The Rice–Wheat Consortium (RWC) is a CGIAR ecoregional program that has the following goal:

Strengthen existing linkages and partnerships with national research programs (NARSs), other international centers, advanced institutions and the private sector working in the region to develop and deploy more efficient, productive and sustainable technologies for the diverse rice–wheat production systems of the Indo-Gangetic Plains (IGP) so as to produce more food at less cost and improve livelihoods of those involved with agriculture and eventual decrease poverty.

The consortium was established in 1994 to deal with the rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) (RW) farming systems practiced extensively in the Indo-Gangetic Plains (IGP) and Himalayan midhills of South Asia. These RW systems are one of the most important cropping systems in South Asia for food production, and millions of farmers depend on it for their livelihoods. Since almost as much area is devoted to RW systems in China, they represent one of the major farming systems in the world. This chapter provides information on...
various aspects of these systems in relation to no-till farming to acquaint readers
with background information for better understanding the other contributions to
this volume.

I. THE INDO-GANGETIC PLAINS

The IGP is a large ecoregion in South Asia with some of the most productive
farmland in the world because of its fertile soils, favorable climate, and the avail-
ability of irrigation water (Fig. 1). The IGP occupies nearly one-sixth of the total
geographical area of the Indian subcontinent and is home to nearly 42% of the
total population of 1.3 billion of South Asia. The population is increasing at about
2% per year, meaning that 26 million more mouths need to be fed each year.
The RW systems are practiced on nearly 13.5 million ha in South Asia (Ladha
et al., 2000) with another 12 m ha in China. In South Asia, these systems are
used on almost one sixth of the cultivated area, and they produce more than 45%
of the region’s total food. Demand for rice and wheat is expected to grow at
2.5% per year over the next 20 years. Meeting this demand will become increas-
ingly more difficult as the per capita rice–wheat growing area has already shrunk
from 1200 m² in 1961 to less than 700 m² in 2001. Future food production growth
will have to come from sustainable and profitable yield increases.

The IGPs are a relatively homogeneous ecological region in terms of vegeta-
tion but can be subdivided into five broad transects — the Trans IGP (shown in
Fig. 1 as region 1 in Pakistan and region 2 in the Indian Punjab and Haryana);
the Upper IGP (region 3); the Middle IGP (region 4); and the Lower IGP, part
of region 4 in eastern India, and region 5 in Bangladesh (Fig. 1). These transects
have been delineated based on factors such as the increasing demand for food, the
development of ground- and surface water, infrastructure for inputs and research
institutions, variables driving agricultural development, factors that affect the
expansion of the rice–wheat area, and productivity constraints.

The climate of the IGP ranges from semi-arid in the west to subhumid in
the east, with a distinct wet monsoon summer season and a dry, cool winter
season. This allows rice and wheat to be grown in a double cropping pattern within
one calendar year, rice in the summer and wheat in the winter. Temperatures
can exceed 45°C in the summer, as well as frost in some areas in the winter.
Evapotranspiration exceeds precipitation in the dry season and even in some
parts in the wet season (especially in the semi-arid areas of the west), making
supplemental irrigation necessary for crop production. The IGP was developed
with extensive canal irrigation systems using water storage reservoirs in the Him-
layan midhills. Canal irrigation is supplemented with tubewell water, and most
of the rice–wheat areas are irrigated or partially irrigated.

Twenty percent of the soils are alluvium derived as a result of the deposition
of the Indus and Ganges river systems. Many of the soils are alkaline in pH,
Although acid soils are also present in the piedmont and some floodplains with acidic geology. Soils range in texture from loamy sands to silty clay loams.

The rice–wheat cropping system does not grow only rice and wheat. The cropping patterns are many and varied, with at least two and sometimes three or more crops grown in any one calendar year (Fig. 2). The triple and more intensive cropping patterns are found in transects 4 and 5 in the east, where average temperatures are warmer than in the west. There are many fields where farmers grow continuous rice–wheat, but in many cases, rotations break this continuous cereal system. Sugarcane, for example, is used in rotation with rice and wheat in parts of the IGP where it occupies the land for two or more years before returning to rice and wheat.

