RESOURCE CONSERVING TECHNOLOGIES:
TRANSFORMING THE RICE-WHEAT SYSTEMS OF
THE INDO-GANGETIC PLAINS

RICE-WHEAT CONSORTIUM — A SUCCESS STORY

Raj K. Gupta, Peter R. Hobbs,
J.K. Ladha and S.V.R.K. Prabhakar

Asia-Pacific Association of Agricultural Research Institutions
FAO Regional Office for Asia & The Pacific
Bangkok
INTRODUCTION

The Green Revolution technologies, beginning 1970s, have remained the cornerstone of South Asian strategy for food security, nutrition, rural development, and poverty alleviation. Farmers have been practicing intensive irrigated rice-wheat (R-W) systems in the Indo-Gangetic Plains (IGP) over the past couple of decades. It is generally observed both by the farmers and scientists that rice-wheat systems have fatigued the natural resources with the result that they now need more inputs to attain same yields they used to obtain in earlier years. Slowed growth of productivity in agriculture, and negative impacts of intensive agriculture on environmental quality, particularly in the northwestern parts of the IGP, suggested for infusion of a complimentary set of new agricultural technologies to boost productivity growth. This points to the need to reorient our strategies for enhancing and sustaining the productivity gains of the Green Revolution era. As a part of the strategy, the paradigm shift focuses on the way agricultural research is prioritized, conducted, coordinated, managed, and knowledge-intensive technologies for establishment and management of R-W system are transferred to farmers in system approach. This ‘Success Story’ highlights the efforts of the Consortium partners in South Asia, which have been very successful in sustaining the Green Revolution through adoption of Resource Conserving Technologies (RCTs). These technologies, which are sustaining and enhancing the productivity of the rice-wheat
system at reduced cost of production, are backed-up by the new research findings conducted in participation with farmers.

In 1994, a Consortium of South Asian NARS (Bangladesh, India, Nepal and Pakistan), International Centres (CIMMYT, CIP, ICRISAT, IRRI and IWMI), NGOs, private enterprise and farmers groups was formed to address the sustainability concerns of the rice-wheat systems (Table 1). This consortium, known as the Rice-Wheat Consortium for the Indo-Gangetic Plains (RWC), is convened by CIMMYT and is one of the Ecoregional Programmes of the CGIAR.

Table 1. List of NARS, IARCs and the advanced research institutions collaborating in a partnership mode with the RWC in South Asia

<table>
<thead>
<tr>
<th>NARS partners</th>
<th>CGIAR Centres</th>
<th>Developed Country Research Institutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangladesh</td>
<td>CIMMYT</td>
<td>IAC, Wageningen, The Netherlands</td>
</tr>
<tr>
<td>India</td>
<td>CIP</td>
<td>IACR, Rothamsted, UK</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CABI, UK</td>
</tr>
<tr>
<td>Nepal</td>
<td>ICRISAT</td>
<td>Cornell University, USA</td>
</tr>
<tr>
<td>Pakistan</td>
<td>IRRI</td>
<td>Michigan State University, USA</td>
</tr>
<tr>
<td></td>
<td>IWMI</td>
<td>ACIAR, University of Melbourne, Australia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>University of Adelaide, Roseworthy, Australia</td>
</tr>
</tbody>
</table>
RICE-WHEAT SYSTEMS OF THE INDO-GANGETIC PLAINS IN SOUTH ASIA

In Asia, the rice-wheat system has been practiced for over 1000 years; it has since expanded and is now estimated at 23.5 million ha, including China with about 10 million ha, and South Asia with about 13.5 million ha. The area of RW systems in India, Pakistan, Bangladesh and Nepal is 10.0, 2.2, 0.8, and 0.5 million ha, respectively. Rice-wheat systems represent 32 per cent of the total rice area and 42 per cent of the wheat area in these countries (Ladha et al., 2000). The importance of intensively cultivated rice-wheat systems is fundamental for employment, income and livelihoods of hundreds of millions of rural and urban population in South Asia. This system has also been adapted, outside the Indo-Gangetic Plains, though to a limited extent, in countries such as Bhutan, Thailand, Egypt, Mali, Niger, and Senegal.

Irrigated rice-wheat systems are practiced in the states of Punjab, Haryana and parts of Uttar Pradesh (India) and Punjab (Pakistan) and rainfed rice-rainfed or irrigated wheat in parts of Uttar Pradesh, Uttaranchal, Bihar and West Bengal (irrigated), and Bangladesh, the Terai of Nepal and hills of India. The production of rice and wheat crops, area coverage and yields are shown in Table 2.
Table 2. Production, area and yield of rice and wheat in South Asia over the past 40 years

