	6 (150)	4 (100)	6 (180)	5 (200)	28 (780)

(no. of participants)							
• Farmers' field days/discussions: no. of events (no. of participants)	5 (115)	4 (150)	14 (280)	3 (135)	6 (220)	4 (260)	36 (1,160)
• Farmers' exchange visits: no. of events (no. of participants)							
• Brochures/banners/posters/wall chalkings	1,000	50	50	1,000	1,000	1,300	4,400
• Popular articles in local newspapers/magazines	12	9	11	6	25	63	126
• Uploads (i.e., reports, events, papers) on ADB Web sites	30	26	21	22	27	20	146
• TV programs on RCTs, ICM, LCC, etc.	4	25	15	-	10	60	114
• Distribution of leaf color charts	9,500	600	400	200	580	9,750	21,030
• Visits of policymakers, scientists: no. of events (no. of participants)	3 (26)	3 (15)	5 (35)	5 (38)	6 (98)	4 (190)	26 (402)

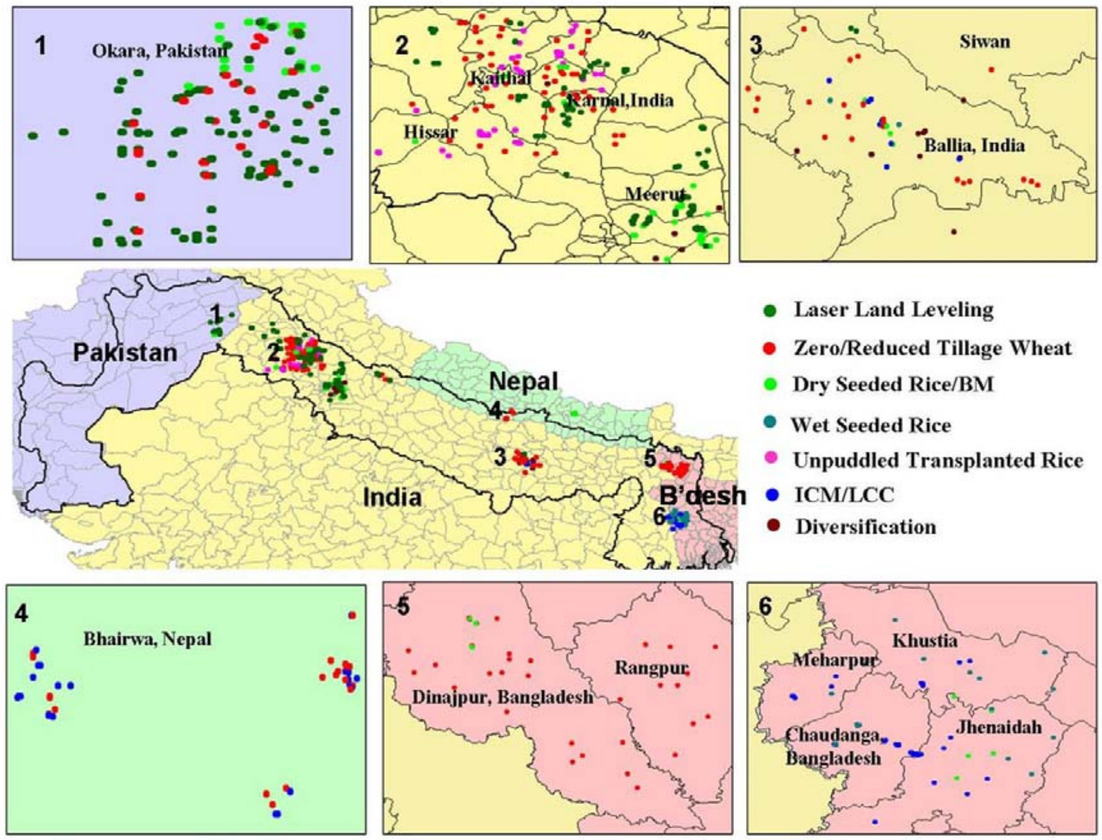

Fig. 1. Demonstration and adoption of targeted RCTs at ADB sites across the IGP in 2005-08.

3.1. Selection of sites/locations, pilot villages, and farmer-cooperators

The project was implemented in four countries in South Asia—Bangladesh, India, Nepal, and Pakistan. These countries have substantial areas under rice and wheat (Ladha et al 2007). The project worked at eight sites in the four countries (Chuadanga, Dinajpur, and Nashipur, Bangladesh; Ballia, Karnal, and Modipuram, India; Bhairahawa and Bhakunde, Nepal; and Sheikhupura and Okara, Pakistan) (Fig. 1). Maps, socioeconomic profiles, past yield data (of districts/provinces), and local knowledge/expertise were used to define the locations and target groups and to select the pilot villages for project implementation (Tripp 1982). The 2005-08 work builds on and complements the earlier project phase. In site and village selection for the ADB project, emphasis was placed on (a) representativeness of the local RW system, (b) good access from a nearby city, (c) potentially suitable for improving and expanding irrigation facilities for intensification of the RW system, (d) areas with farmers interested in trying out new RCT and potential to expand RCT area, (e) high potential for enhancing RW productivity and farmers' income and livelihood, and (f) could serve as model villages for later dissemination of successful RCTs.

Discussion meetings were held with local farmers and/or farmer-groups to introduce the project and explain the various project activities to them. Farmers who are willing were invited to work with the project's staff to identify local crop production problems and opportunities for improving grain yield and net income from RW system.

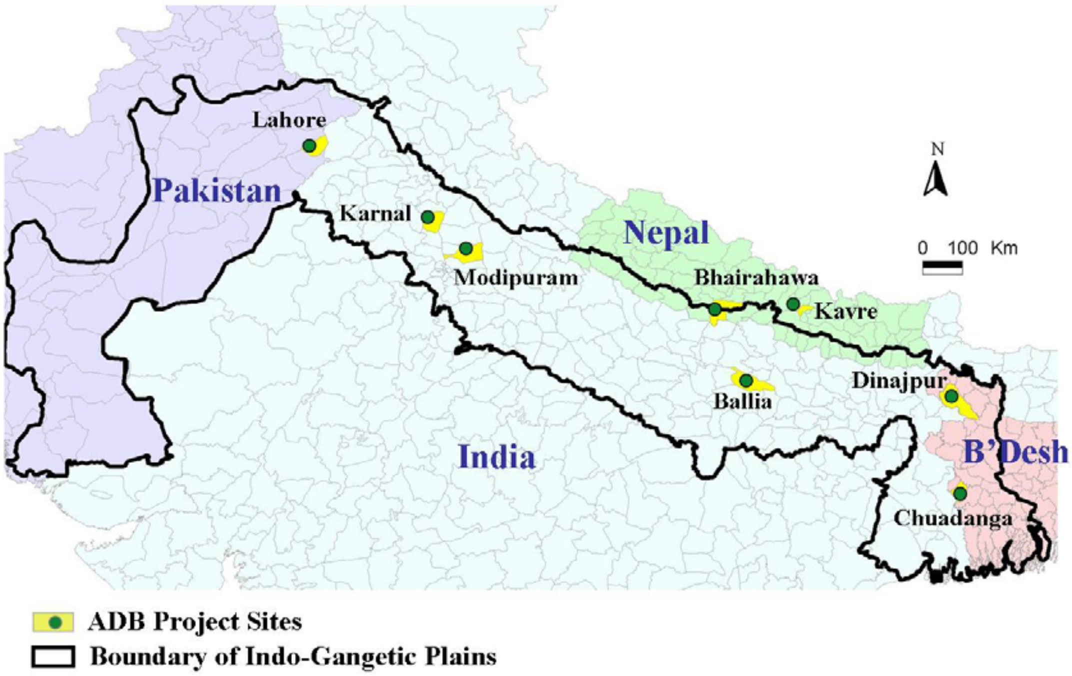

Fig. 2. Location of ADB project sites in the Indo-Gangetic Plains

3.2. Baseline socioeconomic survey

A socioeconomic baseline survey was conducted at each site to determine its geophysical, biological, and socioeconomic characteristics, and crops and crop production systems and related constraints and opportunities, building on previous work (e.g., Fujisaka et al 1994). The site-wise number of villages and farmers covered in the baseline survey are indicated in Table 3a.

Table 3a. Number of villages and farmers covered in the baseline socioeconomic survey conducted.

Country	Site	No. of proposed project villages	No. of farmers surveyed
Pakistan	Okara	6	120
Bangladesh	Chuadanga	9	110

	Nashipur	3	30
Nepal	Bhairahawa	3	112
	Kavre	4	67
India	Haryana	10	74
	Ballia	10	81
	Modipuram	6	62

3.3. Technology refinement, evaluation, and validation

Suitable RCTs for each site were selected from a portfolio of RCTs developed over the past 10 years through carefully designed on-station trials. A brief description of different RCTs for rice and wheat is given in Tables 1a and 1b, respectively. The project staff provided appropriate training and technical support to farmers on suitable RCTs for each location. Trained farmers evaluated different RCTs in about 8,000 rice and wheat fields at eight sites in four IGP countries during 2005-08 (Table 2).

3.4. Support activities to accelerate technology adoption

Several support activities were undertaken to enhance farmer adoption of introduced technologies:

- Soil and water analysis facilities determining irrigation water quality and soil fertility status and related fertilizer rates
- Machinery pools for renting farm machines to farmers at affordable cost
- Rural seed banks to produce and supply good-quality seed at affordable cost
- Improving irrigation efficiency at system and farm levels (canal lining)
- Strengthening multistakeholder partnership for effective validation and dissemination of RCTs

3.5. Simulation of potential yield and yield gaps

Simulation was used to determine the potential yields of rice and wheat in the IGP countries (Aggarwal et al 2000). Potential yield is defined as the maximum yield of a variety restricted only by season-specific climatic conditions. This assumes that other inputs (nutrients, water, etc.) are not limiting and cultural management is optimal. Thus, the potential yield of a crop depends on the temporal variation in CO_2 level in the atmosphere, solar radiation, maximum and minimum temperatures during the crop season, and physiological characteristics of the variety. To simulate potential yield, CERES-RICE 3.5 (98.0) (Singh et al 1998) was used for rice and GENERIC-CERES 3.5 (98.0) (Ritchie et al 1998) was used for wheat.

Yield gaps were estimated at two levels. Yield gap 1 is the difference between the maximum attainable yield (assumed to be 80% of climatic potential yield) and the average yield obtained in ICRM fields (CT-TPR-ICRM/ZT-DSW). Yield gap 2 is the difference between the maximum attainable yield and the average yield obtained in farmers' fields using conventional practices (CT-TPR/CT-BCW).

3.6. Development of decision support system: InfoRCT

A decision support system (DSS), named InfoRCT (Information on Use of Resource Conservation Technologies in Agriculture), has been developed to quantify the input-output budget and fluxes of N and greenhouse gases (GHG) along with detailed cost/benefit analysis of the prominent RCTs in the rice-wheat system of the IGP. The DSS integrates analytical and expert knowledge on biophysical, agronomic, and socioeconomic features to establish input-output relationships related to water, fertilizer, labor, and biocide uses; GHG emissions; biocide residue in soil; and N fluxes in the rice-wheat system. This analysis will help in sensitizing national agricultural policymakers; extension services; public-, private-, and NGO-sector organizations; and farmer groups on the potential benefit of RCTs.

3.7. Statistical analysis

Data were analyzed using SAS mixed model procedure (SAS 2001), in which treatment was used as a fixed effect and farmer as a random effect (Prasad et al 2006). Means separation was done using a Fisher-protected t-test at LSD 0.05. An SAS macro was used for displaying letters of multiple comparisons of the means (Spilke et al 2005). Unless otherwise stated, the data on changes in crop yields with an improved technology (such as laser-aided land leveling, alternative tillage and crop establishment, and integrated crop and resource management) compared with a corresponding farmers' practice (such as traditional land leveling, conventional tillage with transplanting, or farmers' crop management) are presented.

3.8. Diffusion of successful RCTs

Farmers' knowledge and awareness regarding RCTs were enhanced by discussing with individual farmers, arranging field seminars and demonstrations, organizing television programs on RCTs, and distributing technology brochures, posters, calendars, etc. Examples of extension materials developed and promotion activities conducted are

- Field demonstrations
- Field days and seminars
- Traveling seminars and meetings
- Making agro-machinery available to extension workers and farmers
- TV programs
- Brochures/banners/posters/wall chalkings
- Articles on RCTs in local newspapers/magazines

3.9. Training and capacity building

Different types of training were organized for different stakeholders of the project as described below.

3.9.1. Orientation workshop: A one-day orientation workshop was organized at each site to introduce the project and plan the activities (work plan). Selected lead farmers, extension officers, research staff, local seed companies, agro-chemical retailers, fertilizer dealers, and media personnel were invited to this workshop. All of them actively participated in the discussion on project activities, implementation details, and the roles, responsibilities, and expected contribution of each stakeholder in project implementation.

3.9.2. Farmers' training: Every year, the participating farmers were trained on RCTs selected for each site and the ICRM approach. Several practical sessions were also held to demonstrate laser-assisted land leveling; various tillage and crop establishment practices, including seed treatment, modified mat nursery, bed planting, and controlled traffic seeding; proper use of a leaf color chart (LCC) for N management; and use of farm machines such as a tractor with laser equipment, power tiller and power tiller–operated seeder (PTOS), drum seeder, rotating weeders, and harvesters.

3.9.3. Service providers' training: At each site, two-day training was organized for service providers (tractor driver and the owner) to train them on how to use and maintain the tractor and power tiller, ZT drill seeder, PTOS, and bed planter. First, the theory of tractors and tractor operations were explained and then the practical aspects of tractor operation and maintenance were demonstrated to participants with a four-wheel tractor. Then, the trainee drivers also learned how to use and maintain the plows, harrows, and rotovator attachments, power tiller, ZT drill seeder, and bed planter.

3.9.4. Training of extension and research staff: One- to two-day training was organized at project sites for extension and research staff to familiarize them with the various project activities and RCTs and ICRM components to be examined at the respective sites. Regional and local agronomists, breeders, field technicians, and extension officers from the Department of Agriculture Extension took part in the training.

3.9.5. Internship training program: An internship program was organized for training undergraduate students of a local agricultural university (e.g., Pakistan) on RCTs and farmer participatory technology evaluation and dissemination. These students worked with and helped farmers in the project area to learn and apply the new RCTs in both rice and wheat. This intervention was very successful and mutually beneficial to both farmers and students in getting and sharing up-to-date information and field experiences on RCTs.

3.10. Project impact analysis: measurement of impacts

An impact assessment of the ADB project RETA 6208 was conducted in 2008 by surveying farmers and communities in both project and nonproject areas at each site (Singh and

Erenstein 2009). The impact assessment included a village survey (spring 2008) and a subsequent household survey (kharif 2008) at each site. The number of villages and farmers covered in the socioeconomic impact survey conducted in 2008 are given in Table 3b.

Table 3b. Number of villages covered in the socioeconomic impact assessment survey conducted in 2008.

Country	Site	No. of project villages surveyed	No. of control villages surveyed
Pakistan	Okara and Sheikhupura	6	3
Bangladesh	Chuadanga	4	2
	Dinajpur	2	1
	Gazipur	2	1
Nepal	Bhairahawa	4	2
	Kavre	3	2
India	Haryana	8	4
	Ballia	4	2
	Modipuram	4	2

3.11. Documentation of project implementation and progress

Semiannual and final progress/technical reports, proceedings of workshops and seminars, a special publication of the American Society of Agronomy, technology books, socioeconomic and impact survey reports, peer-reviewed journal publications, popular articles in newspapers and magazines, an RWC newsletter, and RWC and ADB Web sites document the implementation details and progress of the project.

4. Summary of major project accomplishments (2005-08)

4.1. On-station trials on RCTs

Well-planned research trials were conducted at selected research farms to refine and evaluate new technologies such as laser-assisted land leveling; double zero-tillage; permanent beds for rice and wheat; rice crop establishment methods in nonpuddled, nonflooded soil; alternate wetting and drying (AWD) irrigation for rice; integration of *Sesbania* with direct-seeded rice to control weeds, enhance soil quality, and save water in the rice-wheat system; and the development of strategies to eliminate the burning of crop residues. Results of on-station trials conducted at different sites during 2005-08 are summarized in Tables 4a for rice, 4b for wheat, and 4c for the RW system.

