Evolution and Acceleration of No-till Farming in Rice-Wheat Cropping System of the Indo-Gangetic Plains

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Abstract
The major challenge facing the rice-wheat cropping system in India is to sustain its long-term productivity. There are signs that the productivity and economic gains of this cropping system are consistently becoming smaller. For a populous country like India such a slow down amounts to food insecurity. One reason for the slow down in the growth of wheat productivity during the 1990s was the widespread development of herbicide resistance in *Phalaris minor*. Even though *P. minor* can now be effectively controlled with technologies introduced over the last 5 years, declining soil health has become an important constraint to the productivity of the region. The adoption of resource conservation technologies such as no-till is considered vital for maintaining the productivity of the rice–wheat system. Research undertaken in wheat has clearly shown the capacity of no-till to dramatically reduce production costs for the farmers while maintaining or sometimes increasing wheat yields. Farmer acceptance of no-till technology only became possible through a concerted farmer-participatory research program that was multidisciplinary in nature and had multi-institutional support. This effort has achieved a paradigm shift in tillage and has the makings of another green revolution to sustain the gains of the first green revolution. The introduction of no-till and other resource conservation technologies into the rice phase of the rice–wheat system has the potential to further increase the long-term profitability on Indian farms. This paper reviews no-till development and its impact on weed management, soil properties and farmer profitability in the Indo-Gangetic plains.

Media Summary
No-till technology developed through a collaborative program between the National Agricultural Research System (NARS-NATP), ACIAR, CIMMYT and the Rice-Wheat Consortium will provide long-term sustainability and profitability in the rice-wheat cropping system in India.

Key Words
Herbicide Resistance, no-till, Bed Planting, Rice-Wheat systems, *Phalaris minor*

Introduction
Since the 1960s, there has been a substantial increase in the area sown to rice–wheat (R-W) in South and East Asia, made possible by the development of short-duration cultivars of both species and the expansion of irrigation. Most of the area under this cropping system is located within subtropical to warm-temperate climates, characterised by cool, dry winters, and warm, wet summers. R-W systems extend across the Indo-Gangetic Plains (IGP) into the Himalayan foothills, spanning a vast area from Pakistan's Swat Valley in the north to India's Maharashtra State in the south, and from the mountainous Hindu Kush of Afghanistan in the west to the Brahamputra floodplains of Bangladesh in the east. The IGP is composed of the Indus (areas in Pakistan, and parts of Punjab and Haryana in India) and the Gangetic Plains (UP, Bihar, and West Bengal in India, Nepal and Bangladesh).

The Indus Plains component of the IGP has experienced increasing levels of farm mechanisation over the last 20 years. Cultivation for seed-bed preparation and harvesting in particular is now commonly undertaken with farm machinery. Even growers with small landholdings have access to local contractors who provide mechanised services for these operations. Wheat residue after grain harvest is valued highly for animal feed and therefore presents no difficulty in terms of management for it is largely removed. Rice residues, on the other hand, can be large and are generally not used for animal feed (except Basmati rice). Consequently, rice residues are usually burnt to enable tillage and seeding machinery to work effectively. This large scale burning of rice residue is a major source of CO_2 and air pollution, which is known to aggravate asthma and other respiratory problems in the local population.

As long as the government supports prices of wheat and rice, the profitability of Indian farmers in the IGP is dependent on the rice-wheat cropping system. In the three decades since 1970-71, the annual increase in rice production in the IGP was 4.1%. This rate of increase was much greater than that achieved over the entire Indian rice belt, which increased annually by 2.1% over the same period. The annual rate of increase in wheat production during the same period was 4.4% in the IGP as compared to 3.4% when averaged over the entire country. This increase in wheat and rice production in the IGP was caused by the adoption of rice in the non-traditional rice belt of Punjab and Haryana as well as increased yields due to the technological improvements of the green revolution. There is little scope for further increases in land under rice–wheat, as this has already occurred through the utilization of fallow land, increase in cropping intensity and reclamation of degraded soils. Crops such as coarse grains and pulses have also been replaced by rice and wheat. Increased production over the last three decades can also be attributed to the adoption of high yielding varieties, irrigation, fertilizers, herbicides and mechanization of different farming operations. An analysis of productivity changes and future sources of growth for the rice–wheat cropping system was undertaken by Joshi et al. (2003). According to their analysis, productivity gains have slowed down and there is an urgent need for technologies that can prevent any further reduction in the rate of yield decline in the IGP.