<table>
<thead>
<tr>
<th>Countries/Region</th>
<th>Production (million tonnes)</th>
<th>Area (million ha)</th>
<th>Yield (t ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RICE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bangladesh</td>
<td>14.51</td>
<td>35.82</td>
<td>8.86</td>
</tr>
<tr>
<td>India</td>
<td>51.86</td>
<td>134.50</td>
<td>34.13</td>
</tr>
<tr>
<td>Nepal</td>
<td>2.11</td>
<td>4.03</td>
<td>1.08</td>
</tr>
<tr>
<td>Pakistan</td>
<td>1.54</td>
<td>7.00</td>
<td>1.21</td>
</tr>
<tr>
<td>South Asia</td>
<td>70.60</td>
<td>181.35</td>
<td>45.48</td>
</tr>
<tr>
<td><strong>WHEAT</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bangladesh</td>
<td>0.09</td>
<td>1.90</td>
<td>0.10</td>
</tr>
<tr>
<td>India</td>
<td>11.00</td>
<td>74.25</td>
<td>12.93</td>
</tr>
<tr>
<td>Nepal</td>
<td>0.14</td>
<td>11.84</td>
<td>0.11</td>
</tr>
<tr>
<td>Pakistan</td>
<td>4.03</td>
<td>21.08</td>
<td>4.64</td>
</tr>
<tr>
<td>South Asia</td>
<td>16.24</td>
<td>109.07</td>
<td>17.57</td>
</tr>
</tbody>
</table>

* Year 2000 figures are FAO estimates.
PRODUCTION CONSTRAINTS/SUSTAINABILITY DIMENSIONS OF THE RICE-WHEAT SYSTEM

Rice is usually grown in the wet summer season (May-June to October-November) and wheat in the dry winter season (November-December to February-March). Even though most rice-wheat cropped area is under irrigation, the soils and crop management undergo drastic changes during wet season rice to upland wheat in winter season. Besides the contrasting edaphic needs, continuous cropping of rice-wheat system for long has resulted in increased pest pressure and yield decline in some areas, thus questioning the sustainability of the system. Contrasting edaphic requirements of rice and wheat pose some key concerns of system ecology as illustrated in Figure 1 (Hobbs and Morris, 1996; Harrington et al., 1993; Harrington et al., 1990).

The various causes for the decline in the sustainability of the rice-wheat system derive from the late onset of monsoons, labour shortages, delayed and excessive tillage and shortage of the draft energy needed for the tillage operations resulting in the late planting of the wheat crop. Apart from these reasons, water shortages in western part of the IGP and insufficient use of water resources in the eastern parts of the IGP is a major dimension to be dealt with to sustain this important cropping system.
Figure 1. Sustainability dimensions of rice-wheat systems of the Indo-Gangetic Plains
LOCATION-SPECIFIC CROP ESTABLISHMENT OPTIONS

The key elements of the strategy, which led to successes of the Consortium, lay in the realization that natural resources management problems are complex and location-specific and have to be resolved in participatory mode with the farmers. Crop establishment techniques/ options vary in different transects of the IGP. This implies that crop and soil management practices (tillage, nutrient, water, weed etc.) have to be fine-tuned, the way the crops are established in different transects of the IGP for success of the RCTs (Figure 2). Following the approach, the Indo-Gangetic Plains were delineated into five broad regions - the Trans (region 1 in Pakistan & 2 in India: Punjab and Haryana), Upper-(region 3), Middle-(region 4) and Lower Gangetic Plains (region 4 in Nepal and eastern India, and Region 5 in Bangladesh).

Rice and wheat crops grown in sequence are planted following various tillage and crop establishment practices, and are shown in the following matrix (Table 3).

The priority matrix points out that:

- Non-puddled transplanted or direct seeded rice can be grown in combination with wheat planted with zero-till or reduced-till. These combination options have relatively great potential of establishing RW across the region.
Figure 2. Generalized Map showing the five broad regions of study presenting relatively more homogenous transects in the Indo-Gangetic Plains
Table 3. Matrix for Crop Establishment Techniques and their Potential in Different IGP transects

<table>
<thead>
<tr>
<th>Wheat →</th>
<th>Conventional tillage</th>
<th>Zero-till</th>
<th>Surface seeding</th>
<th>Reduced tillage</th>
<th>Bed planting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>General Control</td>
<td>TUM</td>
<td>ML</td>
<td>ML</td>
<td>TU</td>
</tr>
<tr>
<td>PTR</td>
<td>TU</td>
<td>TUM</td>
<td>ML</td>
<td>ML</td>
<td>TU</td>
</tr>
<tr>
<td>PDSR</td>
<td>TUM</td>
<td>TUM</td>
<td>TUML</td>
<td>ML</td>
<td>TU</td>
</tr>
<tr>
<td>NPTR</td>
<td>TUML</td>
<td>TUM</td>
<td>TUML</td>
<td>ML</td>
<td>TU</td>
</tr>
<tr>
<td>NPDSR</td>
<td>TUML</td>
<td>TUM</td>
<td>TUML</td>
<td>ML</td>
<td>TU</td>
</tr>
</tbody>
</table>

Legend: T = Trans-Gangetic Plains; U = Upper Gangetic Plains; M = Middle Gangetic Plains; L = Lower Gangetic Plains.