4.1.1. Performance of rice: Rice consumes about 80% of the total water applied in the rice-wheat system and requires extensive tillage, including puddling, to establish the crop. On-station research therefore aimed at minimizing tillage and or eliminating puddling and saving water in rice cultivation with a minimum or no penalty to rice yield and net income. We calculated changes in crop yields with an improved technology (such as laser-aided land leveling, alternative tillage and crop establishment, and integrated crop and resource management) compared to the corresponding farmers' practice (such as traditional land leveling, conventional tillage with transplanting, or farmers' crop management). Results show that laser-assisted precision land leveling reduced the total (irrigation + rainfall) water use by 235 mm and increased rice yield by 0.27 t ha^{-1}; as a result, net income was higher by US$49 ha^{-1} than with traditionally leveled fields (Table 4a). Grain yield of wet drum-seeded rice was similar to that of transplanted rice on puddled soil, but there was a savings in irrigation water (52 mm) and labor cost ($44 ha^{-1}), leading to an additional profit of $55 ha^{-1}. Although AWD irrigation saved significant amounts of water (233 to 490 mm), there was a yield penalty of 0.3 to 0.5 t ha^{-1} with variable net income. Similarly, reductions in grain yield and net income were noted for reduced-till and zero-till direct-seeded rice, and bed-planted (transplanted and direct-seeded) rice, despite significant savings in irrigation and total water use (Table 4a); in these cases, weed pressure was high, requiring investments in herbicides to control weeds. Earlier research results confirm these findings (Sharma et al 2002, Phoung et al 2005). Therefore, more work is needed to refine alternative tillage and crop establishment (TCE) methods for rice on nonpuddled soil, especially to minimize weed pressure, improve crop stand, and maintain high yields (Balasubramanian and Hill 2002, Singh et al 2008a). In addition, greater attention must be paid to soil fertility status and crop nutrition in DSR.

Table 4a. Changes in rice productivity, water use, input cost, and net income from alternative technologies over farmers' practice (results of on-station trials conducted at different sites in IGP countries during 2005-08).[a]

Technology option	Ave. of no. of crop cycles	Yield (t ha^{-1})	Water use (mm)	Labor cost (US$ ha^{-1})	Herbicide cost ($ ha^{-1})	Net income ($ ha^{-1})	References
LASER-Level	2	0.27	–235**	–[b]	–	49	Jat et al (2009)
CT-DrumR	4	0.00	–52* 80**	-44	–2.5	55	Harunar-Rashid et al (2009)
CT-TPR-AWD	4	–0.50	–233*	–	24	–56	Mandal et al. (2009)
	6	–0.30	–490*	0	0	30	Gathala et al (2009)
RT-DSR	4	–0.50	–259*	–	33	–5	Mandal et al. (2009)
	6	–0.85	86*	–13	21	–142	Gathala et

							al (2009)
	2	–1.1	–230**	–	–	–108	Jat et al (2009)
Bed-DSR	6	–3.27	–51*	–21	47	–357	Gathala et al (2009)
	2	–1.03	–	–	–	–	Singh et al (2009)
	4	–0.80	–262*	–	34	–108	Mandal et al (2009)
	2	–2.60	–430**	–	–	–287	Jat et al (2009)
Bed-TPR	6	–1.90	–183*	12	17	–166	Gathala et al (2009)
	2	–0.26	–	–	–	–	Singh et al. (2009)
ZT-DSR	6	–1.15	–61*	–20	50	–60	Gathala et al (2009)
	2	–0.22	–	–	–	–	Singh et al (2009)
	2	–1.1	–265**	–	–	–49	Jat et al (2009)

[a]Change in case of laser leveling was from traditional leveling and in other cases it was from CT-TPR.
[b]No data available.
* = change in irrigation water use; ** = change in total water use (rainfall + irrigation).

4.1.2. Performance of wheat: For wheat in the RW system, the short turnaround time between crops, excessive tillage in the traditional system, and scarcity of labor at planting time delay wheat planting and reduce yields (Hobbs and Gupta 2003, Pathak et al 2003, Ladha et al 2007). Research conducted to overcome these wheat production problems indicates that yield advantage and water savings were negligible or zero for reduced-till planting, but positive for zero-till wheat, probably due to timely planting. Net income for zero-till wheat was three times as high as that of reduced-till wheat, mainly due to reduced or no tillage cost. Laser-assisted leveling increased wheat yield by 0.4 t ha^{-1} and net income by \$95 ha^{-1}, with a savings of 35 mm of irrigation water (Table 4b). Bed planting of wheat was not effective due to lower yields and variable net income, despite savings in irrigation water use. Therefore, only two RCTs—laser-aided leveling and zero-till wheat—are attractive to farmers because of high productivity and net returns (Ahmad et al 1994, Hobbs and Gupta 2003, Ladha et al 2003a).

Table 4b. **Changes in wheat productivity, water use, input cost, and net income from alternative technologies over farmers' practice (results of on-station trials conducted at different sites in IGP countries during 2005-08).**

Technology option	Average of no. of crop cycles	Yield (t ha^{-1})	Water use (mm)	Net income (US$ ha^{-1})	References
Laser-Level	2	0.40	–35**	95	Jat et al (2009)
Bed-DSW	2	–0.50	–115**	–30	Jat et al (2009)
	6	0.09	–105**	80	Gathala et al (2009)
RT-DSW	4	0.00	0*	54	Mandal et al (2009)
ZT-DSW	2	0.40	–40**	186	Jat et al (2009)
	6	0.6	–34*	171	Gathala et al (2009)

** = change in irrigation water use; ** = change in total water use (rainfall + irrigation).*

4.1.3. Performance of the rice-wheat system: The productivity of the RW system has been stagnant in recent years due to various problems: (a) contrasting tillage requirements for rice and wheat, (b) delayed wheat sowing, (c) poor maintenance of soil structure, and (d) poor management of irrigation, weeds and other pests, fertilizer, and crop residues (Ladha et al 2003a, 2007). The short turnaround time between rice and wheat and farmers' persistent practice of excessive preparatory tillage delay wheat planting, resulting in yield losses of 35 kg day^{-1} ha^{-1} in the northwest and up to 60 kg day^{-1} ha^{-1} in the eastern parts of the IGP (Pathak et al 2003). Therefore, different combinations of new tillage, crop establishment, and irrigation practices (Table 4c) were evaluated at research sites in the IGP countries to address RW system productivity, profitability, and sustainability issues. Compared with traditional leveling, laser-assisted leveling enhanced RW system productivity by 0.6 t ha^{-1} and net income by $144 ha^{-1}, with a savings of 280 mm of irrigation water per year (Jat et al 2009). Additional grain yield gains were either negligible or lower for alternate wetting and drying irrigation in rice followed by zero-till drill-seeded wheat, despite significant reductions in irrigation water use and some gains in net income (Mandal et al 2009, Gathala et al 2007, 2009). Drill seeding of rice and wheat on reduced-till flat land or on raised beds saved irrigation or total water use by 6 to 550 mm, but was less productive and profitable than conventional practices; yield loss was high in bed-planted crops (Table 4c). Although total productivity was less in double zero-till drill-seeded rice and wheat (0.5 to 0.8 t ha^{-1}), water savings and net income were high due to lower costs of tillage, irrigation, and labor (Jat et al 2008, Ladha et al 2008). We therefore need further work on double zero-tillage systems and promising options such as AWD

irrigation. However, RCTs such as laser leveling and zero-tillage for aerobic crops such as wheat are ready for farmer evaluation and promotion in the region.

Table 4c. Changes in rice-wheat system productivity, water use, input cost, and net income from alternative technologies over farmers' practice (results of on-station trials conducted at different sites in IGP countries during 2005-08).

Technology option	No. of years	Yield (t ha^{-1})	Water use (mm)	Net income (US$ ha^{-1})	References
Laser-Level	2	0.6	–280**	144	Jat et al (2009)
CT-TPR-AWD/ZT-DSW	6	0.1	–262*	26	Gathala et al (2009)
	4	–0.4	–206*	101	Mandal et al (2009)
RT-DSR/RT-DSW	2	–0.7	–250**	–16	Jat et al (2009)
	6	–0.2	–6*	–250	Gathala et al (2009)
	4	–0.4	–233*	17	Mandal et al (2009)
Bed-DSR/Bed-DSW	6	–3.2	–76*	–277	Gathala et al (core exp.)
	2	–2.9	–550**	–272	Jat et al (2008)
Bed-TPR/Bed-DSW	6	–2.1	–145*	–18	Gathala et al (2009
ZT-DSR/ZT-DSW	2	–0.5	–310**	182	Jat et al (2009)
	6	–0.8	–47*	112	Gathala et al (2009)

** = change in irrigation water use; ** = change in total water use (rainfall + irrigation).*

4.2. *On-farm validation and dissemination of RCTs*

Farmers evaluated different RCTs for crop yield, production cost, net income, and resource-/input-use patterns. The performance of RCTs from farmers' perspective is discussed below.

A. Rice performance with various RCTs

4.2.1. Laser-assisted leveling: Most of the agricultural lands are unleveled or poorly leveled. A larger quantity of irrigation water is therefore required because of poor water distribution in fields. Similar to experiences in on-station trials, compared with traditional land leveling, laser-assisted leveling increased mean rice yields by 0.62 t ha^{-1} and saved on average 100 mm of irrigation water in farmers' fields (Table 5a). As a result, precision land leveling through a laser-assisted land leveler was extended to farmers, especially in India and Pakistan. During the past few years, laser land leveling in the Indian part of the Gangetic Plains has increased to nearly 0.2 million ha and the number of laser units to 925 (Fig. 3).

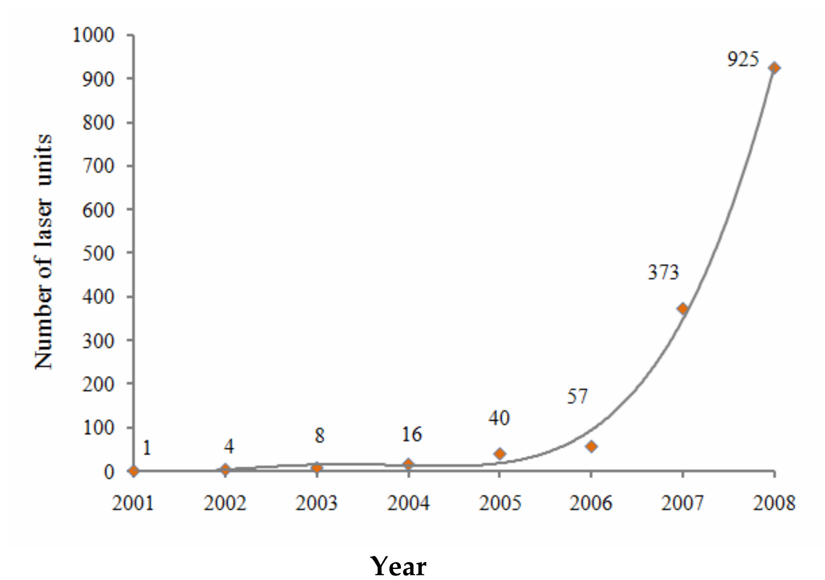

Fig. 3. Adoption of laser-aided land-leveling technology in western Uttar Pradesh, Punjab, and Haryana in 2000-08.

4.2.2. Drum seeding of rice on puddled soil (CT-DrumR): Compared to the farmers' practice (CT-TPR), the yield advantage and additional income due to drum seeding (CT-DrumR) were negligible, with high variability from site to site and in different years. Previous studies have reported no difference in grain yields between transplanted and drum-seeded rice (Balasubramanian and Hill 2002, Pandey et al 2002, Subbaiah et al 2002, PARC-RWC 2003, Tripathi et al 2003, BRRI 2005). Savings in crop establishment costs could have been neutralized by increased costs for extended irrigation, herbicide use for weed control, and additional N fertilizer application for drum-seeded rice (Table 5a); similar experiences in direct-seeded rice have been reported by Balasubramanian and Subbaiah (2000). The high variability in performance of drum-seeded rice could be due to variable farmers' skills in mastering the technology and related practices such as land leveling, water control for the first 10–15 days, and weed management (Khan et al 2009). Therefore,

drum-seeding technology needs further work with farmers to improve and refine it before it is ready for dissemination.

4.2.3. Tillage and crop establishment for rice in nonpuddled soil: In reduced-till unpuddled fields, transplanting was more productive and profitable than drill seeding of rice (Table 5a). Transplanting of rice on raised beds reduced mean grain yield and net income, whereas zero-till transplanting increased rice yield. Earlier studies conducted during the rice season in 2006 at different project sites showed that direct drill seeding on nonpuddled soil instead of conventional transplanting on puddled soil reduced yield from 0.5 to 2.0 t ha^{-1} in 27% of the farmers' fields, whereas 48% of the farmers had no yield change and 25% obtained higher yield, varying from 0.5 to 1.5 t ha^{-1} (unpublished). Therefore, additional research efforts are needed to refine direct drill-seeding technology for rice in nonpuddled soil.

4.2.4. Integrated crop and resource management (ICRM) and leaf color chart for rice: There is a need to evaluate the simple LCC technology for precision N management in rice and to integrate it with other crop management techniques in an integrated crop and resource management (ICMR) approach to improve productivity, profit, and product quality in rice. Crop need-based N management with the help of an LCC (CT-TPR-LCC) and ICRM for transplanted rice (CT-TPR-ICRM) have increased grain yield by 0.24 to 0.75 t ha^{-1} and net income by \$41 to \$49 ha^{-1} and reduced fertilizer cost due to efficient N use (Table 5a). Thus, farmers can effectively reduce their yield gaps and enhance their farm income by adopting a full package of ICRM technologies in rice (Balasubramanian et al 2003, 2004, 2005, Regmi and Ladha 2005, Khan et al 2009).

Table 5a. Average changes in rice productivity, income, and input use from alternative technologies versus farmers' practices from on-farm farmers' participatory trials conducted in Bangladesh, India, and Nepal during 2005-08.

Technological option	No. of crop cycles	No. of sites	No. of farmers	Yield change (t ha^{-1})[a]	Income change (US$ ha^{-1})	Labor cost (d ha^{-1})	Irrigation (mm)	Herbicide (US$ ha^{-1})	Nitrogen (kg ha^{-1})
Laser-aided land leveling	3	2	54	0.62 (0.2 to 1.1)	–[b]	–	–100 (–130 to –30)	–	–
CT-Drum	3	4	73	–0.01 (–2.3 to 0.9)	–1 (–464 to 236)	–	180 (–60 to 340)	2 (–6 to 22)	19 (–44 to 84)
RT-TPR	3	3	89	0.32 (–2.0 to 2.4)	63 (–117 to 637)	–5 (–7 to –4)	90 (–140 to 250)	1 (–4 to 6)	–1 (–25 to 23)
RT-DSR	3	4	223	0.05 (–2.3 to 1.9)	34 (–663 to 593)	–17 (–25 to –10)	–120 (–490 to 80)	12 (–26 to 41)	–4 (–100 to 44)
Bed-TPR	3	3	19	–0.19 (–1.3 to 1.1)	–25 (–119 to 73)	–	–	0.1 (–1 to 2)	–5 (–30 to 0)
ZT-TPR	3	2	14	0.29 (–0.8 to 1.5)	–	–	–	0.3 (–2 to 3)	–2 (–20 to 5)
CT-TPR-ICRM	4	2	1179	0.75 (–1.2 to 3.5)	41 (–92 to 350)	5 (–4 to 9)	–	7 (–22 to 22)	–45 (–509 to 469)
CT-TPR-LCC	3	1	551	0.24 (–0.3 to 0.9)	49 (–25 to 154)	–	–		–29 (–86 to 10)

[a]Numbers in parentheses indicate the range

[b]No data available.

B. Wheat performance with various RCTs

4.2.5. Reduced- and zero-till wheat: Reduced- or zero-tillage facilitates timely wheat planting, especially in relatively high-moisture conditions where farmers find it difficult to prepare the land on time for sowing wheat (Gupta and Rickman 2002). Minimum- or zero-till wheat is established by tractor-operated drill seeding in the presence of crop residues in combine-harvested rice fields in the northwestern IGP (Gupta and Rickman 2002) and seeding by PTOS in manually harvested rice fields in the eastern IGP (Meisner et al 1998). Appropriate wheat and rice varieties and related crop management (nutrient and water management and weed and pest control) practices and farm machines, including seeders, have been developed to suit the zero-till wheat-based RW system (Hobbs and Gupta 2003, Ladha et al 2003a). Therefore, minimum- or zero-tillage is becoming increasingly popular among farmers in parts of the IGP (Singh and Erenstein 2009, Erenstein et al 2007, Farooq et al 2007).

Reduced-till and zero-till drill-seeded wheat were highly productive and profitable, with yield increases ranging from 0.14 to 0.46 t ha^{-1} and net income from \$76 to \$200 ha^{-1} (Table 5b). This is due to the timely planting of wheat after the rice harvest and reduced energy costs for tillage. Refined and efficient seeders are available for drill seeding of wheat in fields without any tillage and in the presence of crop residues (Gupta and Rickman 2002, Sidhu et al 2008). Retaining crop residues as mulch would reduce the perceived need to burn rice residues in the northwest IGP (Erenstein et al 2007b; 2007c), enhance the scope of organic matter accumulation in the soil, and move the system toward conservation agriculture.

Table 5b. Average changes in wheat productivity, income, and input use from alternative technologies versus farmers' practices from on-farm farmers' participatory trials conducted in Bangladesh, India, and Nepal during 2005-08.