Field monitoring, evaluation and research undertaken in Haryana have identified five key issues relevant to rice wheat productivity that warrant further research effort. These include:

1. **Plant breeding**: conventional breeding is not delivering expected gains in cereal yields and there is a need for varieties with improved pest resistance and greater crop vigour, which may be achieved through hybrid rice technology and/or genetic engineering.
2. **Soil health and nutrient use efficiency**: decline in soil health and fertility has caused a decline in nutrient use efficiency and total factor productivity.
3. **Pest and weed management**: increased incidence of pests, diseases and weeds especially in the high productivity zones and evolution of problems such as herbicide resistance.
4. **Water use**: irrigation, which has been instrumental in enabling intensification of agriculture, is impaired by lack of maintenance. Water tables in some areas have increased while water tables have receded in other areas to alarming extents. Salinity and alkalinity problems are also becoming more serious.
5. **Rising labour costs**: farm labour costs are rising rapidly while commodity prices are relatively stable. This trend is having serious effects on farm sector profitability.

The traditional farming system in the IGP is heavily reliant on tillage to prepare a fine seed-bed for wheat. The importance of intensive tillage for achieving high productivity is an entrenched local practice. There is an expectation in the farming community that a 'good' farmer should plough the land many times to achieve a fine seed-bed. Such thinking is reflected in the results of a farmer survey in Haryana, which showed that on average farmers cultivate their fields 8 times before planting wheat (Figure 1). This pre-sowing land preparation starts with an irrigation followed by a series of cultivation and planking operations.

Herbicide resistance, a threat to productivity in the IGP

In the mid 1990s, the productivity of wheat in states like Haryana and Punjab started to stagnate due to the widespread problem of herbicide resistance. Profitability of cropping was being seriously affected by the failure of wheat crops on many farms. This problem had the potential to make the rice-wheat cropping system unsustainable in the region. The causes of stagnation in productivity of this cropping system have been highlighted in previous reports (Harrington et al. 1992; Malik and Singh 1995; Malik et al. 1998).

The herbicide isoproturon was recommended for *P. minor* control in late 1970s and continued to work well for nearly 20 years. However, its repeated use eventually resulted in the evolution of resistance to this herbicide and cross-resistance to other substituted urea herbicides such as methabenzthiazuron and metoxuron. In areas affected by resistance, wheat yields were showing serious reductions in the early- to mid-1990s. Many growers were forced to harvest their wheat crops at anthesis for stock feed. However, the introduction of three new herbicides (clodinafop, fenoxaprop and sulfosulfuron) in 1997-98 and supporting technologies (eg. no-till) that enabled their ready adoption by the growers turned this trend around and wheat yields showed the first sign of increase in 1999-2000 (Figure 2; Malik et al. 2002). As seen in Figure 2, wheat yields in areas affected by herbicide resistance had stagnated at around 3.5 t/ha, which was slightly below the average yields in areas where resistance in *P. minor* had not become a problem. In these resistance-affected areas, first signs of yield improvements were only seen after the introduction of the new herbicide chemistry that could control this weed effectively and then the yields climbed up to 4.1 t/ha. In contrast, average yield increase in areas not affected by resistance has been much more modest (0.1 t as compared to 0.9 t/ha).

The local cropping system is highly intensive (2-3 crops per year) and lacks diversity in crops and herbicides being used. Both of these factors increase the risk of development of resistance to the new herbicides. Monitoring of resistance is now undertaken on an ongoing basis at several permanent sites and there are already signs of resistance to fenoxaprop in some of these locations (Yadav et al. 2002).

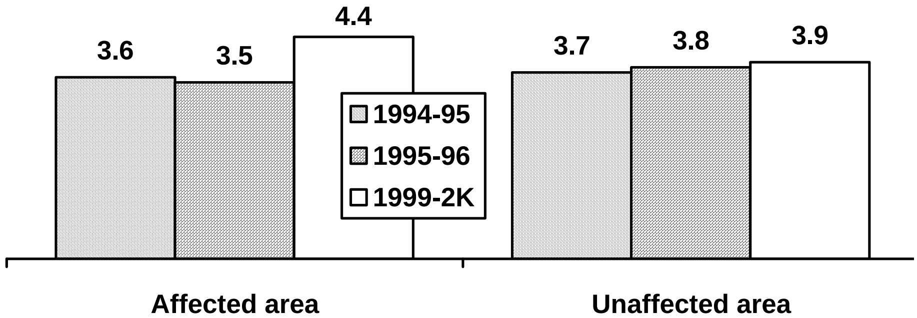

Figure 2. Average wheat grain yield (t/ha) in resistance-affected and unaffected areas of Haryana, India.