Crop establishment techniques: Puddled Transplanted Rice (PTR); Puddled Direct Seeded Rice (PDSR); Non-puddled Transplanted Rice (NPTR); Non-Puddled Direct Seeded Rice (NPDSR)

Potential of crop establishment techniques by colours:

- Most important for a large area
- Important for many areas
- May be important in some areas

* Bed planting system offers opportunities for diversification of Rice-Wheat

- Permanent raised bed planting system is ‘water-wise’ and offers scope for diversification of RW system even in the monsoon season.
- Surface seeding of wheat and other crops offers great potential in many areas of the middle and lower Gangetic Plains and reduce rice fallows.
RESOURCE CONSERVING TECHNOLOGIES: SUCCESSES ACHIEVED

The successes of the resource conserving technologies pursued over the years in farmer participatory mode have been due to strong commitment of National Agricultural Research Systems (NARS), CG Centres and other national/international partners. Some of the successes observed in different regions of the Indo-Gangetic Plains include:

- Crop establishment options for wheat
- Crop establishment options for rice
- Site-specific nutrient management

Crop establishment options for wheat
Several conservation tillage options have been/are being tried to harvest the benefits of reduced input costs and time saving. Some of these options have been briefly described here.

Surface seeding (Putting aside the plough)
The practice of surface seeding is becoming popular in eastern parts of the IGP in areas where soils are finer in texture and poorly drained, impeding normal tillage. These soils take long to come to workable soil moisture conditions before they can be ploughed. This delays sowing of wheat resulting in either the
rice-fallows or in uneconomic yields with the traditional tillage practices.

Surface seeding is the simplest of all the crop establishment options. Seeds of wheat and other upland crops are broadcast or seeded in rows using drum seeders on the surface without any disturbance of the soil. The treated seed (with Vitavax, 2.5 g kg\(^{-1}\) seed) can be sown before or after the rice harvest depending on the soil moisture. The key to success is having the soil moist/saturated during the initial stage as this facilitates seed germination and corking-in of roots into soil during root elongation stage. Timely seeding of peas, lentil and wheat crops have been observed to significantly improve yields at relatively little costs, something that all farmers like. Surface seeding is becoming increasingly popular with the farmers in Nepal, Bihar (India) and in China for its potential of increasing the cropping intensity in many areas where soils remain waterlogged for long or fields are vacated late for winter season crops. Mulching of surface seeded crops deters weed growth; keep the soil surface moist for long and delaying nitrogen application. In the Yangtze River Valley of China, seeds are sown after a pre-plant herbicide application and then covered with rice straw mulch. Table 4 presents the results indicating the benefits of this system, based on the trials conducted on the establishment of wheat following rice, undertaken at Bhairahawa, Nepal.

**Zero-till system**

In the zero- or no-tilt system, an inverted-T coulter or a chisel opener is attached to a normal seed drill. This coulter makes a narrow groove/slit in the soil for the placement of the seed and fertilizer in one pass. Soil is disturbed in a very narrow groove 5 cm wide and 5 to 7 cm deep. For proper seed germination, wheat should be planted at slightly more than field capacity soil moisture content. High moisture keeps the soil strength low and
Table 4. Data from trials on establishment of wheat following rice, Bhairahawa Agricultural Farm, Nepal, 1993-94

<table>
<thead>
<tr>
<th>Method</th>
<th>Wheat yield (Kg ha⁻¹)</th>
<th>1000-grain weight (g)</th>
<th>Cost to plough (Rs ha⁻¹)</th>
<th>Net benefit (Rs ha⁻¹)</th>
<th>Extra days needed for planting*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface seeding</td>
<td>2.775a</td>
<td>46.11a</td>
<td>0</td>
<td>11.485a</td>
<td>0</td>
</tr>
<tr>
<td>Chinese seed drill</td>
<td>2.831a</td>
<td>45.43b</td>
<td>600</td>
<td>12.090a</td>
<td>8</td>
</tr>
<tr>
<td>Farmers’ practice</td>
<td>2.314b</td>
<td>40.87c</td>
<td>2,300</td>
<td>8.065b</td>
<td>15</td>
</tr>
</tbody>
</table>

Note: Figures followed by the same letter are not significantly different at 5 per cent probability using DMRT.

* Number of extra days needed for land preparation before seeding compared to the surface seeding.

General view of surface seeded wheat in Patna, India showing untilled moist fields vacated by rice in the front and large areas left as rice fallows in the background.
TRANSFORMING THE RICE-WHEAT SYSTEMS OF THE INDO-GANGETIC PLAINS

A general view of good crop stand

Germination of surface seeded wheat mulched with rice straws
allows good germination and good root penetration. If planted into drier soil to keep sowing time right, then first irrigation must be given within a few days or depending upon germination a week before the crown root stage. This technology has been the basis for a revolution in Pakistan, terai of Nepal and northwestern parts of India. Data in Figure 3 shows the rapid spread of this technology, resulting in increased zero-till area in rice-wheat systems in India and Pakistan.

![Figure 3. Trends in wheat zero-till area in rice-wheat systems in India and Pakistan](image)

Results of 132 farmer participatory trials conducted in the state of Haryana have been presented in Figure 4. Relationship between wheat yield and date of planting has clearly shown that wheat can be seeded with zero-tillage system both for timely and late sown conditions.
Figure 4. The interaction of different tillage options (ZT = zero-tilled wheat timely sown; CTS = conventionally tilled and timely sown wheat; CTD = conventionally tilled and late sown wheat with date of wheat planting in Haryana, India, based on 132 participatory trials (Mehla et al., 2000).
Also, on the regional scale, the study further revealed that zero-till planting improved the productivity of wheat by nearly 15 per cent due to timely planting, efficient use of inputs and better weed management. Saving in irrigation water with zero-tillage is in the range of 20 per cent of total irrigation water applied to wheat in conventionally tilled fields. Besides, savings in water and improved productivity, early planting reduces the population of Isoproturon-resistant *Phalaris minor* nearly to half. In village Teak, Haryana, studies by Malik and his associates have shown that the combined use of new herbicides and zero-tillage completely controls the menace of this weed, which facilitates further improvement in yield of wheat over the period (Malik *et al.*, 1998; Table 5). The relative performance of wheat crop planted with different tillage systems can be seen in Table 6.