The high population density of the region and the fact that agriculture is the main form of employment and income mean that farm size is relatively small.
There are some larger farmers in the area, and some of these use tenants to crop their land. Many farmers crop less than one hectare of land, and many of these have to rely on off-farm employment to feed their families. Small landholders also lease out extra land to farm.

Mechanization has increased gradually from west to east over the last 30 years. Small four-wheeled tractors (35 hp mainly) in NW India and Pakistan do most of the land preparation, with farmers who do not own tractors renting them from service providers. In the east, many farmers still rely on animal power for land preparation. This is also changing since it is becoming expensive to keep a pair of bullocks year-round just for this purpose. Two-wheeled tractors are becoming popular on small farms in Bangladesh. There is also the issue of status, as the use of tractors gives higher status than the use of animals.

Many of the other farm operations like rice transplanting, weeding, fertilizer application, harvesting, and threshing are done manually. However, combine harvesters are becoming popular in NW India and Pakistan, and wheat thresher have spread from west to east over the past 20 years. Labor constraints, especially
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at key times like planting and harvesting, are gradually becoming significant, affecting timeliness of operations as industrialization grows. Many younger people shun the drudgery of farming and leave the rural areas for the cities in search of employment. Mechanization is therefore bound to increase to fill this power gap.

II. TRADITIONAL TILLAGE PRACTICES IN THE IGP

The most common practice for establishing rice in the rice–wheat systems of South Asia involves puddling—plowing soils when they are saturated—before transplanting rice seedlings. Puddling benefits rice by reducing water percolation and controlling weeds. However, puddling also results in degraded soil physical properties, particularly for finer-textured soils, and it subsequently creates difficulties in terms of providing good soil tilth for wheat. It also promotes the formation of a plow pan, which affects rooting depth in the next crop. This conflicting soil management situation is unique to the rice–wheat cropping system.

The implement most frequently used for preparing the soil with tractor power is either a nine-tine cultivator or a disk harrow. Deep plowing with a moldboard or disk plow is rare. With animal power a wooden plow with a metal tip is used. Although tractors allow land to be prepared more rapidly for wheat after rice, farmers still make many passes of plowing and planking: Six to eight passes with the plowing implement are common, usually followed by planking (leveling of the field using a wooden plank). Table 1 illustrates the time and number of operations for plowing in several areas of the IGP based on diagnostic surveys conducted at selected locations.

Table 1  Data on Tillage and Crop Establishment from Diagnostic Surveys of Selected Rice–Wheat Cropping Systems, South Asia

<table>
<thead>
<tr>
<th>Location</th>
<th>Area planted late (%)</th>
<th>Turnaround time (days)</th>
<th>Average number of passes with plow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punjab, Pakistan</td>
<td>40</td>
<td>2–10</td>
<td>2–10 (6)</td>
</tr>
<tr>
<td>Pantnagar, India</td>
<td>35</td>
<td>15–20</td>
<td>5–12 (8)</td>
</tr>
<tr>
<td>Faizabad, India</td>
<td>25</td>
<td>20–45</td>
<td>5–12 (6)</td>
</tr>
<tr>
<td>Haryana, India</td>
<td>25</td>
<td>15–35</td>
<td>4–12 (8)</td>
</tr>
<tr>
<td>Bhairahawa, Nepal</td>
<td>40</td>
<td>15–35</td>
<td>4–8 (6)</td>
</tr>
</tbody>
</table>

Source: Data for Punjab, Pakistan, from Byerlee et al. (1984); for Pantnagar, India, from Hobbs et al. (1991); for Faizabad, India, from Hobbs et al. (1992); for Haryana, India, from Harrington et al. (1993b); and for Bhairahawa, Nepal, from Harrington et al. (1993a).