Technological option	No. of crop cycles	No. of sites	No. of farmers	Yield (t ha^{-1})[a]	Net Income (US$ ha^{-1})	Nitrogen (kg ha^{-1})	Herbicide ($ ha^{-1})	Tillage cost ($ ha^{-1})
RT-DSW	3	2	42	0.14 (–1.3 to 2.8)	182 (–221 to 580)	–19 (–113 to 43)	1.0 (0 to 15)	–
RT-DSW (PTOS)	2	1	18	0.45 (–0.8 to 1.2)	200 (–48 to 425)	–	–	–
RT-BCW (rotovator): surface seeding	1	1	10	0.06 (–0.8 to 0.4)	–8 (–333 to 112)	–	0.1 (–18 to 18)	–
Bed-DSW	3	2	60	0.36 (–1.2 to 3.0)	76 (–130 to 502)	–3 (–38 to 38)	0.1 (–7 to 6)	–8 (–51 to 51)
ZT-DSW	3	4	419	0.35 (–1.3 to 3.5)	150 (–235 to 740)	–5 (–92 to 132)	–0.1 (–17 to 78)	–31 (–11 to 0)
DZT-DSW	3	1	31	0.46 (–0.8 to 1.5)	112 (–198 to 307)	–18 (–51 to 74)	1.2 (–5 to 7)	–33 (–61 to 0)
CT-ICRM	1	1	44	1.06 (0.4 to 1.6)	–[b]	–	–	–

[a]Numbers in parentheses indicate the range.
[b]No data available.

4.2.6. Integrated crop and resource management (ICRM) in wheat: The practice of ICRM for conventional-till drill-seeded wheat (CT-DSW-ICRM) has increased the mean grain yield by 1.06 t ha^{-1} (Table 5b). The adoption of ICMR in wheat and rice will lead to enhanced system productivity and higher net income, and save resources (Regmi et al 2009).

4.3. Diversification of the RW system

In RW, farmers keep their land fallow after the harvest of wheat for about 70–80 days in the premonsoon (prekharif) season, especially in the eastern IGP. On-farm trials were conducted with short-season pulses such as mungbean, green manure crops, vegetables, and other high-value crops during the premonsoon fallow period with an aim to intensify and diversify the RW cropping system, to improve soil quality, and to increase farmers' income. For example, farmers in Bangladesh earned an additional income of \$677 ha^{-1} in 2006 and \$666 ha^{-1} in 2007 by planting mungbean during the short fallow period between winter wheat and monsoon rice. Improved short-duration crop varieties (e.g., BARI mung-6 in Bangladesh) are available for crop intensification/diversification in the IGP of Bangladesh (Khan et al 2009). New and more profitable cropping systems involving maize and potato have been developed and extended to farmers in the eastern IGP. Wherever possible, suitable crop-livestock systems can also be developed and promoted to enhance diversification and intensification of the rice-wheat system. Farmers' participatory trials on simultaneous planting of sugarcane and wheat through bed planting revealed that, with this simultaneous planting, cane planting can be advanced by 90 to 110 days with an increase of 15–20% in sugarcane yield without any yield penalty to the wheat crop. Also, there is a savings in the cost of production of sugarcane. To popularize the technology, a large number of demonstrations were conducted and efforts are also being made to have linkages with sugar mills and the UP cane department to accelerate the technology in western UP.

4.4. Overall prospects of RCTs in the RW system

Laser-assisted land leveling has been shown to be very effective in enhancing the productivity of the RW system by increasing grain yields of both rice and wheat and making more efficient use of irrigation water and other inputs such as fertilizers and pesticides (Jat et al 2006). Reduced- and zero-till drill-seeded wheat are attractive to farmers because of higher grain yields due to timely sowing, reduced energy use and lower land preparation costs, higher labor productivity due to locally adapted efficient tillers and seeders, effective handling and incorporation of crop residues without a need for burning, and overall higher profit for farmers (Ladha et al 2003a, Laxmi et al 2007). However, farmers outside the project villages are yet to benefit from these technologies, especially in rice. The work in the ADB-supported projects has stimulated investment by other donors and NARES to disseminate laser-assisted land leveling, reduced- and zero-till wheat, and other improved technologies in other areas.

Although much on-station and on-farm research has been carried out on nutrient and crop management strategies, the integrated use of different technologies is critical to enhance their synergistic effects on crop productivity, product quality, and profit. The use of ICRM for rice and wheat has been hugely successful in on-station and on-farm trials conducted at project sites during 2005-08. What we need now is to develop an effective program for wider dissemination of RCTs and the ICMR approach in the eastern Gangetic Plains, including proper validation by farmers and training of research and extension staff to support farmers. There is also a need to sensitize agricultural policymakers and encourage them to allocate more resources for wider dissemination of successful RCTs within an ICMR framework.

4.5. Support to farmers for accelerating the adoption of RCTs

4.5.1. Soil and water analysis facilities: A total of 1,260 soil and water samples (Table 2) were collected and analyzed to determine soil fertility status and irrigation water quality at some project sites (India and Pakistan). For example, 455 soil and 230 irrigation water samples were analyzed free of cost in collaboration with Fauji Fertilizers Company (FFC) in Pakistan to properly decide on correct doses of agricultural inputs based on soil test values and water analysis data (Mujeeb ur Rehman et al 2009). Thus, soil testing was instrumental in developing and using location-specific fertilizer recommendations (precision nutrient management), which helped in enhancing crop yields and nutrient uptake efficiency, and saving resources (Mujeeb ur Rehman et al 2009).

4.5.2. A machinery pool for renting farm machines to farmers at affordable costs: Most of the farmer-cooperators have very small landholdings (0.5 to 2.0 ha) and are too poor to purchase farm machines needed for taking up RCTs. To overcome this problem, 175 machinery pools and service providers (Table 2) were established at the project sites in Pakistan, Nepal, and India (Ballia). The services for different mechanized farm operations were extended at a nominal rent to farmers who do not have capacity to purchase their own machinery. As an example, farm machines obtained from different sources and rented to farmers in Pakistan are listed in Table 6 (Mujeeb ur Rehman et al 2009).

Table 6. Machinery pool established in village 18D for renting farm machines to farmers at affordable cost in the project area, Okara District, Punjab, Pakistan (2007).

Name of machinery	ADB project	Project farmers purchased	Allotted to service providers	OFWM district government	Total
Bed planter	1	1	1	–	3
Laser leveler	–	1	4	2	7
Power sprayer	1	3	–	–	4
Combo Happy Seeder	1 (RWC)	–	–	–	1
Turbo multicrop seeder	2 (RWC)	–	–	–	2
Zero-till seed drills	2	7	–	1	10
Wheat straw chopper	–	–	1	–	1

There was a need to introduce new machinery able to cope with high crop residue levels in the field when seeding with zero-tillage in combine-harvested fields. The turbo multicrop seeder (Happy Seeder) was found useful to manage residues and avoid burning (Gupta and Rickman 2002, Sidhu et al 2008). A research project funded by the Australian Centre for International Agricultural Research (ACIAR) helped to assess and fine-tune the Happy Seeder in on-farm experiments in collaboration with farmers, machinery manufacturers, and contractors and to optimize nitrogen × residue × irrigation management using the Happy Seeder approach on the major soil types of northwest India (Sidhu et al 2008).

4.5.3. Village seed banks to produce and supply good-quality seed at affordable cost: Healthy seed is a basic necessity to enhance crop productivity. However, farmers at several project sites were using poor-quality seed saved from previous harvests, resulting in poor performance of introduced technologies. Therefore, 115 rural seed banks (Table 2) were established and high-quality seed was distributed to farmers on a no-profit, no-loss basis.

4.5.4. Improve irrigation efficiency at system and farm level through lining of canals: A huge quantity of water is also wasted through seepage because of unlined irrigation channels or canals. The project gave emphasis to the lining of canals, wherever possible. For example, the government of Pakistan launched a mega-program in the ADB project areas for lining of water courses on a cost-sharing basis, that is, 80% of the funds were provided by government and 20% by farmers. A special fund (PAK Rs. 20 million) was allocated for water-course improvement in the six ADB-IRRI project villages. Sixteen canals were lined for a total length of 4,362 m. These lined canals provided efficient and timely irrigation to 942 ha of command area; they also saved 30% to 40% of the irrigation water and 30% of the labor used for irrigation (Mujeeb ur Rehman et al 2009). Another example is the improvement of shallow tubewell irrigation in Bangladesh.

4.5.5. Strengthening multistakeholder partnership: The ADB-supported projects have applied a new model for farm technology development and dissemination in South Asia, and have encouraged farmers, researchers, and extension agents to work as teams. This is helping to break down the hierarchical boundary once separating researchers from extension staff and farmers. Farmers actively participate in testing, refining, and promoting promising innovations with technical support from researchers and extension staff. Researchers are beginning to take pride and pleasure in working with farmers and seeing their ideas actually put into practice or helping solve mutually identified problems in the field. As part of this, researchers and extension agents work with multiple actors, including farm implement manufacturers, input suppliers, and others along the complex innovation pathway. Joint field visits and discussions with farmers as well as field seminars provided an opportunity to strengthen this partnership further for the benefit of all. This multistakeholder partnership is effective in the speedy validation and dissemination of useful technologies to farmers in the project areas and outside. This partnership model is an example of a win-win situation in which all stakeholders actively participate in the process and derive mutual benefits.

4.6. Human resource development: training and capacity building

The project worked extensively on empowering NARES staff to train local extension and development personnel and support them in the dissemination of proven RCTs to farmers. Different types of training were conducted to enhance the knowledge and skills of research and extension staff, undergraduate students involved in the project as interns (Pakistan), private-sector agencies connected to the project, and farmers of the project area. At each site, a trainer group of selected research and extension staff was trained on key project activities, RCTs, farmer participatory research methodology, and extension strategies. These people were also trained on how to produce fact sheets, training materials, and leaflets/posters/calendars on RCTs for wider dissemination to farmers. The internship program organized for undergraduate students was very successful and mutually beneficial to both farmers and students in getting and sharing up-to-date information and field experiences on RCTs. Some national scientists and students were trained on data collection and database management.

The trainer groups in turn trained village-level extension personnel and lead farmers on RCTs and related activities. Establishment of a farmers' field school (FFS) at some sites helped train and enable farmers to make correct and timely decisions on agricultural production systems. National scientists and extension staff, private service providers, and farmers visited the research trials and demonstration plots and attended the training programs and farmers' field days organized by site coordinators. Training was organized at each site for service providers (tractor drivers and the owners) to train them on how to use and maintain the tractor and power tiller, ZT drill seeder, PTOS, and bed planter. Policymakers were educated and sensitized for appropriate planning for promoting RCTs and making provisions for subsidy for farm machines, irrigation facilities, and a community approach for using fallow land for crop diversification.

During the project period of 2005-08, 131 training and education events were organized in all four countries, with an estimated 5,284 participants (Table 2). The categorized training activities included 48 training sessions to train 1,703 research and extension staff, 8 internship training sessions with 52 student interns, 11 practical training events with 133 private machine manufacturers and service providers, 33 hands-on training events on RCTs for 1,385 farmers, 19 traveling seminars with 246 participants, and 12 household socioeconomic surveys with 1,765 participants. Detailed accounts of these activities are provided in country papers and can also be obtained from the ADB project Web site (www.rwc.cgiar.org/PROMIS/ADB).

4.7. Technology promotion and dissemination strategies

Resource-conserving technologies play a significant role in enhancing the productivity, profitability, and sustainability of the RW system. However, it was difficult to turn the attention of farmers from conventional crop production practices to RCTs. Therefore, promotion and dissemination strategies such as a video documentary, television programs,

and popular articles were prepared for the promotion of RCTs. Some 114 television programs on RCTs were broadcast to farmers to create awareness about the new technologies and their potential to increase rice and wheat yields and income. Technical and popular articles were published in local newspapers and various magazines. A number of technology brochures and a full package of improved crop production technologies were distributed to farmers. A total of 4,400 brochures/banners/posters/wall chalkings (billboards) (Table 2) were distributed to farmers to popularize the RCTs. In addition, farmers were contacted individually and also in groups through field seminars organized in different villages. During 2005-08, 28 field workshops/seminars were organized to train 780 farmers on RCTs and 36 farmers' field days were held to showcase RCTs to 1,160 participants. These activities provided a good opportunity for shifting the attention of farmers from conventional production techniques to RCTs. In addition, 402 policymakers and scientists (Table 2) visited the project sites and learned about project activities and the performance of RCTs in farmers' fields. During field visits, they discussed with farmers how they could support them to expand the adoption of RCTs in project villages and beyond.

*4.7.1. Sharing of information and experience*s: Many national and international scientists visited the project sites and shared their knowledge and experiences with local staff and farmers. Successful farmers' experiences were conveyed to other farmers through field demonstrations, farmers' days, and farmer-to-farmer exchange visits. At the end of every year, traveling seminars were organized for key farmers, project staff and student interns, and policymakers and private-sector actors involved in the project to share their information with leading agricultural institutions/organizations and to establish linkage and collaboration with scientists, farmers, agricultural graduates, manufacturers, and other stakeholders involved in other projects in other parts of the same country or in other countries. The traveling seminar is another strategy used to help in the dissemination of new technologies, clear doubts on the socioeconomic and biophysical impacts of the emerging technologies, and generate new ideas for the refinement and up-scaling of technologies in a farmers' participatory mode. The seminars provide a unique opportunity to the farmers and officials of eastern India to interact with their counterparts, scientists, machine manufacturers, and service providers of northwest India in understanding the prospects for and constraints to wider adoption of RCTs. A total of 246 participants took part in 19 traveling seminars organized during 2005-08 (Table 2).

4.7.2. Technology targeting: Potential zones suitable for targeting RCTs in all four IGP countries were identified through satellite images, geographic information systems (GIS), etc. Satellite images were used to extract information on soil moisture regimes, problematic lands, including salt-affected ones, crop area, and late-planted crops. A village-level geo-referenced database on soil and water (physical and chemical properties) has been created so that fertilizer recommendations can be targeted along with appropriate RCTs (Chandna 2007).

5. Impacts of the ADB project (RETA 6208)

The aim of the ADB project (RETA 6208) was to enhance farmers' income and livelihood in the project area. The impacts of the project were assessed by comparing the baseline information and data collected from the baseline socioeconomic survey conducted at the beginning of the project in 2005 and the final outputs and accomplishments of the project obtained from the project impact survey conducted in 2008. The impacts of major project activities on farmers' income and livelihood as well as on resource use and environmental quality are discussed below.

5.1. Widespread adoption of RCTs: direct and indirect impacts

The project has had a positive impact on RCT use rates in the project communities across northern South Asia (Singh and Erenstein 2009). The village surveys at project sites also confirm that RCTs generally are cost-saving without yield loss, thereby enhancing farmers' income. The scale of impacts on yields, returns, and livelihoods in the project area needs further verification from the complementary household survey conducted at the project sites (forthcoming in a separate report). The village surveys do, however, highlight that the better endowed farmers tend to be the first adopters of RCTs. Purposive efforts are therefore needed to ensure that access to and uptake of RCTs are more inclusive (Singh and Erenstein 2009).

Despite the apparent similarity within the rice-wheat system, the village surveys show that there is significant regional variation in this system across South Asia (Singh and Erenstein 2009). Particularly striking are the gradients of resources, practices, and RCT adoption. These reiterate the need to take care in making sweeping generalizations and extrapolations across northern South Asia or the IGP. The marked regional variation, however, also emphasizes the need for local adaptation—giving further impetus to the need for such initiatives as an underlying project to help adapt promising technological innovations to the local and diverse circumstances faced by resource-poor farmers (Singh and Erenstein 2009).

The portfolio of RCTs differs in terms of tillage, water management, and crop establishment techniques of the rice-wheat production system and RCTs are variously being adopted by farmers at the project sites. Figure 3 shows the estimated diffusion of zero-till drill use (zero- and reduced-tillage combined) based on expert estimates in the IGP. Recent estimates indicate that, as of 2005-06, approximately 4.0 million ha out of the 13.5 million ha of RW area are under RCTs in the IGP countries. Specifically, the estimated area under zero-till, reduced-till, surface seeding, and bed planting of wheat is 1.94 million ha; direct-seeded rice, 0.19 million ha; laser land leveling, 0.07 million ha; crop diversification, 1.80 million ha; LCC, 0.06 million ha; and nonpuddled transplanted rice, 0.01 million ha. About 300 scientists in South Asia are using RCTs in their research and extension activities and an estimated 500,000 farmers are using these technologies. The vast majority of farmers in the IGP have adopted RCTs because of the reduced costs and increased profitability, aided by their "divisibility in application and flexibility of options."

Large-scale adoption of RCTs had pronounced direct effects on crop productivity and profitability and indirect effects on rural employment through farm machine rental and repair services and processing and trading in the region.