**Table 5. Effect of zero-till on wheat yield and *Phalaris minor* population at the Teak village site in Haryana, India**

<table>
<thead>
<tr>
<th>Year</th>
<th>Grain Yield kg ha⁻¹</th>
<th><em>P. minor</em> plants m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997-98</td>
<td>5350</td>
<td>1165</td>
</tr>
<tr>
<td>1998-99</td>
<td>5500</td>
<td>28</td>
</tr>
<tr>
<td>1999-2K</td>
<td>6240</td>
<td>6</td>
</tr>
</tbody>
</table>

**Table 6. Average yield of wheat planted with different tillage systems (conventional, zero-till and bed planting) in farmers participatory trials in Haryana, India during 1998-2000**

<table>
<thead>
<tr>
<th>Sowing methods</th>
<th>No. of trials</th>
<th>Grain yield, Mg ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>23*</td>
<td>5.28</td>
</tr>
<tr>
<td>Zero-till †</td>
<td>134</td>
<td>5.52</td>
</tr>
<tr>
<td>Bed Planting</td>
<td>23*</td>
<td>5.73</td>
</tr>
</tbody>
</table>

*Seeding dates kept comparable: Average yields of two years.
Source: Samar Singh, HAU Uchani, 2000 (personal communication); † Mehla *et al.*, 2000.
Zero-Tillage: Small Changes, Astonishing Benefits

Zero-Tillage saves ~70 L of diesel/ha and 1.0 million L water and prevents yield losses due to late planting of wheat @ 35 kg/ha/day in northwest of IGP and up to 60 kg/day/ha in the eastern parts.

- Farmers save Rs. 2500-4000 per hectare in tillage operations.
- Just 0.1 million ha of zero-till in 2000-01 in IGP, saved 7ML diesel, and savings in water can fill a lake of 5 km² to a depth of 100 m.
Environmentally, there are tremendous benefits in terms of greenhouse gas emissions through reduced diesel use and less burning of residues. It is estimated that if zero-tillage is adopted on 1 million ha of the 13.5 million ha under rice-wheat systems in South Asia, CO$_2$ emissions could be reduced by 0.26 million tonnes.

**Reduced-till systems**

Reduced-till system combines the tillage done by a rotovator with seeding. Planting is done in a single pass. Reduced tilling and seeding can be accomplished both by the 2-wheel and 4-wheel tractors. In this system the entire swath of soil is rotovated while in others some of the rotovator blades are removed and only a strip is cultivated and planted. This system is being promoted in the sandy soils of NW India using a strip-till drill on a 4-wheel tractor developed by Punjab Agricultural University, Ludhiana, India and in Eastern IGP areas using a power tiller (2-wheel tractor implement). As an alternative to rotovator seeder, farmers also practice drilling of wheat after one or two tillage operations and planking compared to five to eight operations done in the traditional system of field preparation for sowing of wheat.

*Farmers discussing about the benefits of implements used in reduced-till systems with 2-wheel and 4-wheel tractors in Bihar, eastern India*
Reduced-till system has an advantage in the Eastern areas where rice weeds tend to carryover to the next wheat crop and interfere with surface seeding. Farmers are also using this system by first broadcasting the seed and then using the rotovator to incorporate the seed into the soil. This works better than the Chinese implement on heavy soils if weeds limit surface seeding. Using reduced-tillage systems, crop can be planted within 7-10 days of rice harvest in just a single power tiller/tractor pass. This technology has eased the burden of the farmers in Nepal Terai, Bihar and parts of Bangladesh. It not only reduces the costs of planting, but also spares the power source for use by other implements including reapers, irrigation pumps, threshers, winnowing fans and trailers for transport. In Bangladesh, farmers own nearly 250 thousand 2-wheel hand tractors for seeding crops with reduced-tillage systems. In order to discourage birds from damaging the unprotected seeds, soaking of seeds in cowdung slurry has proved helpful. Many farmers broadcast wheat seed, directly into rice crop before harvest, giving weeds less chance to sprout. Results of farmers’ participatory trials (Table 7) indicate the effect of tillage and date of seeding on crop productivity.