Note: Late planting is defined as wheat planted after the first week of December.
III. NO-TILL FARMING IN THE IGP AND ITS IMPORTANCE
FOR TIMELY PLANTING AND GOOD PLANT STANDS

Late planting is a major problem in most rice–wheat areas of South Asia, except
for the Indian Punjab (Fujisaka et al., 1994). To improve the productivity of the
rice–wheat system, the wheat crop must be planted at the optimal time. The
typical response of wheat to different dates of planting in South Asia, shown in
Figs. 3 and 4, makes the optimum date some time at the end of November, with
a linear decline in yield of 1%–1.5% per day after that (Ortiz-Monasterio et al.,
1994). Although the slope of the line varies by variety and year, all show a decline
regardless of whether they are short- or medium-duration varieties.

Late planting not only reduces yield but also reduces the efficiency of the
inputs applied to the wheat crop. Nitrogen responses are much flatter in plots
planted late compared to those planted at an optimal time (Saunders, 1990). This
means that applying more nitrogen cannot compensate for the decline in yield
due to late planting.

The reasons for late planting of wheat in the rice–wheat system are many
(Fig. 5). An obvious cause of late planting is the late harvest of the preceding
rice crop. Sometimes a short-duration, noncereal third crop will be planted after
rice. In some part of the IGP, farmers grow long-duration, photosensitive, high-
quality basmati rice that matures late. Farmers prefer to grow basmati despite its
lower yields because of its high market value, good straw quality (livestock feed),

Figure 3. The effect of planting date on wheat yields by variety, PAU, Ludhiana, India

Figure 3  The effect of planting date on wheat yields by variety, PAU, Ludhiana, India
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Figure 4. The effect of planting date on wheat yield, 1987–1991

and lower fertilizer requirements. Basmati varieties cannot be readily replaced by a shorter-duration rice variety and thus late rice harvest results. However, in other areas, high-yielding, modern rice varieties are grown, and their planting dates can be manipulated so that wheat planting is not delayed. This is the case in the Indian Punjab, where modern rice varieties are planted early and harvested in early October, and the wheat is planted by the end of October or early November.

The other major cause of late wheat planting is the long turnaround time between rice harvest and wheat planting (Fig. 5). Long turnaround time can be caused by many factors, including excessive time for tillage, soil moisture problems (soil too wet or too dry), lack of animal or mechanical power for plowing, and the priority that farmers place on threshing and handling the rice crop before preparing land for wheat.

In addition to the problem of late planting of wheat is also the problem of poor germination and plant stands. The majority of farmers in IGP plant wheat by broadcasting the seed into plowed land and then incorporating the seed by another plowing. Part of the reason for this is residue management problems in fields following rice. The loose straw and stubbles are raked and clog the seed drills. Broadcast seed results in seed placement at many different depths and into different soil moistures with variable germination as a result.

The problems of late planting and poor plant stand have been addressed in the RWC by promoting various resource-conserving tillage and crop establish-
Figure 5  The most common causes of late wheat planting following rice harvest
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No-till farming is now gaining popularity in all five transects of the IGP as a way to overcome the above timing and plant-stand issues as seen in other chapters.

IV. NO-TILL TECHNIQUES PROMOTED IN THE RWC

A. Surface Seeding

This is the simplest no-till system being promoted (Fig. 6). In this tillage option, wheat seed is placed onto a saturated soil surface without any land preparation. This is a traditional farmer practice for wheat, legumes, and other crops in parts of eastern India, Nepal, and Bangladesh. Wheat or other crop seed is broadcast either before the rice crop is harvested (relay planting) or after harvest. One of the major advantages of surface seeding is that no equipment is needed, and any farmer can easily adopt this practice.

Promotion of surface seeding for planting wheat has been done for several years in areas where the soils are fine-textured and drain poorly, and where land preparation is difficult and often results in a cloddy tilth. These are areas that are mostly in rice-fallow but where sufficient moisture is available to grow a crop and where land preparation is very difficult and costly. It is one technology that can increase crop acreage in the future. The key to success with this system is having the correct soil moisture at seeding time. Too little moisture results in poor germination, and too much moisture can cause the seed to rot. A saturated soil is best. The seeds germinate into the moist soil and roots follow the saturation fringe as it drains down the soil profile. The high soil moisture reduces soil strength and thus eliminates the need for tillage. Once the seed germinates and the root extends into the soil, the root can follow the saturation fringe and still

Figure 6  Seed sprouting on surface of the soil after seeding
get sufficient oxygen for growth. A good crop may even be possible without any additional irrigation.