Area (000 ha)

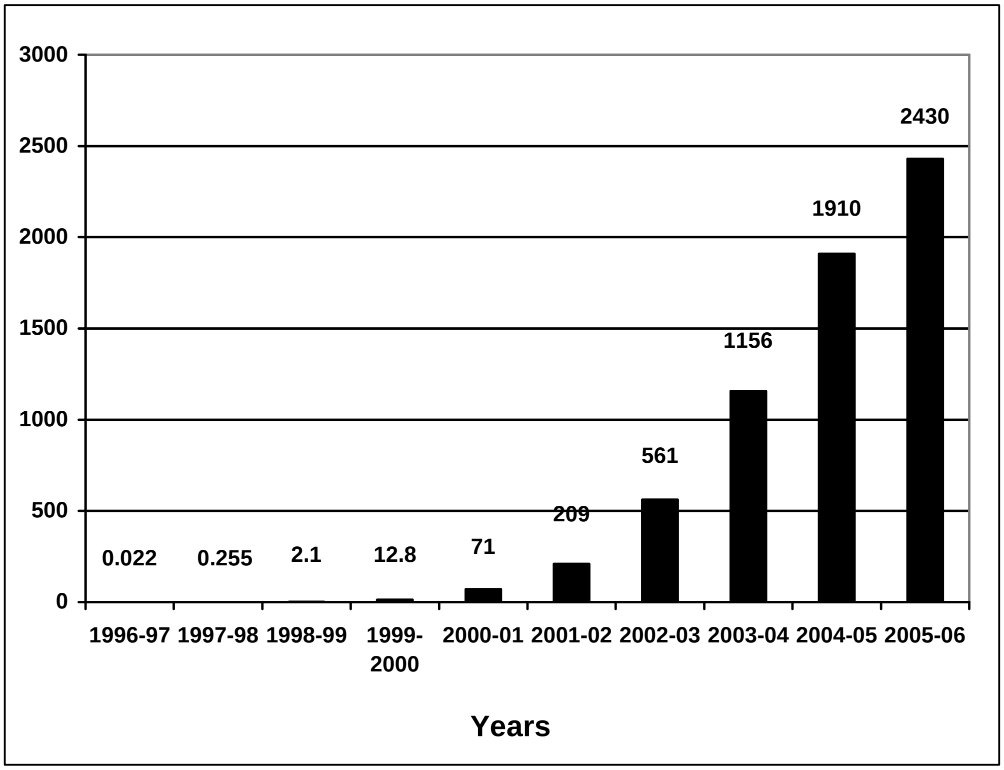

Fig. 3. Area planted using a zero-till drill in the Indo-Gangetic Plains (RWC) (source: expert estimates in Harrington and Hobbs 2008).

5.1.1. Productivity and income: Of the RCTs promoted, zero-/reduced-tillage for wheat proved the most successful (Ladha et al 2003a, Gupta and Seth 2006, Erenstein et al 2007). Zero-tillage facilitated timely wheat planting and good crop establishment, which in turn increased yields by 0.14 to 0.46 t ha^{-1}. Higher yields coupled with reductions in production costs due to savings in energy and input costs contributed to increased net income by \$76 to \$200 ha^{-1} (Table 5b). Survey findings show the cost savings of RCTs such as zero-tillage to be particularly robust, whereas the yield enhancement effect is less consistent (Erenstein et al 2007a). Assuming mean values of 0.30 t ha^{-1} for an increase in wheat yields and \$138 ha^{-1} for additional income and extrapolating these estimates over an area of 1.94 million ha, where zero- or reduced-till and bed-planted wheat are practiced, additional wheat production works out to 582,000 t and additional income accrued to farmers is \$267.72 million. Additional wheat production and income will help improve local food security and farmers' livelihoods in all four IGP countries. For further spread of RCTs to farmers at large, favorable policy support in terms of input supply, farm machinery services, and market development is critical. National policymakers visited the

project area and showed keen interest in improved rice-wheat production technologies and services extended to farmers for mechanized farming. As such, it is expected that they will provide the necessary support for the promotion of RCTs to farmers in other areas.

For rice, the spread of RCTs is still limited. Successful RCTs for rice include laser-aided land leveling, ICMR, and LCC-based precision N management, with alternate wetting and drying irrigation showing promise**.** Precision land leveling increased mean rice yields by 0.44 t ha^{-1} and saved on average 100 mm of irrigation water in farmers' fields. As a result, this technology is spreading fast, with almost 100% coverage of the project area in Pakistan and significant area in India.

Crop need-based N management with the help of an LCC (CT-TPR-LCC) and ICRM for transplanted rice (CT-TPR-ICRM) have increased grain yield by 0.24 to 0.75 t ha^{-1} and net income by \$41-49 ha^{-1} and reduced fertilizer cost by 15–20% due to efficient N use. Thus, farmers can effectively reduce their yield gaps and enhance their farm income by adopting LCC-based precision N management coupled with the integrated use of other nutrients and technologies through ICRM in rice, especially in Bangladesh, eastern India, and Nepal (Balasubramanian et al 2003, 2005, Regmi and Ladha 2005, Khan et al 2009, Regmi et al 2009, Singh et al 2009). If ICRM technologies are practiced by about 50% of the farmers in the irrigated rice-wheat areas in Nepal, total production will increase by about 25%, which will help Nepal to reduce poverty and enhance food security considerably. A total of 21,030 LCCs (Table 2) have been distributed or sold to farmers after training them on the proper use of an LCC for precision N management in rice. The demand for LCCs is growing fast in Bangladesh, and it can be met only by its local manufacture and sale to farmers.

*5.1.2. Control of noxious weed—*Phalaris minor *(little seed canary grass)*: *Phalaris minor* is an accidentally introduced and hard-to-control weed in wheat in northern India. Chemical control of this weed required expensive herbicides, which many farmers could not afford (Kumar et al 2009). Therefore, it was initially thought that farmers might wish to adopt zero-tillage to reduce production costs and use the savings to purchase the expensive new herbicides to control this weed. Later, it was found that fewer weeds germinated in zero-till plots and that a combination of zero-tillage and the new herbicides virtually eliminated the *Phalaris* problem (Vincent and Quirke 2002). Farmers later observed that after 4–5 years of zero-tillage, the *Phalaris* problem declined drastically and there was no need to apply herbicides. The use of zero-tillage to overcome the *Phalaris* problem is a boon to wheat farmers.

5.1.3. Generation of rural employment: Laser leveling and zero-tillage practices have been found to be highly complementary, with each enhancing the favorable effects of the other (Harrington and Hobbs 2008). For effective application of these RCTs by farmers, suitable tractors and seeders as well as laser equipment for precision leveling are needed. Local adaptation and production of these machines and equipment are the key to success. About 65 farm machine manufacturers were trained and helped to make and refine with farmers the required seed drills for rice and wheat seeding. Locally developed zero-till

seed drills include the Pantnagar drill Mark I and Mark II, Happy Seeder, and turbo-seeder (rotary-disc drill). More than 13,000 seed drills have been produced and marketed by different manufacturers in India and Pakistan (Fig. 4). Similarly, more than 925 laser units in India and 170 in Pakistan are being rented to tractor operators for laser-assisted land leveling (Harrington and Hobbs 2008, Jat et al 2009).

A system of custom hiring of tractors for land preparation, laser equipment for land leveling, and zero-till drills for crop establishment has been developed to help farmers adopt RCTs in the project areas. This activity has helped to train and equip 175 private entrepreneurs for them to take up custom-hiring services of farm machines for tillage, land leveling, and seeding in Pakistan and India (Ballia and Modipuram). Some rural youth were trained to repair and maintain these machines. Other farmers were encouraged to earn additional income through seed production to meet local needs.

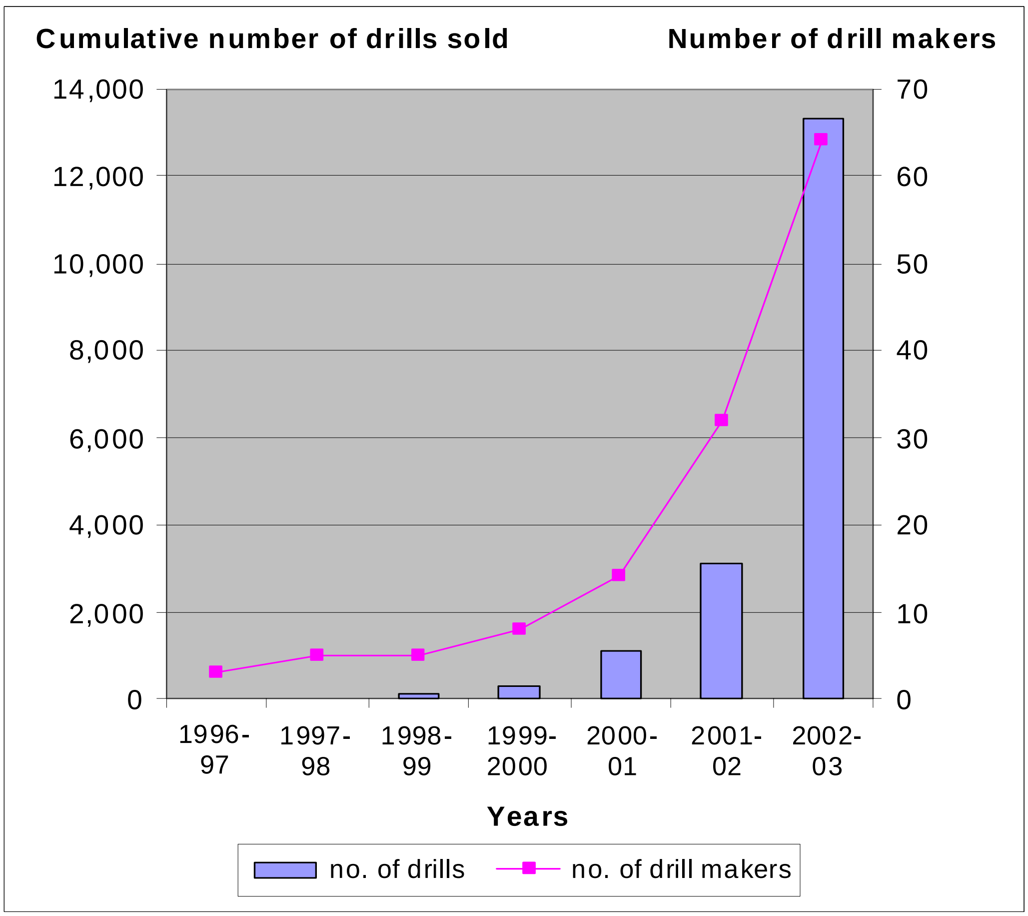

Fig. 4. Trends in the number of zero-till drills and manufacturers in the IGP (source: Harrington and Hobbs 2008).

5.1.4. A model for scientific leadership and multistakeholder partnership: The ADB project (RETA 6208) on the RW system is a model for scientific leadership on multidisciplinary, multicommodity, farmer participatory systems research through a

multistakeholder partnership involving researchers, extension staff, farm machinery manufacturers, input retailers and service providers, and farmers to effectively solve problems of RW system productivity, profitability, and sustainability. Farmers actively participate in testing, refining, and promoting promising innovations with active support from local research and extension staff. The project has also built a strong base for long-term sustainability of the RW system through conservation agriculture with the use of RCTs.

5.2. Environmental impact of RCTs

RCTs have potential to reduce the emission of greenhouse gases (GHG) and minimize the adverse impact of climate change. This implies an urgent need for promoting technologically adapted, economically viable, and environmentally sound RCTs, which represent a "win-win" option, combining private gains (e.g., cost savings, yield enhancement) with environmental gains (e.g., water savings, soil quality, GHG mitigation).

5.2.1. Water savings: Growing water shortages are likely to adversely affect the productivity of the RW system in the IGP countries (Ladha et al 2003a). Water savings at the system and field level are critical for tackling the water crisis in farming.

At the system level, a huge quantity of water is lost as seepage because of unlined irrigation channels or canals. The project gave emphasis to the lining of canals, which resulted in a 30–40% savings in irrigation water as shown in Pakistan (Mujeeb-ur-Rehman et al 2009).

At the field level, rice consumes about 80% of the total water applied in the rice-wheat system. Therefore, much water could be saved if tillage and crop establishment practices of wheat were adopted in rice. For example, zero-tillage direct-seeded rice (ZT-DSR) required 35–40% less irrigation water than the traditional puddled transplanted rice (CT-TPR). Similarly, drill-seeded rice on raised beds (Bed-DSR) saved 30–40% of irrigation water, but with an associated yield penalty when compared with CT-TPR. Earlier research reports indicate that direct seeding of rice on flat land (Bouman 2001, Cabangon et al 2001, Sharma et al 2002) or on raised beds (Borrel et al 1997, Sharma et al 2002, Bhushan et al 2007) could save significant amounts (16–43%) of water, but with an associated yield loss (of about 15% or more). We therefore need to develop effective rice crop establishment methods under zero-tillage that would save water without any significant yield loss. Similarly, AWD irrigation and mid-season drying of soil instead of continuous submergence as used in conventional TPR could be other options for saving water in rice farming.

5.2.2. Soil quality: It has been shown that zero-till drill seeding of wheat in the presence of crop residues provided an opportunity to build up the organic matter of soils in the IGP (Sidhu et al 2008). In addition, the inclusion of grain legumes, green manure crops, or *Sesbania* can add biologically fixed N (BNF) and organic matter to soils, thereby building up soil fertility in the long run (Peoples et al 1995, Ladha et al 1996). Simultaneous

sowing of rice and *Sesbania* and killing of young *Sesbania* plants at 45 days after sowing by selective herbicides labeled "brown manuring" which may help build up soil fertility in the RW system (Singh et al 2007). In a 7-year rice-wheat rotation in Modipuram, India, we have observed positive improvement in certain soil quality parameters such as soil aggregates, water-holding capacity, and surface-layer C accumulation (Gathala et al, unpublished).

5.2.3. Greenhouse gas emission: Nitrous oxide (N_2O) is an important greenhouse gas, accounting for about 5% of total global warming. The emission of N_2O occurs as a result of nitrification and denitrification processes occurring in aerobic and anaerobic soil conditions, respectively. The total emission of N_2O-N was lower (0.002 kg ha^{-1}) under continuous submergence than under alternate wetting and drying (0.048 to 0.054 kg ha^{-1}). Over a period of 12 days, approximately 0.12% of applied N was emitted as N_2O from soil under AWD, whereas this value was negligible under continuous submergence (Mohanty et al 2009). Thus, growing rice in nonpuddled soil under aerobic conditions will have implications for the emission of greenhouse gas N_2O (Pathak et al 2007). However, emission of methane, another greenhouse gas, is less under aerobic conditions than under flooded rice cultivation (Gupta-Vandana et al 2009). We also observed that continuous no-tillage resulted in a lower net global warming potential (GWP) (Pathak et al 2009).

Crop residue burning is another problem in the IGP countries—particularly rice straw after combine harvesting in the northwest IGP (Erenstein et al 2007b, 2007c). The development of zero-till drill seeding of wheat and rice under crop residue mulch provides an option to reduce residue burning in the region and enrich the soil with retained organic matter. Another bonus of the zero-till wheat is that it provides a better habitat for stem borer predators, leading to stem borer larvae declining to low levels by late April when the moths hatch to infect new rice plants (Srivastava et al 2005).

5.3. Cumulative impact of ADB support to the RWC

Harrington and Hobbs (2009) documented the impact of various ADB-supported projects, including RETA 6208, on the RWC. In this paper, the authors have collected all the data from all four IGP countries and critically analyzed the data to bring out the key achievements/accomplishments of the three ADB projects since 1990 and their impacts on rural poverty, and farmers' income and livelihood. Milestones of progress of different ADB- and other donor-supported projects in the RW system are given in Annex 1.

6. Lessons learned: emerging issues and problems

In spite of the success with RCTs such as laser-assisted land leveling, zero-till wheat seeding, integrated crop and resource management in irrigated agriculture in the IGP, the full socioeconomic and environmental benefits are yet to be fully attained. The following emerging issues require urgent attention to make continuing progress with RCTs.

6.1. Varying performance of the RCTs

There were large differences in the performance of RCTs among and between on-station and on-farm trials over space and soil types and between crops (Tables 4a, b, c; 5a,b). These divergences are still not fully understood and highlight the need for further product development—hands-on R&D to adapt RCTs in farmers' fields to the different agroecological conditions (Erenstein et al 2007a, Laxmi et al 2007).

6.2. Varying spread of RCTs

The initial rapid diffusion of RCTs was in the more intensive northwest IGP, with less uptake in the eastern IGP (Laxmi et al 2007). The RCTs have particular potential in less endowed areas such as the eastern IGP and can provide important benefits, yet it is there that these technologies are less well known and farmers' access to RCTs is generally problematic. Realizing the full potential of RCTs in less endowed areas poses particular challenges in view of the generally weak institutional context and the inability of poor farmers to access and apply RCTs in their small and scattered fields (Chandna et al 2009). Within a region, some sites and partners are also markedly more successful than others.

6.3. Diverging impacts

So far, the better endowed farmers typically adopted RCTs (Erenstein et al 2007a). Survey findings also show the cost savings of RCTs such as zero-tillage to be particularly robust, whereas the yield enhancement effect is less consistent (Erenstein et al 2007a, 2008). Similarly, environmental impacts may be less than expected, as in the case of the northwest IGP, where widespread adoption of zero-till did not reduce the practice of rice stubble burning during land preparation (Erenstein et al 2007a, 2008). Some farmers also discontinue the use of RCTs under certain conditions that are still not fully understood.