Table 7. Yield of wheat as influenced by seeding technique and date of seeding in eastern India

<table>
<thead>
<tr>
<th>Seeding method</th>
<th>Seeding date</th>
<th>Grain yield (*Mg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>10-12-1999</td>
<td>2.81</td>
</tr>
<tr>
<td>Surface seeding</td>
<td>10-12-1999</td>
<td>3.33</td>
</tr>
<tr>
<td>Seed broadcast &amp; mixing by Chinese hand tractor</td>
<td>02-12-1999</td>
<td>3.82</td>
</tr>
<tr>
<td>Reduced-tillage</td>
<td>16-12-1999</td>
<td>3.07</td>
</tr>
</tbody>
</table>

(* 1 Mg = 10⁶ g)
**Raised bed-planting system (rice, wheat and other crops)**

The bed-planting technology is growing crops on raised beds and using the beds permanently with consecutive crops which adds to the benefits of zero-till to bed planting and is a more sustainable system. Most research in the RWC has used beds about 70 cm apart (two beds can be made between the two tractor tires). Two to three rows of wheat have been tested. Two rows give the advantage that the weeds can be cultivated between the two rows of wheat, fertilizer can be placed as a top dress application between the rows (increasing efficiency) and there is less lodging. Bed planting also has the advantage of lower seed rates, bolder seed and greater panicle length, an important issue for hybrid seed multiplication programmes.

The main benefit of bed planting is savings in water. Almost all farmers report 30-35 per cent less irrigation time in tube-well irrigated areas and also less crop lodging and possibility of last irrigation to be given. Therefore under high production situations, bed planting exceeds the yields possible on the flat
bed. This technology is gaining popularity in the Consortium countries as it opens up avenues for farmers for diversification and intensification of the cropping systems in the IGP even during the monsoon season. Bed-planting system offers great potential for inter-cropping maize and sugarcane in wheat growing season.

In rice-wheat areas raised beds work best in partially reclaimed alkali soils, low-lying areas where water-logging and weeds are problems, and in cracking soils. Where there is an urgent need for rainwater conservation to prevent receding

*Bed planting: A catalyst for crop diversification (a) Vegetables grown on raised beds, (b) Inter-cropping of wheat and mint, (c) Sugarcane planted in furrows to be covered and wheat sown on beds (Locations in India)*
water-tables and need to increase water-use efficiency dramatically, bed planting is a blessing in disguise. Raised bed prepared from the amended soils increases the depth of rooting zone and improves crop productivity. The technology can be used in at least more than 3 million ha of partially reclaimed or unreclaimed soils with advantage in the northwest IGP.

Wheat crop raised on beds prepared in partially reclaimed alkali soils in India

**Crop establishment options for rice**

Rice in the IGP region has been grown traditionally by raising seedlings in a separate field (nursery) and transplanting them in the main field or through various other means of direct seeding like dry seeding and seeding on the puddled field. These methods are labour intensive and poor in resource-use efficiency. NARS scientists have been working with farmers to generate options for timely establishment of the rice crop. Some of the options are given here:
**Zero-till rice**

One possible sub-system of dry seeded rice could be zero-till rice. In this system, weeds are allowed to germinate and are then controlled with a non-selective herbicide like Glyphosate. A zero-till drill is then used to seed rice. If there is time, weeds that germinate with first showers/light irrigation could be controlled with *shallow plowing* (stale seed bed method) combined with mechanical hand weeding or herbicide use after germination and growth of primed rice seed with zero-till machine in dry/moist soil or seeding of pre-germinated rice seeds in wet or moist soils.

Another version of zero-till rice is practiced in China. The fields after wheat harvest are flooded and the seedlings are transplanted by broadcasting into the softened wet soil after a few days. Continuous use of this system over ten years in China gave good production and weeds got reduced over time. This system reduces the cost of land preparation. It is also becoming popular in other countries of South Asia.

**Bed planting**

Very encouraging results have been obtained with transplanting or direct seeding of rice on raised beds.

In permanent bed planting rice-wheat system, the savings in irrigation water could be anywhere around 35-40 per cent and more if the technology is combined with field leveling and better farm layouts. Crop lodging is less in bed planted crops. Farmers already like transplanting of rice on beds used for growing wheat.

**Parachute planting/seedling broadcasting**

In parachute technique of planting rice, main field is properly puddled or irrigated several days before planting. Separately, rice seedlings are grown in bubbled plastic sheets. The sheets
(a) Rice crop established on the raised beds by transplanting at Karnal,

(b) Direct seeded rice, at Ghaziabad, India
contain small cup type depressions sufficient to hold the seedlings of age ready for transplanting. One to two seeds are placed in each cup holding 5-7 g of soil. The seedlings are allowed to grow for 15-20 days and then separated from the bubbled plastic sheets.

The young seedlings with roots holding a small lump of soil are then broadcasted manually or power blown into puddled or wet fields. Since the soil attached to the roots makes them bottom-heavy, the young seedlings land and anchor into the wet soil just like a parachute. After the seedlings stand erect, depending on the availability of the labour, plant geometry is re-aligned. Realignment facilitates fertilizer application and weeding operations. Scientists in Pakistan are developing technology to reduce the production cost of the plastic bubbled sheet and also increase the life of the sheet.