As long as soil moisture can be manipulated, surface seeding is also successful on coarse-textured soils. There must be enough surface moisture to germinate the seed (soaking the seed before sowing can help), and soil strength at the root penetration stage must be low (moisture-dependent) to allow root growth. This may require an early, light irrigation on coarse-textured soils. Some farmers who relay wheat into the standing rice crop place the cut rice bundles on the ground after harvest. This allows the rice to dry but also acts as mulch, keeping the soil surface moist and ensuring good wheat rooting. In China, where surface seeding is also practiced, farmers apply cut straw to mulch the soil, reduce evaporative losses of moisture, and control weeds. The standing stubble also protects the young seedlings from birds. However, relay planting can be done only if the amount of soil moisture is correct for planting at this stage.

B. No-Till with Inverted-T Openers

No-till is another resource-conserving technology (RCT), where the seed is placed into a soil slit made by a seed drill without prior land preparation (Fig. 7). This technology is presently being tested throughout the IGPs, and it has made substantial gains in NW India and Pakistan. It is estimated that 300,000 ha of no-till wheat were grown in 2002 in the IGP (Fig. 8). In eastern zones, equipment adapted to animal power and two-wheeled hand tractors (Fig. 9) is being developed. However, farmers in this region are even using four-wheeled equipment through contractual services.

The basis for this technology is inverted-T opener equipment (Fig. 10) that was developed and imported from New Zealand to Pakistan by CIMMYT in

![Figure 7](image-url)  
**Figure 7** No-till seeder made in Ludhiana in India
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Figure 8  Trends in wheat no-tillage area rice–wheat systems in India and Pakistan

Figure 9  Modified no-till drill with inverted T openers for two-wheeled hand tractors
1983. This coulter and seeding system places the seed into a narrow slot made by the inverted-T as it is drawn through the soil by the four-wheeled tractor (Fig. 10). The coulters can be rigid or spring-loaded depending on the design and cost of the machine. This type of seed drill works very well in situations where there is little surface residue after rice harvest. This usually occurs after manual harvesting. Using a combine to harvest wheat is becoming popular among farmers in northwestern India and Pakistan. In this combine system, loose straw and residue are commonly left after harvest (Fig. 11). The inverted-T opener does not work as well where combines are used, since the opener acts as a rake for the loose straw. Farmers presently burn residues to overcome this problem (Fig. 11) of loose stubble whether they use no-till or the traditional system. Since the RWC discourages the practice of burning because of its environmental and air pollution impacts, future strategies will look at alternative machinery and techniques to facilitate planting into the residue. Leaving the straw as mulch on the soil surface has not been given much thought in Asian agriculture until now. However, results from rainfed systems and some preliminary results elsewhere in Asia suggest that this may be very beneficial to the establishment and vigor of crops planted with no-till (Sayre, 2000). Studies are needed to explore the benefits and long-term consequences of this approach.

C. Reduced Tillage

Many farmers are reluctant at first to accept that no-till will work. It goes against their experience with farming. Many farmers first try reduced tillage using the same no-till drill described above. In other situations, carryover weeds from the rice crop create problems. A reduced tillage system may be more feasible since
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Figure 11  Surface residue after rice combine harvesting and burning of the residue

The Chinese have developed a seeder for their 12-horsepower, 2-wheeled diesel tractor that prepares the soil and plants the seed in one operation. This system consists of a shallow rotovator followed by a six-row seeding system and a roller for compaction of the soil (Fig. 12). Funding from the Department for International Development (DFID, UK) and CIMMYT made it possible to import several tractors and implements from Nanjing, China, into Nepal, Pakistan, and India in the early 1990s, where they have been tested over the past several years with positive results. In Bangladesh, farmers are using more than 200,000 hand tractors from China in their agriculture.