6.4. Problem of arsenic poisoning from groundwater in the eastern IGP

The overexploitation of groundwater in the lower Gangetic plains—West Bengal, India, and Bangladesh—has exposed the local people to a high concentration of arsenic in groundwater. Arsenic has no taste or smell, and hence its slow buildup in the human body is hard to detect before symptoms appear in a few years of exposure to contaminated water. Water containing arsenic above 300 ppb (parts per billion) could cause cancer within three to four years. Reports indicate that exposure to arsenic from contaminated wells is projected to double the number of cancer deaths in Bangladesh in the next two to three decades. In problem areas, the adoption of water-saving RCTs can reduce irrigation water use by 30–40%, thereby reducing the need for using the contaminated deep tubewells for irrigation and household uses, including drinking.

7. Conclusions and recommendations

The project has developed and promoted RCTs, which encompass practices that enhance resource- or input-use efficiency; provide immediate, identifiable, and demonstrable economic benefits such as reductions in production costs, and savings in water, fuel, and labor requirements; and ensure timely crop establishment and uniform crop stands, resulting in higher crop yields. Indirect benefits of RCTs include effective control of *Phalaris minor* weed in wheat by zero-tillage; replacement of residue burning by retention of crop residues in the RW system, resulting in short-term soil carbon sequestration; reduction in methane emission from nonpuddled and nonflooded rice fields; buildup of soil fertility over the long term, leading to sustainability of intensive rice-wheat cultivation; and generation of rural employment by training and empowering local farm machine manufacturers, custom-hire service providers, retailers and traders, and seed producers. While tillage and crop establishment options have been more successful in wheat, the next frontier will be to make similar headway in rice. In addition, integrated crop management (good agronomy) will continue to be a key to improving productivity and production and eventually attaining national food security.

The project has emerged as an innovative model for regional and international collaboration and has developed a credible record of achievements, the most important being the effectiveness of partnership between CGIAR centers and NARES partners. The multistakeholder partnership adopted in the project was particularly successful in bringing together public- and private-sector innovators, investors, and implementers to develop and promote the system and region-specific technologies. While, in general, the successes made so far are widely applauded (Seth et al 2003, Erenstein and Laxmi 2008, Hazell and Wood 2008, Raitzer and Kelley 2008), much greater effort is needed to fine-tune and mainstream these technologies as a regular feature of program planning and implementation by NARES. What we need now is to develop an effective program for wider dissemination of proven RCTs and ICMR to deprived farming communities outside project areas to realize their great impact on food security and farmers' livelihood in South Asia. For this to happen, we need to sensitize agricultural policymakers and encourage them to allocate more resources for wider dissemination of successful RCTs in the region. In addition, there are needs to (a) foster new models of public-private partnerships, especially for faster, scalable, and sustainable delivery of improved crop and resource management technologies along with associated knowledge; and (b) create a highly qualified professional workforce for private- and public-sector extension by establishing a Certified Crop Advisor (CCA) program.

8. Project publications (2005-08)

The project collaborators worked actively in documenting and publishing their research work. Papers published in refereed journals and book chapters, books, proceedings of workshops and conferences, and papers presented in workshops and conferences are listed in Annex 3.

In addition, the results obtained in the project will be published in the form of a book titled Enhancing Farmers' Income and Livelihoods through Integrated Crop and Resource Management in the Rice-Wheat System in South Asia. The tentative chapters and authors of the book are given below.

Chapter no.	Title	Authors
1	The Rice-Wheat Consortium and the Asian Development Bank: a history	L.W. Harrington and P.H. Hobbs
2	Enhancing farmers' income and livelihoods through integrated crop and resource management in the rice-wheat system in South Asia: accomplishments	J.K. Ladha et al
3	Evaluation and promotion of integrated crop and resource management technologies in the rice-wheat system in Pakistan	Hafiz Mujeeb ur Rehman, M.A Gill, N.A. Awan, and J.K Ladha
4	Evaluation and promotion of integrated crop and resource management technologies in the rice-wheat system in northwest India	Y.S. Sahrawat, M. Gathala, J.K. Ladha, R.K. Malik, Samar Singh, M.L. Jat, Raj K Gupta, H. Pathak, Kuldeep Singh
5	Evaluation and promotion of resource-conserving tillage and crop establishment techniques in the rice-wheat system in eastern India	Udai P. Singh, Y. Singh, Virender Kumar, and J.K. Ladha
6	Improving food security through integrated crop and resource manageme in the rice-wheat system in Nepal	A.P. Regmi, J. Tripathi, G.S. Giri, M.R. Bhatta, D.P. Sherchan, K.B. Karki, B.P. Tripathi, Virender Kumar, and J.K. Ladha
7	Validation and delivery of improved technologies in the rice-wheat ecosystem in Bangladesh	M. Akhter Hossain Khan, M. Murshedul Alam, M. Israil Hossain, M. Harunur Rashid, M. Islam Uddin Mollah, M. Abdul Quddus, M. Ismail Bhuiyan Miah, M. Abbas Ali Sikder, and J.K. Ladha
8	Resource-conserving technologies in rice-wheat systems of South Asia: field evaluation and simulation analysis	H. Pathak, J.K. Ladha, Yadvinder-Singh, A. Hussain, F. Hussain, R. Munankarmy, M.K. Gathala, S. Verma, U.K. Singh, and Minh-Long Nguyen
9	Laser-assisted precision land leveling: a potential technology for resource conservation in irrigated intensive production systems of the Indo-Ganges	M.L. Jat, Raj Gupta, P. Ramasundaram, M. K. Gathala, H.S. Sidhu, Samar Singh, Ravi G. Singh, Y.S. Saharawat, V. Kumar, P. Chandna, and J.K. Ladha

10	Crop establishment, tillage, and water management effects on crop and water productivity in the rice-wheat rotation in Nepal	S.N. Mandal, J.K. Ladha, T.P. Tuong, and A.P. Regmi
11	Integrated weed management: a key to success for direct-seeded rice in the Indo-Gangetic Plains	Samar Singh, R.S. Chhokar, Ravi Gopal, Virender Kumar, and M. Singh
12	Simulating the impact of resource-conserving technologies in the rice-wheat system on productivity, income, and environment	H. Pathak, Y.S. Saharawat, M. Gathala, S. Mohanty, and J.K. Ladha
13	Technologies in underused lands of the Middle and Lower Gangetic Plains of South Asia for enhancing productivity	Parvesh Chandna, J.K Ladha, U.P. Singh, Milap Punia, O. Erenstein, H. Pathak, and Raj Gupta
14	Impact	O. Erenstein, Ram Singh et al
15	On-farm data analysis	R. Prasad et al

9. References

Aggarwal PK, Talukdar KK, Malik RK. 2000. Potential yields of rice-wheat system in the Indo-Gangetic Plains of India. Rice-Wheat Consortium for the Indo-Gangetic Plains/Centre for Applications of Systems Simulation, New Delhi, India.

Ahmad M, Zaidi MA, Khan AS. 1994. Development and adoption of no-till technology for wheat sowing. Agric. Mechan. Asia, Africa, Latin Am. Jpn. 25(4):24-28.

Ahmed UA, Hill RV, Weismann DM, Smith LC. 2008. Reducing Poverty and Hunger in Asia. Brief 3, 2020 Focus No. 15, Reducing poverty and hunger in Asia. Washington, D.C.: (USA): International Food Policy Research Institute.

Balasubramanian V, Rajendran R, Ravi V, Chellaiah N, Castro E, Chandrasekaran B, Jayaraj T, Ramanathan S. 2005. Integrated crop management for enhancing yield, factor productivity, and profitability in Asian rice farms. Int. Rice Comm. (FAO) Newsl. 54:63-72.

Balasubramanian V, Alves B, Aulak MS, Bekunda M, Cai Z, Drinkwater L, Mugendi D, Kessel C van, Oenema O. 2004. Crop, environmental and management factors affecting fertilizer nitrogen use efficiency. In: Mosier AR, Syers JK, Freney JR, editors. Agriculture and the nitrogen cycle: assessing the impacts of fertilizer use efficiency on food production and the environment. SCOPE Series Vol. 65. Washington, D.C. (USA): Island Press. p 19-33.

Balasubramanian V, Hill J. 2002. Direct seeding of rice in Asia: emerging issues and strategic research needs for the 21st century. In: Pandey et al, editors. Direct seeding: research strategies and opportunities. Los Baños (Philippines): International Rice Research Institute. p 15-39.

Balasubramanian V, Ladha JK, Gupta RK, Mehla RS, Singh Bijay, Singh Yadvinder. 2003. Technology options for rice in rice-wheat system in South Asia. In: Ladha JK et al. editors Improving the productivity and sustainability of rice-wheat systems: issues and impact. ASA Special Publication 65. Madison, Wis. (USA): ASA, CSSA, and SSSA. p 115-147.

Bhushan L, Ladha JK, Gupta RK, Singh S, Tirol-Padre A, Saharawat, YS, Gathala M, Pathak H. 2007. Saving of water and labor in rice-wheat system with no-tillage and direct-seeding technologies. Agron. J. 99:1288-1296.

Borrell A, Garside A, Fukai S. 1997. Improving efficiency of water use for irrigated rice in a semi-arid tropical environment. Field Crops Res. 52:231-248.

Bouman BAM. 2001. Water-efficient management strategies in rice production. Int. Rice Res. Notes 16(2):17-22.

BRRI (Bangladesh Rice Research Institute). 2005. BRRI annual internal review report for 2004-05. Rajshahi Regional Station. Bangladesh Rice Research Institute, Gazipur (Bangladesh): BRRI. p 32-35.

Cabangon RJ, Castillo EG, Bao LX, Lu G, Wang GH, Cui YL, Tuong TP, Bouman BAM, Li YH, Chen CD, Wang JS. 2001. Impact of alternate wetting and drying irrigation on rice growth and resource-use efficiency. In: Barker R, Loeve R, Lie YH, Tuong TP, editors. Proceedings of the International Workshop on Water Saving Irrigation for Rice, 23-25 March 2001, Wuhan, China. Colombo (Sri Lanka): International Water Management Institute. p 55-79.

Chandna P. 2007. Use of remote sensing/GIS technologies for targeting resource conserving technologies in underutilized lands. Regional Technical Coordination Committee of Rice-Wheat Consortium and ADB Project Review and Planning Meeting, Kathmandu, Nepal, 12-16 February 2007.

Chandna P, Ladha JK, Singh UP, Punia M, Erenstein O, Pathak H, Gupta R. 2009. Targeting technologies in underutilized lands of middle and lower Gangetic Plains of South Asia for enhancing productivity. In: Ladha JK, Singh Yadvinder, Erenstein O, editors. Integrated Crop and Resource Management technologies for sustainable rice-wheat systems of south Asia. Manila (Philippines): International Rice Research Institute.

Dahiya SS, Chauhan YS, Johansen C, Waldia RS, Sekhon HS, Nandal JK. 2002. Extra-short-duration pigeonpea for diversifying wheat-based cropping systems in the sub-tropics. Exp. Agric: 38(1):1-11.

Erenstein O, Farooq U, Malik RK, Sharif M. 2007a. Adoption and impacts of zero tillage as a resource conserving technology in the irrigated plains of South Asia. Comprehensive Assessment of Water Management in Agriculture Research Report 19. Colombo (Sri Lanka): International Water Management Institute. 55 p.

Erenstein O, Laxmi V. 2008. Zero tillage impacts in India's rice-wheat systems: a review. Soil Tillage Res. 100:1-14.

Erenstein O, Thorpe W, Singh J, Varma A. 2007b. Crop-livestock interactions and livelihoods in the Indo-Gangetic Plains, India: a regional synthesis. Crop-livestock Interactions Scoping Study - Synthesis. New Delhi (India): CIMMYT-ILRI-RWC. www.rwc.cgiar.org/Pub_Info.asp?ID=184.

Erenstein O, Thorpe W, Singh J, Varma A. 2007c. Crop-livestock interactions and livelihoods in the Trans-Gangetic Plains, India. Crop-livestock interactions scoping study-Report 1. Research Report 10. Nairobi (Kenya): International Livestock Research Institute. www.vslp.org/front_content.php?idcatart=220.

Erenstein O, Farooq U, Malik RK, Sharif M. 2008. On-farm impacts of zero tillage wheat in South Asia's rice-wheat systems. Field Crops Res. 105:240-252.

Farooq U, Sharif M, Erenstein O. 2007. Adoption and impacts of zero tillage in the rice-wheat zone of irrigated Punjab, Pakistan. New Delhi (India): CIMMYT &RWC. 69 p.

Fujisaka S, Harrington L, Hobbs P. 1994. Rice-wheat in South Asia: systems and long-term priorities established through diagnostic research. Agric. Syst. 46:169-187.

Gathala M, Ladha JK, Gupta RK, Jat ML, Saharawat Y, Pathak H, Singh A, Yadav MP. 2007. ADB Project Progress and Accomplishment Report—Modipuram (satellite site). Regional Technical Coordination Committee of Rice-Wheat Consortium and ADB Project Review and Planning Meeting Katmandu, Nepal, 12-16 February 2007.

Gathala MK, Pathak H, Ladha JK, Kumar V, Mishra D, Blackwell J, Roth C, Kumar V, Kumar V, Sharma S. 2009. Happy seeder technology provides an alternate to burning for managing rice loose straw after combine harvest. In: Conservation agriculture: Innovations for improving efficiency, equity and environment. Proceedings of 4th World Congress on Conservation Agriculture, 4-7 February 2009. New Delhi (India): Indian Council of Agriculture Research. p 0.

Gupta V, Singh S, Chandna P, Tewari A, Kumar K, Ladha JK, Gupta RK, Gupta PK. Mitigating Methane emission in rice with resource conserving technologies. 2009. In: Conservation agriculture: Innovations for improving efficiency, equity and

environment. Proceedings of 4th World Congress on Conservation Agriculture, 4-7 February 2009. New Delhi (India): Indian Council of Agriculture Research. p 0.

Gupta, RK, Rickman J. 2002. Design improvements in existing zero-till machines for residue conditions. Traveling Seminar Report Series 3. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

Gupta R, Seth A. 2006. A review of resource conserving technologies for sustainable management of the rice-wheat cropping system of the Indo-Gangetic Plains (GCP). Crop Prot. 26:436-447.

Harrington L. 2001. Synthesis of systems diagnosis: Is the sustainability of the rice-wheat cropping system threatened? An epilogue. *J. Crop Prod.* 6(3):119.

Harrington L, Hobbs PR. 2008. The Rice-Wheat Consortium and the Asian Development Bank: a history. A joint ADB-IRRI-RWC Report prepared for the ADB Project (RETA 6208). Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India; International Rice Research Institute (IRRI), Los Baños, Philippines; Asian Development Bank, Manila, Philippines**.**

Harrington LW, Hobbs PH. 2009. The Rice-Wheat Consortium and the Asian Development Bank: A History. In: Ladha JK, Singh Yadvinder, Erenstein O, editors. Integrated Crop and Resource Management technologies for sustainable rice-wheat systems of South Asia. Manila (Philippines): International Rice Research Institute.

Harunur Rashid M, Alam MM, Akhter Hossain Khan M, Ladha JK. 2009. Productivity and resource use of direct-(drum)-seeded and transplanted rice in puddled soils in rice-rice and rice-wheat ecosystems (under review).

Hazell PBR, Wood S. 2008. Drivers of change in global agriculture. Philos. Trans. Royal Soc. B 363(1491):495-515.

Hobbs PR, Gupta RK. 2003. Resource conservation technologies for wheat in the rice-wheat systems. In: Ladha JK et al, editors. Improving the productivity and sustainability of rice-wheat system: issues and impact. Madison, Wis. (USA): American Society of Agronomy.

IRRI (International Rice Research Institute). 2005. Project proposal: Enhancing farmers' income and livelihoods through integrated crop and resource management in the rice-wheat system in South Asia. Los Baños (Philippines): IRRI.

Jat ML, Chandana P, Sharma SK, Gill MA, Gupta RK. 2006. Laser land leveling: a precursor technology for resource conservation. Rice-Wheat Consortium Technical Bulletin Series 7. New Delhi (India): Rice-Wheat Consortium for the Indo-Gangetic Plains. 48 p.

Jat ML, Gathala MK, Singh KK, Ladha JK, Gupta RK, Singh S, Sharma SK, Saharawat YS, Tetarwal JP. 2008. Experiences with permanent beds in rice-wheat system of the western Indo-Gangetic Plain. In: Humphreys E, Roth CH, editors. Permanent beds and rice-residue management for rice-wheat systems in the Indo-Gangetic Plain. Proceedings of a workshop held in Ludhiana, India, 7-9 September 2006. ACIAR Proceedings No. 127. p 98-107.