(a) Chinese method of seedling raising on beds in bubble sheets for healthy seedlings (3-4 tillers in 20 days), (b) Seedling broadcast method into puddled/unpuddled fields
Alignment of seedlings broadcasted with power blower and general look of the crop after establishment

Site-Specific Nutrient Management (SSNM)

Success of on-farm trials
Quantification of the soil’s capacity to supply N, P, and K is essential to increase yields and nutrient-use efficiency. Recent on-farm trials in Rice-Wheat Consortium countries have clearly demonstrated that the indigenous soil supply of N, P, and K
under wheat is much smaller than that measured for rice, besides being highly variable among farms. Therefore, a new concept for specific nutrient management (SSNM) in rice-rice and rice-wheat systems was developed (Dobermann and White, 1999). In the SSNM approach, one has to measure the potential indigenous soil supply of N, P, and K; estimate the reserves without depletion; monitor plant N status during critical periods of rice growth to optimize fertilizer N efficiency using a leaf colour chart developed to save on nitrogen and avoid groundwater pollution in high fertilizer-use regions.

**Leaf colour chart**
The leaf colour chart (LCC) is a good eco-friendly cheap tool in the hands of small farmers to approximately optimize N use, irrespective of the source of N applied - organic, bio-, or chemical fertilizers. It costs about US$1 per piece. It is being introduced to farmers through field researchers, extension staff and private-sector agencies (Balasubramanian et al., 2000). It was observed that 74 per cent of the farmers obtained equal or higher yields
in LCC N-managed trials and saved N on an average 25 kg ha\(^{-1}\) (Table 8). The remaining 26 per cent of farmers affected saving of N but had lower yields due to several reasons. On the whole, farmers like to use the LCC even for the scented rice crop, the current limitation of this technology.

Farmer collaborators provided feedback on the LCC technique, which has the following advantages:

- Inexpensive, simple and easy to use
- Useful in determining the right time of in-season N side-dressing
- Helpful in avoiding too much N application

**Urea super granules**

IRRI collaborates with the USAID-funded and IFDC-executed Agro-based Industries and Technology Development Project (ATDP) in Bangladesh to promote the Urea super granules (USG) technology. The ATDP and Mark Industries (private sector) have perfected a urea briquette machine. By June 2000, more than 540 urea briquette machines had been sold to private entrepreneurs who produced urea briquettes for rice farmers in 45 out of the 64 districts in the country. In Bangladesh, the

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N applied (kg ha(^{-1}))</th>
<th>Grain yield (kg ha(^{-1}))</th>
<th>PFP-N</th>
<th>N saved (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmers’ practice*</td>
<td>149</td>
<td>6359</td>
<td>42.7</td>
<td>–</td>
</tr>
<tr>
<td>LCC-N*</td>
<td>124</td>
<td>6371</td>
<td>51.4</td>
<td>25</td>
</tr>
</tbody>
</table>

* Average of 164 farmer participatory trials in Karnal district conducted by Soil Testing Laboratory, Karnal. PFP-N+ partial factor productivity of N (grain yield per unit of N applied).
cost of urea briquettes is about 10 per cent higher than that of prilled urea. During 1999, more than 100,000 ha of boro rice were fertilized with urea briquettes.

Urea super granules (USG), when placed at 10 cm depth, in puddled soils saves nitrogen up to 25 per cent with no reduction in yield of the rice crop. Farmers' major problem had been the difficulty of manual deep placement of urea briquettes, especially when rice in randomly transplanted by contractual labourers. The hand applicator, developed and widely used in Indonesia, has not found favour with farmers in the Consortium countries. RWC partners have redesigned the fluted roller used for fertilizer application in zero-till/bed-planting machines. The machine has since been modified and now it is possible to deep-place N fertilizers mechanically in just one pass of the machine.
The RWC was convened in response to growing concerns about the sustainability of rice-wheat systems in the Indo-Gangetic Plains. These systems are fundamental to food security, incomes and employment to hundreds of millions of rural and urban poor in South Asia. To meet this goal, the RWC facilitates integrated research to solve rice-wheat system problems, and helps Consortium partners improve their capacity to address them. The principal beneficiaries of the RWC’s research and technology driven agenda, are the hundreds of millions of rural poor living on the approximately 12 million ha of land devoted to rice-wheat systems in the Indo-Gangetic Plains. Finally, it should be recognized that RWC members are also the beneficiaries, as they improve their capacity to identify and solve productivity and sustainability problems. There have been four kinds of results and impacts from the RWC:

- Better understanding of rice-wheat system problems;
- New technologies that address these problems;
- Impacts on farming communities as new technologies take hold; and
- Improved capacity among collaborating institutions to undertake systems research.

**Better understanding of problems**

RWC research has found that resource degradation in rice-wheat systems takes many forms. In addition, there are problems that reduce system productivity, e.g., delayed crop sowing and
inefficient use of water or fertilizers. Many of these problems are interrelated. Soil degradation and system ecology problems tend to be concentrated in areas where farmers practice continuous rice-wheat rotations. Low nutrient and water use efficiency is associated with delayed crop establishment, in turn driven by inappropriate tillage practices. Excessive pumping from wells leads to declining water tables in some areas, while in others inadequate drainage leads to waterlogging and salinity.

New technologies

Tillage and establishment
Timely sowing and good plant stands are crucial for rice-wheat system productivity. Delays in sowing wheat after rice can reduce yields as much as 1.5 per cent per day, while reducing the efficiency of fertilizer and water. RWC scientists have developed and tested various conservation tillage technologies that result in timely sowing, lower production costs, increased productivity, and enhanced soil quality. These new tillage options also open up “space” (time, labour and land) for farmers to experiment with more diverse systems. Work has also started on the rice establishment phase and its effect on total system productivity. Results show that by not puddling rice soils, the next wheat crop does better when established without tillage.