Soil moisture is a critical factor in this reduced tillage system. The rotovator fluffs up the soil, which then dries out faster than with normal land preparation. The seeding coulter does not place the seed very deep, so soil moisture must be high during seeding to ensure seed germination and root extension before the

Figure 12  The Chinese seeder for the two-wheeled hand tractor
soil dries appreciably. Modifying the seed coulter to place the seed a little deeper would help correct this problem.

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

Engineers are experimenting with removing some of the blades that rototill the soil. In this way, a strip of soil rather than the whole area is cultivated. This reduces the power needs and costs and makes it easier for farmers to manage the tractor. In India, a four-wheeled tractor version of this “strip-tillage” machinery is available in the Punjab (Fig. 13).

Most farmers in Bangladesh do not have the Chinese seeder attachment and instead broadcast seed and fertilizer and then rototill to incorporate. This is popular because it saves time and cost and gives good results. Engineers are also substituting the smaller rotary tines found in the Chinese seeder onto the rototiller that is often provided with the two-wheeled tractor. They will also change the speed gear so that the rototiller can be used to incorporate seed and fertilizer faster with a finer tilth. Interestingly, many farmers prefer this system because they often want to plant at night and cannot see the seed drop in the Chinese seeder.

**Figure 13** A strip till drill blade on machinery made in Punjab, India
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D. Bed Planting

Bed planting is another RCT practice being promoted (Fig. 14). It has many advantages in the RW system, especially in regard to water saving, mechanical weeding possibilities, fertilizer placement, better grain production, and less lodging. When this system is combined with no-till or reduced tillage, the permanent beds may be preferred more by farmers since bed-making costs are reduced. This is the latest RCT activity being researched within the RWC. For this system to be attractive, a permanent bed system would have to be successful for rice as well as wheat even if it provides better drainage and better conditions of growth for nonrice crops in the wet season. Data in the past two years suggest that rice beds is a feasible technology. Rice can be grown either by transplanting or by direct seeding, although the latter system has weed problems that need to be addressed. Farmers in India and Pakistan have obtained up to 9 t/ha of rice on beds and saved 60% of the water needed to grow normal rice. This is confirmed by monitoring farmer fields where this practice is being adopted. Yields might be further enhanced by SRI practices discussed in other chapters in this volume.

V. WHY IS NO-TILL FARMING GAINING POPULARITY IN SOUTH ASIAN RW SYSTEMS?

Subsequent chapters give examples of the benefits of no-till farming in the IGPs, which are enumerated below. The following set of benefits is based on observations and discussions with scientists, farmers, and other stakeholders:

1. No-till significantly reduces costs of production. Farmers estimate this at about 2,500 rupees/ha ($60/ha), mostly due to using less diesel and less labor. Farming has become uneconomic for many farmers
as prices for inputs rise and the prices received for products decline. No-till allows farmers to make a profit.

2. Less tillage means less tractor wear and tear, and less maintenance expense.

3. Earlier, more timely planting is the main reason for the additional yields obtained. No-tilled plots can be planted closer to the optimum date for planting wheat, and the resulting higher yield means more income.

4. The seed and fertilizer drill used with no-till improves germination and plant stands over traditional broadcasting systems and improves fertilizer efficiency through better placement. Less water is used in no-till, and therefore there is less leaching of nitrogen.

5. Because weeds in wheat germinate only after temperatures drop below critical levels, no-till results in less weed emergence because less soil is disturbed. Fewer weeds mean less need for herbicide and lower cost. This is very important in areas where weeds have developed herbicide resistance to commonly available chemicals.

6. It takes less time for water to flow across the field in no-till compared to conventional-till plots for the first irrigation. That means farmers can save on water applications and, just as important, this reduces waterlogging and yellowing of the crop.

7. If surface residue management is combined with no-till, there is no need to burn the residue. This reduces air pollution as well as GHGs emitted into the atmosphere.

8. No-till reduces diesel consumption by 60–80 liters per hectare. This not only saves the foreign exchange for imports but also reduces GHG emissions significantly.

9. With no-till cultivation, anchored residues are left standing. Data show that this promotes the population of beneficial insects since it provides a good habitat for their survival and this reduces insect damage. This effect is enhanced if burning is stopped.