Jat ML, Gupta Raj, Ramasundaram P, Gathala MK, Sidhu HS, Singh Samar, Singh Ravi G, Saharawat YS, Kumar V, Chandna P, Ladha JK. 2009. Laser assisted precision land leveling: a potential technology for resource conservation in irrigated intensive production systems of Indo-Ganges. In: Ladha JK, Singh Yadvinder, Erenstein O, editors. Integrated Crop and Resource Management technologies for sustainable rice-

wheat systems of South Asia. Manila (Philippines): International Rice Research Institute.
Khan M Akhter Hossain, Alam MM, Hossain M Israil, Rashid M Harunur, Mollah M Islam Uddin, Quddus M Abdul, Miah M Ismail Bhuiyan, Sikder M Abbas Ali, Ladha JK. 2009. Validation and delivery of improved technologies in the Rice-Wheat ecosystem in Bangladesh. In: Ladha JK, Singh Yadvinder, Erenstein O, editors. Integrated Crop and Resource Management technologies for sustainable rice-wheat systems of South Asia. Manila (Philippines): International Rice Research Institute.
Kumar Virender, Ladha JK, Gathala Mahesh, Bellinder Robin R. Role of herbicide tolerant rice in promoting conservation agriculture in the Indo-Gangetic plains of South Asia. In: Conservation agriculture: Innovations for improving efficiency, equity and environment. Proceedings of 4th World Congress on Conservation Agriculture, 4-7 February 2009. New Delhi (India): Indian Council of Agriculture Research. P 0.
Ladha JK, Bhushan L, Gupta RK, Pathak H. 2008. Performance of furrow-irrigated raised beds in rice-wheat cropping system of the Indo-Gangetic plains. In: Humphreys E and Roth CH editors. Permanent beds and rice-residue management for rice-wheat systems in the Indo-Gangetic Plain. ACIAR Proceedings No. 127. p 108-110.
Ladha JK, Dawe D, Pathak H, Padre AT, Yadav RL, Singh Bijay, Singh Yadvinder, Singh Y, Singh P, Kundu AL, Sakal R, Ram N, Regmi AP, Gami SK, Bhandari AL, Amin R, Yadav CR, Bhattarai EM, Das S, Aggarwal HP, Gupta RK, Hobbs PR. 2003b. How extensive are yield declines in long-term rice-wheat experiments in Asia? Field Crops Res. 81:159-180.
Ladha JK, Kundu DK, Angelo-Van Coppenolle MG, Carangal VR, Peoples MB, Dart PJ. 1996. Legume productivity and soil nitrogen dynamics in lowland rice-based cropping systems. Soil Sci. Soc. Am. J. 60:183-192.
Ladha JK, Pathak H, Gupta RK. 2007. Sustainability of the rice-wheat cropping system: issues, constraints, and remedial options. J. Crop Improve. 19(1/2):125-136.
Ladha, JK, Hill JE, Duxbury JD, Gupta RK, Buresh RJ, editors. 2003a. Improving the productivity and sustainability of rice-wheat systems: issues and impact. American Society of Agronomy Special Publication 65. Madison, Wis. (USA): ASA, CSSA, SSSA. 211 p.
Laxmi V, Erenstein O, Gupta RK. 2007. Assessing the impact of natural resource management research: The case of zero-tillage in India's rice-wheat systems. In: Waibel H, Zilberman D, editors. International Research on Natural Resource Management: advances in impact assessment. Wallingford (UK): FAO and CAB International. p 68-90.
Mandal SN, Ladha JK, Tuong TP, Regmi AP. 2009. Crop establishment, tillage and water management effects on crop and water productivity in Rice-wheat rotation in Nepal. In: Ladha JK, Singh Yadvinder, Erenstein O, editors. Integrated crop and resource Management technologies for sustainable rice-wheat systems of south Asia. Manila (Philippines): International Rice Research Institute.
Meisner C, Hobbs PR, Badaruddin M, Razzaque MA, Giri GS, Justice S. 1998. Mechanical revolution among small landholders of South Asia: the growing use of Chinese hand tractors. Mexico, D.F.: CIMMYT.

Mohanty S, Ladha JK, Gathala M, Pathak H, Jain N, Sharma S. Emission of N_2O from soil with different resource conserving technologies. In: Conservation agriculture: Innovations for improving efficiency, equity and environment. Proceedings of 4th World Congress on Conservation Agriculture, 4-7 February 2009. New Delhi (India): Indian Council of Agriculture Research. P 0.

Mujeeb-ur-Rehman H, Gill MA, Awan NA, Ladha, JK. 2009. Evaluation and promotion of integrated crop and resource management technologies in Rice-Wheat Systems in Pakistan. In: Ladha JK, Singh Yadvinder, Erenstein O, editors. Integrated Crop and Resource Management technologies for sustainable rice-wheat systems of south Asia. Manila (Philippines): International Rice Research Institute.

Pandey S, Mortimer M, Wade L, Tuong TP, Lopez K, Hardy B, editors. 2002. Direct seeding: research strategies and opportunities. Los Baños (Philippines): International Rice Research Institute. 383 p.

PARC-RWC. 2003. Proceedings of the National Workshop on Rice-Wheat Systems, Islamabad, Pakistan, 11-12 Dec. 2002. Pakistan Agricultural Research Council, Islamabad, Pakistan, and Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India. 118 p.

Pathak H, Ladha JK, Aggarwal PK, Peng S, Das S, Singh Yadvinder, Singh Bijay, Kamra SK, Mishra B, Sastri ASRAS, Aggarwal HP, Das DK, Gupta RK. 2003. Climatic potential and on-farm yield trends of rice and wheat in the Indo-Gangetic plains. Field Crops Res. 80(3):223-234.

Pathak H, Ladha JK, Saharawat YS, Gathala M. 2007. Impact, productivity, income and environmental impact assessment of RCTs in RW system using modeling tool. In: Proceedings of the 94th Indian Science Congress, 3-7 Jan. 2007, Chidambaram, India. p 32

Pathak H, Saharawat YS, Gathala M, Mohanty S, Ladha JK. 2009. Simulating the impact of resource conserving technologies in Rice-Wheat system on productivity, Income and Environment. In: Ladha JK, Singh Yadvinder, Erenstein O, editors. Integrated Crop and Resource Management technologies for sustainable rice-wheat systems of South Asia. Manila (Philippines): International Rice Research Institute.

Peoples MB, Herridge DF, Ladha JK. 1995. Biological nitrogen fixation: an efficient source of nitrogen for sustainable agricultural production? Plant Soil 174:3-28.

Phoung LT, Denich M, Vlek PLG, Balasubramanian V. 2005. Suppressing weeds in direct-seeded lowland rice: effects of methods and rates of seeding. J. Agron. Crop Sci. 191:185-194.

Prasad R, Crossa J, Gupta VK. 2006. Farmers' participatory research trials: some case studies. Chapter 10 in the Reference Manual of the Training Programme on Design and Analysis of Farmers' Participatory Research Trials organized at IASRI, New Delhi, during 10-12 August 2006.

Raitzer DA, Kelley TG. 2008. Benefit-cost meta-analysis of investment in the International Agricultural Research Centers of the CGIAR. Agric. Syst.. 96:108-123.

Regmi AP, Ladha JK. 2005. Enhancing productivity of rice-wheat system through integrated crop management in the eastern-Gangetic Plains of South Asia. J. Crop Imp. 15(1):29.

Regmi AP, Tripathi, Giri GS, Bhatta MR, Sherchan DP, Karki KB, Tripathi BP, Kumar Virender, Ladha JK. 2009. Improving food security through integrated crop and resource management in rice-wheat system in Nepal. In: Ladha JK, Singh Yadvinder, Erenstein O, editors. Integrated Crop and Resource Management technologies for sustainable rice-wheat systems of South Asia. Manila (Philippines): International Rice Research Institute.

Ritchie JT, Singh U, Godwin DC, Bowen WT, Wilkens PW, Baer B, Hoogenboom G, Hunt LA. 1998. GENERIC-CERES V3.5. IFDC, Michigan State University, University of Georgia, USA.

RWC (Rice-Wheat Consortium). 2006. A research strategy for improved livelihoods and sustainable rice-wheat cropping system in the Indo-Gangetic plains: vision for 2006-2010 and beyond. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India.

SAS Institute. 2001. SAS/STAT users' guide Version 8-1. Cary, N.C. (USA): SAS Institute. 1,030 p.

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

Sharma PK, Bhushan Lav, Ladha JK, Naresh RK, Gupta RK, Balasubramanian V, Bouman BAM. 2002. Crop-water relations in rice-wheat cropping under different tillage systems and water management practices in a marginally sodic, medium textured soil. In: Bouman BAM et al, editors. Water-wise rice production. Proceedings of the International Workshop on Water-wise Rice Production, 8-11 April 2002, Los Baños, Philippines. Los Baños (Philippines): International Rice Research Institute. p 223-235.

Sidhu HS, Singh M, Blackwell J, Humphreyes E, Bector V, Singh Y, Singh M, Singh S. 2008. In: Humphreyes E, Roth CH, editors. Permanent bed and rice-residue management for rice-wheat system in the Indo-Gangetic Plain. Proceedings of a workshop held in Ludhiana, India, 7-9 September 2006. ACIAR Proceedings No. 127. p 171-181.

Singh R, Erenstein O. 2009. Socio-economics of integrated crop and resource management in the rice-wheat systems of South Asia: Site contrasts, adoption and impacts using village survey findings In: Ladha JK, Yadvinder-Singh, Erenstein O, editors. Integrated Crop and Resource Management technologies for sustainable rice-wheat systems of South Asia. Manila (Philippines): International Rice Research Institute.

Singh S, Ladha JK, Gupta RK, Bhushan L, Rao AN. 2008a. Weed management in aerobic rice systems under varying establishment methods. Crop Prot. 27:660-671.

Singh S, Ladha JK, Gupta RK, Bhushan L, Rao AN, Sivaprasad B, Singh PP. 2007. Evaluation of mulching, intercropping with *Sesbania* and herbicide use for weed management in dry-seeded rice (*Oryza sativa* L.). Crop Prot. 26:518-524.

Singh S, Chhokar RS, Gopal R, Kumar V, Singh M. 2009. Integrated weed management - a key for success of direct seeded rice in Indo-Gangetic Plains. In: Ladha JK, Singh Yadvinder, Erenstein O, editors. Integrated Crop and Resource Management technologies for sustainable rice-wheat systems of South Asia. Manila (Philippines): International Rice Research Institute.

Singh U, Godwin DC, Ritchie JT, Bowen WT, Wilkens PW, Baer B, Hoogenboom G, Hunt LA. 1998. CERES-RICE V3.5. IFDC, Michigan State University, University of Georgia, USA.

Singh UP, Singh Y, Kumar Virender, Ladha JK. 2009. Evaluation and Promotion of Resource Conserving Tillage and Crop Establishment Techniques in Rice-Wheat System in Eastern India. In: Ladha JK, Singh Yadvinder, Erenstein O, editors. Integrated Crop and Resource Management technologies for sustainable rice-wheat systems of South Asia. Manila (Philippines): International Rice Research Institute.

Srivastava SK, Biswas R, Garg DK, Gyawali BK, Haque NMM, Ijaj P, Jaipal Saroj, Kamal NQ, Kumar P, Pathak M, Pathak PK, Prasad CS, Ramzan M, Rehman A, Rurmzan M, Salim M, Singh A, Singh US, Tiwari SN. 2005. Management of stem borers of rice and wheat in rice-wheat system of Pakistan, Nepal, India and Bangladesh. New Delhi, Rice-Wheat Consortium for the Indo-Gangetic Plains. Rice-Wheat Consortium Paper Series 17. 191 p.

Spilke J, Piepho HP, Hu X. 2005. Analysis of unbalanced data by mixed linear models using the mixed procedure of the SAS system. J. Agron. Crop Sci. 191:47-54.

Subbaiah SV, Krishnaiah K, Balasubramanian V. 2002. Evaluation of drum seeder in puddled rice fields. Agric. Mech. Asia, Africa, and Latin Am. 33(4):23-26.

Tripathi RP, Gaur MK, Rawat MS. 2003. Puddling effects on soil physical properties and rice performance under shallow water table conditions of Tarai. J. Indian Soc. Soil Sci. 51(2):118-124.

Tripp R. 1982. Data collection, site selection and farmer participation in on-farm experimentation. CIMMYT Working Paper No. 82/1. Mexico, D.F.: CIMMYT.

Vincent D, Quirke D. 2002. Controlling *Phalaris minor* in the Indian Rice-Wheat Belt. ACIAR Impact Assessment Series No. 18. Canberra (Australia): ACIAR. p 1-35.

Zandstra HG, Price EC, Litsinger JA, Morris RA. 1991. A Methodology for On-Farm cropping systems research. Philippines: IRRI

10. Annexes

Annex 1. Milestones in the development of the rice-wheat (RW) system in the Indo-Gangetic Plains (IGP).

Period	Funding support & project focus	Focus countries	Major developments
1984-89	**Various donors & NARES**: Commodity research and varietal improvement	Mostly irrigated areas of IGP, especially in Pakistan	**Institutional**: move from single crop to cropping systems research (CSR) (Zandstra et al 1991) and then to farming systems research (FSR) encompassing crops, animals, fish, trees, and agroforestry; farmer participation in technology development and validation; joint working of technical and social scientists. **Research**: post-Green Revolution systems research on productivity stagnation or decline and sustainability issues in the RW system; tillage and crop establishment (TCE). **Outcomes**: wheat zero-till for timely planting (Pakistan); imported zero-till drill.
1990-93	**ADB's RETA 5414:** Decentralized participatory research for less favorable rice ecosystems and RW system of Asia	Rainfed lowland rice and upland rice and RW agro-ecosystems of IGP countries	**Institutional**: research consortia developed for multidisciplinary ecosystem-based research (IRRI 1990); joint publication and exchange of information across disciplines and national borders; NARES staff development. **Research**: resource degradation (salinity, groundwater contamination, soil fertility depletion, pest buildup) and farmer-defined problems, including TCE, farm- and system-level water management, site-specific nutrient status, IPM and pest carryover, and RW productivity and sustainability issues. **Outcomes**: wheat zero-/minimum-till for timely planting; locally adapted zero-till drill; green manure or break crops to improve soil fertility and RW system productivity; yield trends in long-term experiments (LTEs)
1994-99	**FAO, World Bank, IARCs, and NARES**: Production, sustainability, and eco-regional	IGP countries: Bangladesh, India, Nepal, and Pakistan	**Institutional**: consortium for system-wide and ecoregional programs; NARES-led RW consortium (RWC), Regional Steering Committee (RSC), Regional Technical Coordinating Committee (RTCC), Facilitation Unit (FU), a regional facilitator, national conveners, and donor support

Period	Funding support & project focus	Focus countries	Major developments
	research on the RW system of South Asia		group (DSG) established. **Research**: strategic, applied, and on-farm research on TCE, nutrients, water, IPM, and policy issues. **Outcomes**: RWC structure formalized; RTCC meeting held in Nepal (1994), China (1995), and annually thereafter; RWC expanded—associate member China (1995), IWMI (1995), CIP (1997), AVRDC (1998), Cornell Univ. (1996), IAC-Waginingen and Univ. of Adelaide (1998), Rothamsted (1999); traveling seminar, RWC Web site, RWC publication series, technical and training workshop started; traveling seminars: China (1995 and 1999); wheat zero-till covered 10,000 ha.
2000-03	**ADB's RETA 5945**:	IGP countries: Bangladesh, India, Nepal, and Pakistan	**Institutional**: site-specific integrated systems research; public-private partnership; private service providers; local farm machine manufacturers. **Research**: integrated systems research on new varieties, TCE, nutrients, water, and crop diversification; expansions of zero-/minimum-tillage for wheat; new crop establishment methods; crop diversification; cost/benefit and policy analysis; technical and socioeconomic impact evaluation; GIS and spatial analysis; training and technical workshops. **Outcomes**: improved collaboration among IARCs—CIMMYT, IRRI, IWMI, CIP, ICRISAT; PRISM database; zero-till wheat and wheat varieties for zero-till; resource-conserving technologies (RCTs): laser leveling, surface seeding, wet drum seeding and direct dry seeding for rice, bed planting, LCC for N management, reduced-till seeding with power tiller, intercropping wheat in sugarcane and maize in potato; RW Symposium at American Society of Agronomy (ASA) 2002 and subsequently an ASA Special Publication (Ladha et al 2003); traveling seminars: China (2000), northwest India and Pakistan (2000), eastern IGP—Bangladesh, Nepal, Bihar-India (2001), Australia (2001), northwest IGP (2004);

Period	Funding support & project focus	Focus countries	Major developments
			locally produced zero-till drills and laser equipment for leveling; RCTs such as zero- and minimum-till, beds and furrows, drum seeding, leaf color chart.
2004	**Various donors**	Same as above	Same as above
2005-08	**ADB's RETA 6208**: Enhancing farmers' income and livelihoods through integrated crop and resource management in the RW system in South Asia. **Other bilateral donors.**	IGP countries: Bangladesh, India, Nepal, and Pakistan	**Institutional**: integrated crop and resource management (ICRM), farmer participatory technology evaluation; enhancing adoption of RCTs: through information sharing, training, technology dissemination, and policy change. **Research**: ICRM in rice and wheat; targeted on-farm technology evaluation. **Outcomes**: higher yield and income through ICRM; reduced cost and increased profit for zero-/reduced-tillage wheat and rice; efficient NPK management, particularly N management using LCC and addition/omission plots; higher water productivity in zero-/reduced-till; improved irrigation through canal lining; quality seed production and supply; rural machinery pools; 4-wheel tractor with narrow wheels for controlled-traffic planting; lightweight zero-till drills; impact on productivity, profitability, input-use efficiency, greenhouse gas emission, and carbon sequestration assessed.