Surface seeding
Surface seeding of wheat onto unplowed, wet soil before harvesting rice has worked well in heavy, poorly drained soils. The technique is particularly relevant to farmers with small land holdings and who have limited or no power sources. In the 1997-98 wheat season, continued rain hampered wheat planting in Nepal. Farmers using surface seeding were able to get their crop planted on time and harvested three to four tonnes of grain per hectare, but farmers who used traditional methods were unable to plant a crop.
**Reduced-tillage sowing**

Using a seed drill locally manufactured in India and Pakistan has significantly reduced production costs, enhanced yields, and generated enthusiasm among farmers in extensive on-farm tests during the past three years. By the year 2001/02, it is estimated that about 250,000 ha of wheat were planted on farmers' fields using the drills, about half each in Pakistan and India. Observations by farmers and scientists include: equal or better yields, fewer weeds, less irrigation water needed for the first irrigation, less leaching of nutrients, and reduced fuel use. The number of private entrepreneurs manufacturing the drills and bed planter has increased from just 3 to more than 20 now within a span of last two years in India and Pakistan. Now more than 6000 machines are available to farmers in India and Pakistan.

**Two-wheel hand tractor**

Another reduced-tillage option, sows wheat into standing rice stubble. Developed in China, the tractor rotovates the soil ahead of the drill. Field trials in Nepal, Bangladesh, and Eastern India have yielded encouraging results. Two-wheel tractors can also be used to power other implements – pumps, threshers, reapers, winnowing fans, and trailers. Nearly 250 thousand 2-wheel tractors are now operating in Bangladesh alone.

**Rice transplanting and dry seeded rice**

In South Asia, transplanting is a predominant method and involves raising seedlings and transplanting them into puddled soil. Puddling destroys physical properties of soils and is increasingly expensive as real rural wages increase. Direct sowing has system benefits and is becoming increasingly attractive. Transplanting of rice on raised beds is a ‘water-wise’ technology, saves irrigation water and promotes *in situ* rainwater conservation and crop diversification.
Integrated pest management

To minimize use of chemicals, the RWC scientists have developed integrated control measures for pests, weeds, and diseases in rice-wheat systems. *Planting wheat in beds* facilitates mechanical weeding and provides good control without the use of herbicides. *Crop diversification* with sunflower, sugarcane and other crops helps reduce losses due to weeds. Stem borers survive in rice crop residue, but *zero-tillage practices* actually help reduce this problem because rice stubble harbours beneficial insects that help control stem borers.

Integrated nutrient management

Long-term experiments on continuous rice-wheat rotations in India and Nepal show evidence of depletion and imbalance in soil nutrients, including micronutrients, and a general reduction in soil organic matter, all or some of which appear linked to stagnating or lower yields. On-farm research to develop *site-specific nutrient management* (SSNM) has focused on: (1) crop nutrient requirements based on an economically efficient yield target; (2) estimation of potential soil supply of N, P and K; and (3) plant N status during critical periods of rice growth. On an average across fields and two consecutive seasons, yield gains from SSNM were about 10 per cent, but can be as large as 15-20 per cent. In farmer participatory trials, use of LCC has been shown to allow a 20-25 per cent reduction in fertilizer applications without affecting rice yields. The technique permits an estimation of leaf nitrogen content at specific stages in plant growth by comparing leaf greenness with a colour chart. In this way, it gives farmers an idea of when to apply fertilizer and how much is needed. Simple colour charts are being introduced to help the farmers better target their fertilizer applications. Soil organic matter dynamics are being studied and monitored in fields with new tillage options, rotations and crop technical innovations.
Regional salt and water balances
Demand for water from the rice-wheat system exceeds that available from rain, canal and groundwater sources. In some areas, farmers use saline/sodic water that can damage the soil. The RWC scientists have initiated research to assess long-term regional hydrologic salt and water balances as influenced by existing and alternate management practices; and as driven by policies (e.g., pricing, common property management). Scientists are using crop growth simulation and risk programming models to evaluate risk-efficient water-use strategies at the district level. Initial results suggest that improved water and energy pricing policies could reduce water use by 25 per cent.

An ecoregional approach to natural resource management
Scientists from IRRI, CIMMYT, and several participating countries are developing tools for land-use planning via a systems research network called SysNet. Their “toolkit” includes simulation and optimization models, and geographic information systems. Alternative land-use scenarios are analyzed to assess development potential and opportunities, as well as trade-offs among agricultural activities and economic and environmental goals, for defined region.

Impacts on farming communities
To date, the most obvious impacts of RWC research on farming communities are through its work on tillage and crop establishment. Through system interactions, however, these impacts potentially affect nutrient management, varietal selection, crop rotations and system diversification, water management, and basin-level water resource quantity and quality. In Bangladesh, small-scale mechanization is creating a revolution in crop production. More than 250 thousand hand tractors are used by farmers in this country today compared to hardly any ten years back. This is speeding up operations, reducing costs and
resulting in higher productivity and input-use efficiency. Similar gains are expected in Nepal as more sets of equipment become accessible to farmers. The next step is local manufacture of the reduced-tillage/direct seeding implements and other accessories.