10. No-till means less carbon oxidation during plowing and possibly enhanced carbon sequestration, especially if residue management is good. However, we are not sure what effect the subsequent puddled rice crop has on the soil organic matter dynamics. This is being studied by monitoring farmer fields over time where no-till has been accepted.

VI. PROBLEMS INHIBITING WIDESPREAD ADOPTION OF NO-TILL FARMING

The main constraint to accelerating the adoption of no-till wheat farming in RW systems is people’s mindset and the ability to make farmers aware of the technol-
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Technology and benefits. Examples abound of farmers being ridiculed when they first tried this technology. However, once the crop germinated, other farmers wanted to know how they achieved the results and were convinced that it would work, although many waited until seeing the harvest before making a final conclusion. It is not only by seeing but also by doing that a farmer is convinced. Since his livelihood is dependent on farming, he is not going to change practices unless he can see and do for himself. The RWC is promoting a participatory research approach where we provide the equipment to the farmer so he can experiment with the technology and come to his own conclusions. This is a major change in paradigm compared to the traditional top-down and researcher-demonstration model. Another mechanism that works is to identify service providers, convince them of the utility of no-till, and then provide training. They will then seek business and promote the technology.

Another issue is availability of suitable, good-quality equipment. Most of the no-till drills in the region are made by small-scale manufacturers in simple workshops. In order for the technology to be available to millions of farmers who grow RW, many more machines are needed. This scaling-up is hampering adoption as farmers accept this technology. We are encouraging service providers to help with this issue. Many farmers do not own tractors and get their land plowed on contract. When a service provider gets a no-till drill, he can plant at least 200 acres of no-till per season by contract and maximize the use of each drill. This benefits the farmer and the tractor owner. With a charge of 250 rupees an acre for planting no-till, the operator can pay for the drill in one year. The cost of the drill is about $400. This system means that any farmer, resource-poor or-medium, who does not have a tractor can benefit from this technology.

There is the issue of resistance from those farmers who own tractors and make money by plowing land on contract. One can try to handle this by encouraging these tractor owners to buy a no-till drill and continue to be service providers.

VII. FUTURE RESEARCH ISSUES

Several issues need to be addressed by site-specific research. These are as follows:

1. There is still a need for better no-till equipment that provides more uniform results. This is especially important in areas where combine harvesting leaves loose residues on the field. This will require involving local manufacturers in the program and introducing new, innovative designs.

2. Research is needed on the total farming system. Would the benefits of no-till wheat be better if rice soils were not puddled? Data suggest this may be so, and this could receive benefits from the system of rice intensification (SRI).
3. Monitoring long-term consequences of no-till cultivation is needed to make certain that soil and biotic factors (insects, diseases, weeds, rodents, etc.) are not going to become a future problem.

4. The social issues of no-till farming need to be assessed. Who benefits from the adoption of no-till, and who loses? What happens to the livelihoods of the poor if no-till becomes a common practice?

5. More research is needed on the role of no-till practices on soil organic matter and on soil properties.

6. There is a need to effectively document the effects of no-till cultivation on GHG emissions and its possible impact on global warming.

7. No-till establishment of other crops including rice, legumes, and maize is possible. What happens if both rice and wheat are no-tilled?

8. Permanent bed-planting systems need more research to determine if they are sustainable systems for a whole range of cropping.

VIII. CONCLUSIONS

No-till farming is becoming very popular in the rice–wheat systems of South Asia as farmers struggle to make farming profitable. It provides an opportunity for farmers to grow more food at reduced cost and thus improve their livelihoods. It also has several important benefits in regard to the environment. Several farmers have raised no-till wheat for the past four years without any problems and, in fact, report higher yields. Overcoming age-old prejudices about “more tillage giving better crops” and changing the mindsets of farmers is an important problem. A lack of available, good-quality machinery has also hampered and slowed adoption. However, this is being corrected. A “tillage revolution” is underway in the IGPs that will help maintain food security, improve farmer welfare, and possibly have some demonstrable effect on poverty. However, these gains will be futile unless South Asia can more rapidly reduce its massive population growth.

REFERENCES


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