Annex 2. Collaborating agencies/institutions and contact persons. (Names are listed)

Country	Implementing agencies
Rice-Wheat Consortium (RWC)	RWC for Bangladesh, India, Nepal, and Pakistan
Bangladesh	Bangladesh Rice Research Institute (BRRI) and Bangladesh Agricultural Research Institute (BARI)
India	Department of Agriculture (DA), Karnal
	Haryana Agricultural University (HAU)
	Banaras Hindu University (BHU), Varanasi
	Sardar Vallabh Bhai Patel University of Agriculutre and Technology (SVBPUAT), Modipuram
Nepal	National Agricultural Research Council (NARC)
	Regional Agriculture Station (RAS), Bhairahawa
Pakistan	Pakistan Agricultural Research Center (PARC), Islamabad
	On-Farm Water Management (OWM), Lahore
IRRI-India	International Rice Research Institute-India
CIMMYT-India	International Maize and Wheat Improvement Center

Annex 3. List of project's publications: 2005-08

3.1. Refereed journal publications

1. Alam MM, Ladha JK, Khan Rahman S, Foyjunnessa, Rashid-ur-Harun, Khan AH, Buresh RJ. 2005. Leaf color chart for managing nitrogen fertilizer in lowland rice in Bangladesh. Agron. J. 97:949-959.
2. Bijay-Singh, Yadvinder-Singh, Ladha JK. 2005 Management of crop residues in rice-wheat cropping system in the Indo-Gangetic Plains of South Asia. Jpn. Assoc. Int. Collaboration Agric. Forest. 28:17-24.
3. Ladha JK, Pathak HP, Krupnik TJ, Six J, van Kessel C. 2005. Efficiency of fertilizer nitrogen in cereal production: retrospect and prospect. Adv. Agron. 87:86-156.
4. Ladha JK. 2005. Improving the recovery efficiency of fertilizer nitrogen in cereals. Indian J. Soil Sci. 53:472-483.
5. Regmi AP, Ladha JK. 2005. Enhancing productivity of rice-wheat system through integrated crop management in the Eastern-Gangetic plains of South Asia. J. Crop Improv. 15:1147-1170.
6. Alam MM, Ladha JK, Foyjunnessa, Rahman Z, Khan Rahman S, Rashid-ur-Harun, Khan AH, Buresh RJ. 2006. Nutrient management for increased productivity of rice-wheat cropping system in Bangladesh. Field Crops Res. 96:374-386.
7. Ali MA, Ladha JK, Rickman J, Lales JS. 2006. Comparative evaluation of different methods of rice establishment and nitrogen management strategies for lowland rice. J. Crop Improv. 16:171-187.
8. Padre-Tirol A, Ladha JK. 2006. Integrated rice and wheat productivity trends using the SAS mixed-procedure and meta-analysis. Field Crops Res. 95:75-88.
9. Pathak H, Li C, Wassmann R, Ladha JK. 2006. Simulation of nitrogen balance in the rice-wheat systems of the Indo-Gangetic Plains: upscaling using the DNDC model. Soil Sci. Soc. Am. J. 70:1612-1622.
10. Singh S, Bhushan L, Ladha JK, Gupta RK, Rao AN, Sivaprasad B. 2006. Weed management in dry-seeded rice (*Oryza sativa*) cultivated in the furrow-irrigated raised-bed planting system. Crop Prot. 25:487-495.
11. Ali MA, Ladha JK, Rickman J, Lales JS. 2007. Nitrogen dynamics in lowland rice as affected by crop establishment and nitrogen management. J. Crop Improv. 20(2):89-105.
12. Bhushan L, Ladha JK, Gupta RK, Singh S, Tirol-Padre A, Saharawat, YS, Gathala M, Pathak H. 2007. Saving of water and labor in rice-wheat system with no-tillage and direct-seeding technologies. Agron. J. 99:1288-1296.
13. Gupta RK, Yadvinder-Singh, Ladha JK, Bijay-Singh, Singh J, Singh G, Pathak H. 2007. Yield and phosphorus transformations in a rice-wheat system with crop residue and phosphorus management. Soil Sci. Soc. Am. J. 71:1500-1507.
14. Kundu S, Bhattacharyya Rajan, Prakash Ved, Pathak H, Gupta HS, Ladha JK. 2007. Long-term yield trend and sustainability of rainfed soybean-wheat system through farmyard manure application in a sandy loam soil of the Indian Himalayas. Biol. Fertil. Soils 43:271-280.
15. Ladha, JK, Pathak H, Gupta RK. 2007. Sustainability of rice-wheat cropping system: issues, constraints, and remedial options. J. Crop Improv. 19(1/2):125-136.

16. Padre-Tirol A, Ladha JK, Regmi AP, Bhandari AL, Inubushi K. 2007. Organic amendments affect soil parameters in two long-term rice-wheat experiments. Soil Sci. Soc. Am. J. 71:442-452.
17. Pathak H, Wassmann R. 2007. Introducing greenhouse gas mitigation as a development objective in rice-based agriculture. I. generation of technical coefficients. Agric. Syst. 94:807-825.
18. Rao AN, Johnson DE, Sivaprasad B, Ladha JK, Mortimer AM. 2007. Weed management in direct-seeded rice. Adv. Agron. 93:153-255.
19. Singh S, Ladha JK, Gupta RK, Bhushan L, Rao AN, Sivaprasad B, Singh PP. 2007. Evaluation of mulching, intercropping with *Sesbania* and herbicide use for weed management in dry-seeded rice (*Oryza sativa* L.). Crop Prot. 26:518-524.
20. Varinderpal-Singh, Yadvinder-Singh, Bijay-Singh, Baldev-Singh, Gupta RK, Jagmohan-Singh, Ladha JK, Balasubramanian V. 2007. Performance of site-specific nitrogen management for irrigated transplanted rice in north-western India. Arch. Agron. Soil Sci. 53:567-579.
21. Wassmann R, Pathak H. 2007. Introducing greenhouse gas mitigation as a development objective in rice-based agriculture: II. Cost-benefit assessment for different technologies, regions and scales. Agric. Syst. 94:826-840.
22. Yadvinder-Singh, Bijay-Singh, Ladha JK, Bains JS, Gupta RK, Jagmohan-Singh, Balasubramanian V. 2007. On-farm evaluation of leaf color chart for need based nitrogen management in irrigated transplanted rice in northwestern India. Nutr. Cycl. Agroecosyst. 78:167-176.
23. Pathak H, Wassmann R. 2008. Quantitative evaluation of climatic variability and risks for wheat yield in north-west India. Clim. Change 10.1007/s10584-008-946-4.
24. Sharma C, Tiwari MK, Pathak H. 2008. Estimates of emission and deposition of reactive nitrogenous species for India. Curr. Sci. 94:1439-1446.
25. Singh S, Ladha JK, Gupta RK, Bhushan L, Rao AN. 2008. Weed management in aerobic rice systems under varying establishment methods. Crop Prot. 27:660-671.
26. Yadvinder-Singh, Bijay-Singh, Gupta RK, Ladha JK, Bains JS, Jagmohan-Singh. 2008. Evaluation of press mud cake as a source of nitrogen and phosphorus for rice-wheat cropping system in the Indo-Gangetic plains of India. Biol. Fertil. Soils 44:755-762.

3.2. Proceedings of workshops and seminars

1. Gupta RK, Ladha JK et al. 2006. Production technology for direct seeded rice. Rice-Wheat Consortium Technical Bulletin No. 8. Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi, India. p 1-16.
2. Ladha JK, Pathak H, Gupta RK. 2007. Sustainability of rice-wheat cropping system: issues, constraints, and remedial options. In: Kang MS, editor. Agriculture and environmental sustainability: considerations for the future. Haworth Food and Agricultural Products Press, The Haworth Press, Inc. p 125-136.
3. Pathak H, Ladha JK. 2006. Rice: environmental issues. Indian Farming 56:46-49.
4. Pathak H, Ladha JK. 2007. Improving nitrogen use efficiency: strategies, tools, management and policy options. In: Abrol YP, Raghuram N, Sachdev MS, editors. Agricultural nitrogen use and its environmental implications. IK International Publishing House Pvt. Ltd, New Delhi. p 279-302.

5. Yadvinder-Singh, Bijay-Singh, Ladha JK, Singh JP, Choudhary OP. 2007. Enhancing nitrogen use efficiency for sustainable rice-wheat production system in the Indo-Gangetic Plains of India. In: Abrol YP, Raghuram N, Sachdev MS, editors. Agricultural nitrogen use and its environmental implications. IK International Publishing House Pvt. Ltd., New Delhi. p 139-164.
6. Jat ML, Gathala MK, Singh KK, Ladha JK, Gupta RK, Singh S, Sharma SK, Saharawat YS, Tetarwal JP. 2008. Experiences with permanent beds in rice-wheat system of the western Indo-Ganget Plain. In: Humphreys E, Roth CH, editors. Permanent beds and rice-residue management for rice-wheat systems in the Indo-Gangetic Plain. In: Permanent beds and rice-residue management for rice-wheat systems in the Indo-Gangetic Plain. Proceedings of a workshop held in Ludhiana, India, 7-9 September 2006. ACIAR Proceedings No. 127. p 98-107.
7. Ladha JK, Bhushan L, Gupta RK, Pathak H. 2008. Performance of furrow-irrigated raised beds in rice-wheat cropping system of the Indo-Gangetic plains. In: Humphreys E, Roth CH, editors. Permanent beds and rice-residue management for rice-wheat systems in the Indo-Gangetic Plain. ACIAR Proceedings No. 127. p 108-110.

3.3. Books

1. Aggarwal PK, Ladha JK, Singh RK, Devakumar C, Hardy B, editors. 2008. Science, technology, and trade for peace and prosperity. Proceedings of the 26th International Rice Research Conference, 9-12 October 2006, New Delhi, India. New Delhi: International Rice Research Institute, Indian Council of Agricultural Research, and National Academy of Agricultural Sciences. 782 p.

3.4. Book Chapters

1. Adhya TK, Pathak H, Chhabra A. 2007. N-fertilizers and Gaseous N-emission from rice-based cropping systems. In: Abrol YP, Raghuram N, Sachdev MS, editors. Agricultural nitrogen use and its environmental implications. IK International Publishing House Pvt. Ltd., New Delhi. p 459-476.
2. Ladha JK, Pathak H, Gupta RK. 2007. Sustainability of the rice-wheat cropping system: issues, constraints, and remedial options. In: Agricultural and environmental sustainability: considerations for the future. Kang MS, editor. Haworth Food and Agricultural Products Press, The Haworth Press, Inc. p 125-136.
3. Pathak H, Ladha JK. 2007. Improving nitrogen use efficiency: strategies, tools, management and policy options. In: Abrol YP, Raghuram N, Sachdev MS, editors. Agricultural nitrogen use and its environmental implications. IK International Publishing House Pvt. Ltd., New Delhi. p 279-302.
4. Yadvinder-Singh, Bijay-Singh, Ladha JK, Singh JP, Choudhary OP. 2007. Enhancing nitrogen use efficiency for sustainable rice-wheat production system in the Indo-Gangetic Plains of India. In: Abrol YP, Raghuram N, Sachdev MS, editors. Agricultural nitrogen use and its environmental implications. IK International Publishing House Pvt. Ltd., New Delhi. p 139-164.
5. Ladha JK, Lav Bhushan, Gupta RK, Pathak H. 2008. Performance of furrow-irrigated raised beds in rice-wheat cropping systems of the Indo-Gangetic Plain. In: Humphreys E, Roth CH, editors. Permanent beds and rice-residue management for

rice-wheat systems in the Indo-Gangetic Plain. ACIAR Proc. No. 127. Australian Center for International Agricultural Research, Canberra. p 108-111.

6. Pathak H, Mohanty S, Patra AK, Shalini Singh-Tandon. 2008. Environmental change and biodiversity in India. In: Biodiversity conservation for sustainable development. Asian Society for Entrepreneurship Education & Development (ASEED), New Delhi. p 195-222.

7. Patra AK, Swarup A, Pathak H. 2008. Soil biodiversity and bioprospecting – an overview. In: Biodiversity conservation for sustainable development. Asian Society for Entrepreneurship Education & Development (ASEED), New Delhi. p 189-194.

3.5. Papers presented in seminars/symposiums/workshops

1. Ladha JK, Gupta RK. 2005. Overview of permanent raised beds in the Indo-Gangetic Plain. In: An International Workshop on Evaluation and Performance of Permanent Raised Bed Systems in Asia and Australia. Australian Centre for International Agriculture Research. 1-3 March. CSIRO Land & Water, Griffith Laboratory, New South Wales, Australia.
2. Ladha JK, Gupta RK. 2005. Resource-conserving technologies; a new paradigm transforming agriculture. In: An IRRI-Chinese Ministry of Agriculture workshop on resource conservation technologies for rice-production. 1-2 August. Guilin, China.
3. Ladha JK. 2005. Developing alternative tillage and crop establishment strategies for higher resource use efficiencies in rice-wheat system. In: Third research coordination meeting of IAEA coordinated research project on integrated soil, water and nutrient management for sustainable rice-wheat cropping system in Asia. 9-15 July, Dhaka, Bangladesh.
4. Ladha JK. 2005. Managing nitrogen for crop productivity an environmental quality. In: The Delhi chapter of Indian Society of Soil Science at Division of Soil Science & Agricultural Chemistry. 26 April. Indian Agricultural Research Institute, New Delhi, India.
5. Ladha JK. 2005. Productivity and sustainability of rice-wheat system. In: National agriculture research center. 15 March. Islamabad, Pakistan.
6. Ladha JK. 2005. Sustainability of post-green revolution agriculture: the rice-wheat system of Indo-Gangetic Plain. In: Abstracts of the 2005 ASA/CSSA/SSSA annual meetings. 6-9 November. Salt Lake City, USA.
7. Padre-Tirol A, Ladha JK. 2005. Integrating rice and wheat productivity trends using the SAS mixed-procedure and meta analysis. In: Abstracts of the 2005 ASA/CSSA/SSSA annual meetings. 6-9 November. Salt Lake City, USA.
8. Padre-Tirol A, Tsuchiya K, Inubushi K, Ladha JK. 2005. Long-term effects of organic residue incorporation on soil quality in a rice-wheat system in Japan. In: Abstracts of the 2005 ASA/CSSA/SSSA annual meetings. November 6-9. Salt Lake City, USA.
9. Pathak H, Ladha JK, Gupta RK. 2005. Simulation of nitrogen dynamics in the rice-wheat systems of the Indo-Gangetic Plains. In: Third research coordination meeting of IAEA coordinated research project on integrated soil, water and nutrient management for sustainable rice-wheat cropping system in Asia. 9-15 July, Dhaka, Bangladesh.
10. Sivaprasad B, Ladha JK. 2005. Long-term sustainability of rice-wheat cropping system in Indo-Gangetic Plains. In: Abstracts of the workshop on direct seeded rice

and weed management in the irrigated rice-wheat system of the Indo-Gangetic Plains. 1-2 February. G.B. Pant University of Agriculture and Technology, Pantnagar, and IRRI, India.

11. Aladakatti YR, Patil SG, Channagoudar RF, Hanamaratti NG, Gupta RK, Ladha JK. 2006. Adoption of resource conservation technologies for sustainable direct seeded rice production in Karnataka. In: 2nd International Rice Congress. 9-13 October 2006, New Delhi, India. p 509.
12. Alam MM, Buresh RJ, Ladha JK, Foyjunnessa. 2006. Optimization of phosphorus and potassium management in lowland rice in Bangladesh through site-specific nutrient management approach. A poster presented at 18th World Congress of Soil Science, 9-15 July 2006, Philadelphia, USA.
13. Alam MM, Ladha JK, Buresh RJ, Rashid H, Khan AH. 2006. Nitrogen management in lowland rice by the use of leaf color chart through farmer participatory approach in Bangladesh. A poster presented at 18th World Congress of Soil Science, 9-15 July 2006, Philadelphia, USA.
14. Alam MM, Rashid MH, Khan AH, Ladha JK. 2006. Wet drum-seeded rice in Bangladesh: problems and prospects. In: 2nd International Rice Congress, 9-13 October 2006, New Delhi, India. p 483.
15. Gathala M, Ladha JK, Pathak H, Saharawat, Gupta RK, Yadav MP. 2006. Performance of no-till rice-wheat system in the Indo-Gangetic plains. In: 2nd International Rice Congress, 9-13 October 2006, New Delhi, India. p 474.
16. Haefele SM, Konboon Y, Knoblauch C, Koyama S, Gummert M, Ladha JK. 2006. Black carbon from rice residues as soil amendment and for carbon sequestration. A poster presented at 18th World Congress of Soil Science, 9-15 July 2006, Philadelphia, USA.
17. Jat ML, Gathala M, Sharma SK, Ladha JK, Gupta RK, Saharawat YS, Pathak H. 2006. Productivity and profitability of rice-wheat system with double no-till practice. In: 2nd International Rice Congress, 9-13 October 2006, New Delhi, India. p 88.
18. Pathak H, Ladha JK, Saharawat YS, Gathala M. 2006. Quantitative evaluation of resource conservation technologies in rice-wheat system for productivity, income and environmental impact. In: 2nd International Rice Congress, 9-13 October 2006, New Delhi, India. p 473.
19. Pathak H, Li C, Ladha JK, Wassmann R. 2006. Nitrogen balance in the rice-wheat systems of the Indo-Gangetic plains: simulation and upscaling using the DNDC model. In: Abstracts of 2006 ASA/CSSA/SSSA annual meetings, 12-16 November 2006, Indianapolis, USA.
20. Rao AN, Mortimer AM, Johnson DE, Sivaprasad B, Ladha JK. 2006. Challenges and future research needs in weed management in direct-seeded rice. In: 2nd International Rice Congress, 9-13 October 2006, New Delhi, India. p 533.
21. Saharawat YS, Ladha JK, Gathala M, Pathak H, Mallik RK, Singh S. 2006. On-farm evaluation of resource conservation technologies in rice-wheat system. In: 2nd International Rice Congress, 9-13 October 2006, New Delhi, India. p 571.
22. Saharawat YS, Ladha JK, Pathak H, Gathala M. 2006. On-farm evaluation of resource conservation technologies for yield, income, and global warming potential

in rice-wheat system. In: Abstracts of 2006 ASA/CSSA/SSSA annual meetings, 12-16 November 2006, Indianapolis, USA.