Similarly, in the western part of the Indo-Gangetic Plains, rice-wheat area sown with zero-till drills has increased from virtually nothing to around 200,000 ha in Pakistan and India. Given private sector interest in zero-drill manufacture and maintenance, this may be merely the start of a tillage revolution in rice-wheat systems throughout the Indo-Gangetic Plains.

Impacts on collaborating institutions

Probably the most important achievement of the RWC so far is the establishment of regional and national systems for research collaboration, combined with the introduction of new research methods, perspectives and information management tools. This has taken time but has resulted in national programmes having more confidence in the Consortium and seeing it as a bonus and help to their own research programmes. The various discussions and meetings held by the Consortium and the exposure of national scientists to new ideas in these meetings have had an influence on their thinking on how to improve research efficiency in national programmes. For example, the RWC experience influenced the design and development of the World Bank NATP loan project in India.
SECRETS OF SUCCESS

The secret of successful implementation of the resource conserving technologies (RCTs) vis-à-vis transformation of the rice-wheat systems in the Indo-Gangetic Plains (IGP) of South Asia in India, Pakistan, Bangladesh and Nepal is attributable to the management of RWC and its programmes by the Steering and Technical Coordination Committees both at the regional and national levels and excellent support provided by CIMMYT as the convening centre of the Consortium. Some of the key factors responsible for these successes have been listed here as under:

Management factors

- Consortium agenda is driven by the regional NARS.
- Commitment of the Executives of regional NARS, Centres and ARIs.
- Empowerment of national scientists.
- HRD programmes leveraged to Centres’ training programmes.
- Monitoring of programmes at regional and national levels and through external reviews.
- Involvement of private entrepreneurs in production of prototypes and quality machines.
- Incentive and rewards system for the scientists, farmers, entrepreneurs and other stakeholders.
Technical factors

- Demand-driven agenda, prioritized by stakeholders from NARS.
- Use of transect approach for addressing location-specific NRM issues.
- Tillage and crop establishment as the center stage for integration of other thematic activities.
- Use of farmer participatory research approach in conduct of research in system perspective.
- Inter-linkages between projects for cost effectiveness.
- Promote interactions of scientists with private machine manufacturers for development of indigenous prototypes for increased farmer reach for them.
- Research with 'Innovator and Promoter' farmers.
- Technologies co-evolving with agents for change.

Dr Ian Johnson, Chairman, CGIAR presenting the “Award for Outstanding Scientific Partnership” for the year 2000 to the RWC.
The award was received jointly by Dr R.S. Paroda, Director General, ICAR, on behalf of the NARS and Dr Ronald Cantrell, Director General, IRRI, and Prof. Timothy Reeves, Director General, CIMMYT
Dissemination of information/technologies

- Travelling seminars and exchange visits for all stakeholders within and outside the region.
- Promotion of intra-regional/regional interactions between scientists and the farmers and other stakeholders.
- Promotion of ‘Farmer to Farmer’ interactions
- Involvement of line departments in NARS, NGOs and other stakeholders for technology adoption and dissemination.
- Involvement of small and medium farmers in large numbers.
- Making information/knowledge publicly available.
EPILOGUE

Rice and wheat crops contribute to nations’ food and nutritional security and provide substantial feed for the livestock. The rice-wheat systems are fundamental to employment, income and livelihoods for hundreds of millions of rural and urban poor in the Indo-Gangetic Plains (IGP) of South Asia. In the last few decades, high growth rates for foodgrain production (wheat 3.0%, rice 2.3%) in Consortium member countries, have kept pace with population growth (APAARI, 2000). The sustainability of these systems is continuously under threat. Besides, addressing the sustainability concerns of rice-wheat system ecology, there is also a growing realization that the agriculture of the post-Green Revolution era should be guided by the need to produce more of quality food and that too from more of marginal quality land and water resources and sustain environmental quality. The major challenge for the Consortium countries is to develop rice-wheat systems that produce more at less cost, and are more profitable and sustainable. This implies that agriculture in the Consortium countries is now in need of infusion of new technologies that are able to tap new sources of productivity growth.

Tillage options for crop establishment serve both as guideposts for the choice of agronomic and crop-management practices for management of water, nutrient and pest complexes and also helps integrate the thematic issues in system perspectives. Consortium partners in CG Centres have played a catalytic role by working together and in collaboration with the NARS. In
farmer participatory mode, the Consortium has been successful in generating options for establishment and management of crops and natural resources, and diversification of rice-wheat systems. Raised bed planting of crops is not only a 'water-wise' system but also facilitates diversification and intensification of agriculture. A permanent system of bed planting of crops may even prove helpful in sustaining the sugarcane crop in Bangladesh, and create additional sources of productivity growth for wheat, maize and several other crops besides resolving conflicts between farmers and industry (higher cane yield/time vs. sugar recovery). Resource conserving technologies (RCTs) are contributing to increased agricultural productivity at less cost, improved livelihoods for vulnerable populations and improving the environmental quality. Consortium is making these practices/technologies publicly available through publications and speedy dissemination of information at http://www.rwc-prism.cgiar.org/.
BIBLIOGRAPHY