23. Sherchan DP, Ranjit JD, Shrestha S, Gauchan D, Regmi AP, Ladha JK. 2006. Improving the livelihood of the Nepalese farmers through integrated crops and resource management in the rice-wheat system in the hills of Nepal. In: 2nd International Rice Congress. 9-13 October 2006, New Delhi, India. p 383.
24. Singh D, Atlin G, Ladha JK, Gupta RK, Singh A, Singh S. 2006. Selection of suitable rice genotypes for aerobic conditions in Indo Gangetic Plains. In: 2nd International Rice Congress, 9-13 October 2006, New Delhi, India. p 231.
25. Singh D, Sirohi A, Atlin G, Gupta RK, Ladha JK, Singh S. 2006. Screening and estimation of parameters of rice genotypes under aerobic conditions. In: 2nd International Rice Congress, 9-13 October 2006, New Delhi, India. p 225.
26. Singh S, Bhushan L, Chhokar RS, Sharma RK, Ladha JK, Gupta RK. 2006. Effect of cultural practices and herbicides on weeds in dry seeded rice (*Oryza sativa* L.). In: 2nd International Rice Congress, 9-13 October 2006, New Delhi, India. p 527.
27. Singh Y, Singh B, Ladha JK. 2006. Efficiency management of nutrients in rice-based cropping systems in Asia. In: 2nd International Rice Congress, 9-13 October 2006, New Delhi, India. p 31.
28. Sirohi A, Singh D, Gupta RK, Ladha JK, Sharma AK, Gathala MK. 2006. Selection of suitable varieties and optimum seeding depth for mechanized cultivation of aerobic rice. In: 2nd International Rice Congress, 9-13 October 2006, New Delhi, India. p 259.
29. Tirol-Padre A, Ladha JK, Inubushi K, Bhandari AL, Regmi AP, Tsuchiya K. 2006. Evaluating effects of organic amendments on soil properties in three rice-wheat long-term experiments. In: 2nd International Rice Congress, 9-13 October 2006, New Delhi, India. p 479.
30. Weerakoon WMW, Wickramasinghe WMADB, Bandara KMC, Mutunayake MP, Ladha JK. 2006. Constraints to maximize production and resource utilization efficiencies of direct seeded lowland rice (*Oryza sativa* L.) in Sri Lanka. In: 2nd International Rice Congress, 9-13 October 2006, New Delhi, India. p 338.
31. Alam M, Abbas M, Sikder A, Bowen WT, Ladha JK. 2007. Building farmer awareness of using guti urea and LCC for optimization of urea management in rice. A paper presented in Policy Workshop on "Guti Urea: A Win-Win Technology for Farmers and the Environment" held at Bangladesh Agricultural Research Council (BARC), Farmgate, Dhaka, Bangladesh, 28 February 2007.
32. Alam M, Ladha JK. 2007. Integrated crop and resource management in rice: guidelines for farmers and extension personnel. A paper in Bengali presented in Training on ICRM in Rice for Farmers and Extension Personnel in Sharif Mamtaz Uddin College, Toke, Kapasia, Gazipur, 13 September 2007.
33. Chandna P. 2007. Use of remote sensing/GIS technologies for targeting resource conserving technologies in underutilized lands. Regional Technical Coordination Committee of Rice-Wheat Consortium and ADB Project Review and Planning Meeting, Kathmandu, Nepal, 12-16 February 2007.
34. Gathala M, Ladha JK, Gupta RK, Jat ML, Saharawat Y, Pathak H, Singh A, Yadav MP. 2007. ADB Project Progress and Accomplishment Report-Modipuram (satellite

site). Regional Technical Coordination Committee of Rice-Wheat Consortium and ADB Project Review and Planning Meeting, Kathmandu, Nepal, 12-16 February 2007.

35. Gathala MK, Ladha JK, Saharawat YS, Pathak H, Yadav MP. 2007. Double no till system effects on productivity, profitability and soil physical properties in rice-wheat system. 3rd National Symposium on Integrated Farming System held at ARS, Durgapura, 26-28 October 2007. p 67.
36. Gill MA, Rehman HM Ur. 2007. ADB Project Progress and Accomplishment Report-Pakistan. Regional Technical Coordination Committee of Rice-Wheat Consortium and ADB Project Review and Planning Meeting, Kathmandu, Nepal, 12-16 February 2007.
37. Ladha JK, Gathala M, Pathak H, Saharawat YS, Yadav MP. 2007. No-tillage and direct seeding: water- and labor-efficient alternatives to the conventional rice-wheat system. In: Abstracts of 2007 ASA/CSSA/SSSA annual meetings, 4-8 November 2007. New Orleans, USA.
38. Ladha JK. 2007. Challenges and issues regarding introduction and adoption of resource conservation technologies. Invited paper at the National Workshop on Emerging Issues and Challenges in Water Resources Management in Pakistan: Research Priorities and Required Actions. 12-13 March 2007, IWMI Pakistan Office, Lahore.
39. Ladha JK. 2007. Enhancing farmer's income and livelihoods through integrated crop and resource management in the rice-wheat production systems of Asia – an overview of ADB sponsored project. Presented at the 14th meeting of the regional steering committee. 14-15 Feb 2006, Kathmandu, Nepal.
40. Ladha JK. 2007. Resource conserving technologies: a new paradigm transforming agriculture. Invited paper presented at 42nd All India Rice Research Group Meetings, 9-11 April 2007. Directorate of Rice Research, Hyderabad, India.
41. Ladha JK. 2007. Resource conserving technologies: an overview of ADB RETA 6208. Invited presentation in Brownbag Seminar, 23 April 2007. Asian Development Bank, Manila, Philippines.
42. Ladha JK. 2007. Resource-conserving technologies: a new paradigm transforming agriculture. Presented at the CIFAD Seminar Series on Agro-ecological Perspectives for Sustainable Development. Cornell University, Ithaca, USA. 24 October 2007.
43. Ladha JK. 2007. Role of biological nitrogen fixation in replenishing soil nitrogen in cropping system. Presented at the Department of Crop and Soil Sciences, 30 August 2007. Cornell University, Ithaca, USA.
44. Malik RK, Singh S, Yadav A, Punia SS, Dhrambir LOP, Kamboj BR, Dahiya SS, Yadav R, Yadav VK, Saharawat YS. 2007. ADB Project Progress and Accomplishment Report-Karnal, India. Regional Technical Coordination Committee of Rice-Wheat Consortium and ADB Project Review and Planning Meeting, Kathmandu, Nepal, 12-16 February 2007.
45. Pathak H, Ladha JK, Gupta RK, Saharawat YS, Gathala M. 2007. Mitigation and adaptation to climate change with resource conservation technologies. Regional Technical Coordination Committee meeting of Rice-Wheat Consortium. Kathmandu, Nepal, 12-16 February 2007.

46. Pathak H, Ladha JK, Saharawat YS, Gathala M. 2007. Impact, productivity, income and environmental impact assessment of RCTs in RW system using modeling tool. In: Proceedings 94th Indian Science Congress, 3-7 Jan 2007, Chidambaram India. p 32.
47. Pathak H, Yadvinder-Singh, Hussain A, Hussain F, Munnankarni R, Gathala M, Nguyen Minh-Long, Ladha JK. 2007. Use of CERES model for evaluation of resource conservation technologies in rice-wheat system in south Asia. In: Abstracts of 2007 ASA/CSSA/SSSA annual meetings. 4-8 November 2007, New Orleans, USA.
48. Pathak H. 2007. Climate change: an emerging challenge for the Indian farmers. Proceedings National Symposium on Soil Science Research: Retrospect and Prospect held during 7-9 December 2007 at Central Glass and Ceramic Research Institute, Government of India, Kolkata. p. 12-20.
49. Pathak H. 2007. Managing water for mitigating methane emission from rice fields. National Conference on Climate Change and Indian Agriculture organized by ICAR during 12-13 October 2007 at New Delhi.
50. Pathak H. 2007. Mitigation and adaptation of Indian agriculture to climate change. National Symposium on Global Warming and Its Impact in India. Bipin Chandra Pal Memorial Trust and Department of Management Studies at IIT, Delhi, 17 November 2007.
51. Pathak H. 2007. Productivity, income, and environmental impact assessment of resource conservation technologies in rice-wheat system using a modelling tool. Indian Science Congress held at Annamalai University, Chidambaram, 3-7 January 2007. p. 67.
52. Pathak H, Ladha JK, Gupta RK, Saharawat YS, Gathala M. 2007. Mitigation and adaptation to climate change with resource conservation technologies. Regional Technical Coordination Committee meeting of Rice-Wheat Consortium. Kathmandu, Nepal, 12-16 February 2007.
53. Regmi AP, Bhatta MR, Tripathi J, Giri GS, Khan SU, Bhandari D, Shrestha LL, Adhikari U, Sherchan DP, Shrestha S, Gauchan D, Ranjit JD, Raut S, Tripathi BP, Ladha JK, Gupta RK, Balasubramanian V, Erenstein O, Pathak H, Saharawat YS, Gathala M. 2007. ADB Project Progress and Accomplishment Report-Nepal. Regional Technical Coordination Committee of Rice-Wheat Consortium and ADB Project Review and Planning Meeting, Kathmandu, Nepal, 12-16 February 2007.
54. Saharawat Y, Ladha JK, Gupta RK, Gathala M, Jat ML, Pathak H, Singh A, Malik RK, Singh S. 2007. Brown manuring in direct seeded rice. Regional Technical Coordination Committee of Rice-Wheat Consortium and ADB Project Review and Planning Meeting Kathmandu, Nepal, 12-16 February 2007.
55. Singh UP, Singh Y, Singh HP, Yadav J, Raju SVS, Yadav N, Kumar A, Prakash B, Shukla P, Kumar S, Kumar D, Singh SR, Ladha JK, Gupta RK, Erenstein O, Balasubramanian V, Pathak H, Saharawat Y, Gathala M, Chandna P. 2007. ADB Project Progress and Accomplishment Report-Ballia, India. Regional Technical Coordination Committee of Rice-Wheat Consortium and ADB Project Review and Planning Meeting, Kathmandu, Nepal, 12-16 February 2007.

56. Sufian M. 2007. ADB Project Progress and Accomplishment Report-Bangladesh. Regional Technical Coordination Committee of Rice-Wheat Consortium and ADB Project Review and Planning Meeting, Kathmandu, Nepal, 12-16 February 2007.
57. Tripathi BP, Ladha JK, Pandey S, Kumar A, Regmi AP, Sherchan DP, Gautam AK, Akhtar T, Adhikari BB. 2007. Collaborative rice research and development thrusts between IRRI and Nepal. Paper presented at 25th National Summer Crops Workshop held in Kathmandu, Nepal, 21-23 June 2007.
58. Tripathi BP, Ladha JK, Pandey S, Kumar A, Regmi AP, Sherchan DP, Gautam AK, Akhtar T. 2007. Collaborative rice research and development thrusts between IRRI and Nepal. 25th National Summer Crops Workshop held in Kathmandu, Nepal, 21-23 June 2007.
59. Erenstein O, Farooq U, Malik RK, Sharif M. 2007. Adoption and impacts of zero tillage as a resource conserving technology in the irrigated plains of South Asia. Comprehensive Assessment of Water Management in Agriculture, Research Report 19. IWMI, Colombo, Sri Lanka.
60. Hellin J, Dixon J, Erenstein O, Chandna P. 2008. Livelihood metrics and knowledge bases for ex-ante impact assessment in the rice-wheat farming system of South Asia. Conference proceeding: Rethinking impact: understanding the complexity of poverty and change. Cali, Colombia, held March. p. 1-12.
61. Ladha JK, Pathak H. 2008. Resource conserving technologies in rice-wheat system: problems and prospects. Paper presented at the National Symposium on Technological Innovations for Resource Starved Farmers in Global Perspective held at Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, India, during 28-30 April 2008. p 24-25.
62. Pathak H, Saharawat YS, Gathala M, Mohanty M, Ladha JK. 2008. Simulating the impact of resource conserving technologies in rice-wheat system on productivity, income and environment. In: Abstracts of 2008 ASA/CSSA/SSSA annual meetings. 5-9 October 2008. Houston, USA.
63. Pathak H. 2008. Maintaining soil health under high-input agricultural systems. Indian Science Congress held at Andhra University, Visakhapatnam, 3-7 January 2008. p. 22.
64. Pathak H, Ladha JK, Bhatia A, Jain N, Mohanty S, Chandrasekharan S. 2008. Nitrogen, phosphorus and potassium budgets in Indian agriculture. Indian Science Congress held at Andhra University, Visakhapatnam, 3-7 January 2008. p. 45.
65. Singh B, Saharawat YS, Gathala M, Ladha JK, Malik R.K. 2008. Integrated weed management in direct-seeded rice under different crop establishment methods in rice-wheat system of Indo-Gangetic Plain. 2008. In: Abstracts of 2008 ASA/CSSA/SSSA annual meetings. 5-9 October 2008, Houston, USA.
66. Tripathi BP, Ladha JK, Pandey S, Sherchan DP, Regmi AP, Adhikari BB. 2008. Integrated crop and resource management in rice-wheat system and management of marginal uplands in rice-based cropping systems in the hills of Nepal. In: Abstracts of ICSC 2008 5th International Crop Science Congress and Exhibition. 13-18 April 2008, Jeju, Korea. p 261.

3.6. Popular articles published in local newspapers and magazines

1. Pathak H, Prasad R. 2008. Fate of nitrogen in Indian agriculture and its environmental impact. NAAS News 8(2):1-4.
2. Pathak H, Ladha JK. 2006. Rice: environmental issues. Indian Farming 56(7):46-49.
3. Patra AK, Pathak H, Chhonkar PK. 2006. Leaf color chart: a promising cost-effective tool for better nitrogen management. Indian Farming 55(12): 20-22.

3.7. Training and extension materials produced for promotion of technologies

1. Gupta RK, Ladha JK, Singh S, Singh RG, Jat ML, Saharawat Y, Singh VP, Singh SS, Singh G, Sah G, Gathala M, Shara RK, Gill MS, Alam M, Rehman RAM, Pathak H, Chauhan BS, Bhattacharya P, Malik RK. 2006. Production technology for direct seeded rice. Technical Bulletin 8. New Delhi (India): Rice-Wheat Consortium for the Indo-Gangetic Plains. 16 p.

3.8. Technical reports

1. Erenstein O, Malik RK, Sher Singh. 2007. Adoption and impacts of zero tillage in the irrigated rice-wheat systems of Haryana, India. New Delhi (India): CIMMYT & RWC. 69 p.
2. Farooq U, Sharif M, Erenstein O. 2007. Adoption and impacts of zero tillage in the rice-wheat zone of irrigated Punjab, Pakistan. New Delhi (India): CIMMYT & RWC. 69 p.
3. Laxmi V, Erenstein O, and Gupta RK. 2007. Impact of zero tillage in India's rice-wheat systems. New Delhi: CIMMYT and RWC. 32 p.
4. Erenstein O, Thorpe W, Singh J, Varma A. 2007. Crop-livestock interactions and livelihoods in the Indo-Gangetic Plains, India: a regional synthesis. Crop-Livestock Interactions Scoping Study: Synthesis. New Delhi (India): CIMMYT-ILRI-RWC. 38 p.
5. Erenstein O, Farooq U, Malik RK, Sharif M. 2007. Adoption and impacts of zero tillage as a resource conserving technology in the irrigated plains of South Asia, Comprehensive Assessment of Water Management in Agriculture: Research Report 19. Colombo (Sri Lanka): IWMI. 55 p.
6. Erenstein O, Hellin J, Chandna P. 2007. Livelihoods, poverty and targeting in the Indo-Gangetic Plains: a spatial mapping approach. New Delhi (India): CIMMYT & RWC. 56 p.
7. Bhattacharyya P, Mallick EH, Pathak H, Ladha JK. 2008. Wheat in West Bengal. Govt. of West Bengal and Rice-Wheat Consortium for the Indo-Gangetic Plains, New Delhi. 35 p.