The no-till revolution

At this point it is important to reflect on why no-till became a core component of the collaborative herbicide resistance management initiative funded by the Australian Centre for International Agricultural Research. Previous research had shown that *Phalaris minor* germination is retarded by ambient maximum temperature of $\geq 30^oC$ (Singh and Dhawan 1976). Therefore, early planting offered an opportunity to enhance the competitive ability of wheat against *P. minor*, giving it a substantial head-start (2-4 weeks) over the weed. Such a strategy would require wheat to be planted in late October or early November. This is not feasible under conventional tillage systems.

The concept of no-till was not new to the IGP and the technology had been tried previously but set aside as it did not 'fit' the local farming systems. However, in the(late 1990s there was a key difference - rampant herbicide-resistant *P. minor* was seriously limiting productivity in one of the most productive agricultural regions in India, if not the world. Consequently, no reasonable management option could be overlooked, including no-till. Due to the seriousness and the scale of the problem, scientists engaged in this program were supported by bodies such as ACIAR, CIMMYT and the Rice-Wheat Consortium (RWC), which had also been attempting to introduce reduced tillage systems in this region. Although new herbicides have been the most important tool in the management of herbicide-resistant *P. minor*, their rapid adoption was facilitated by the reduction in the cost of cropping brought about by no-till.

The local no-till system

The basis of the no-till technology is the inverted-T openers that were developed in New Zealand and imported by CIMMYT to Pakistan in 1983 and into India in 1988. The 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-wheel tractor. 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. In fields that have been harvested with a combine, it is common to burn loose surface residue prior to the seeding operation. After the initial modifications to the seeder at Pantnagar, several local companies took up the manufacture of the no-till seeder.

The major benefits from the adoption of no-till in the IGP are briefly discussed below.

Fuel and labour saving
A major driver for no-till adoption was the excessive and rapidly increasing cost of tillage itself. A farmer survey in 1998 in Haryana showed that farmers on average were undertaking 8 pre-sowing tillage operations before planting wheat (Figure 1). The rising cost of diesel fuel in India meant that these farmers engaged in conventional tillage were spending around US$20/ha on pre-sowing tillage operations. System analysis undertaken at that time identified this as a real opportunity for reducing crop establishment costs. These savings could make it feasible for these resource poor farmers to adopt the more expensive new herbicides that were becoming available and had been shown to effectively control resistant *P. minor* populations. This combination of the adoption of new herbicides and early sowing, made possible by savings in crop establishment costs under no-till, has been the key ingredient in the effective management of herbicide resistant *P. minor* in the IGP.

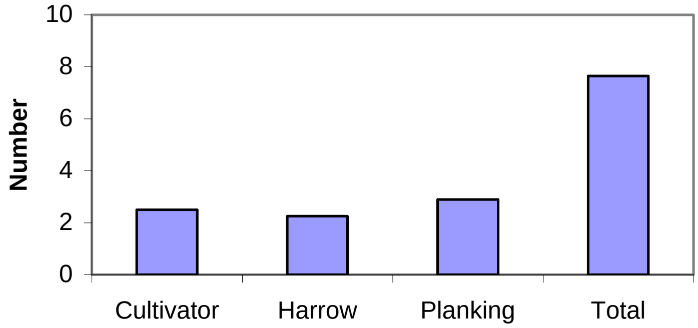

Figure 1. Number of tillage operations ahead of planting wheat after rice, based on a farmer survey in Haryana in 1998 (n=40).

Phalaris population under no-till
The combination of reduced soil disturbance and warmer ambient temperature due to earlier sowing under no-till invariably gave lower in-crop *P. minor* densities and similar or higher wheat yields. The effect of tillage systems in combination with the alternative herbicides over a five year period at six different sites in Haryana is presented in Figure 3. Although *P. minor* infestations declined over time in response to the use of alternative herbicides under both tillage systems, weed densities were consistently lower under no-till. Over the duration of this study, *P. minor* density declined from around 1400 plants/m^2 to around 16 plants/m^2 under no-till (Figure 3).

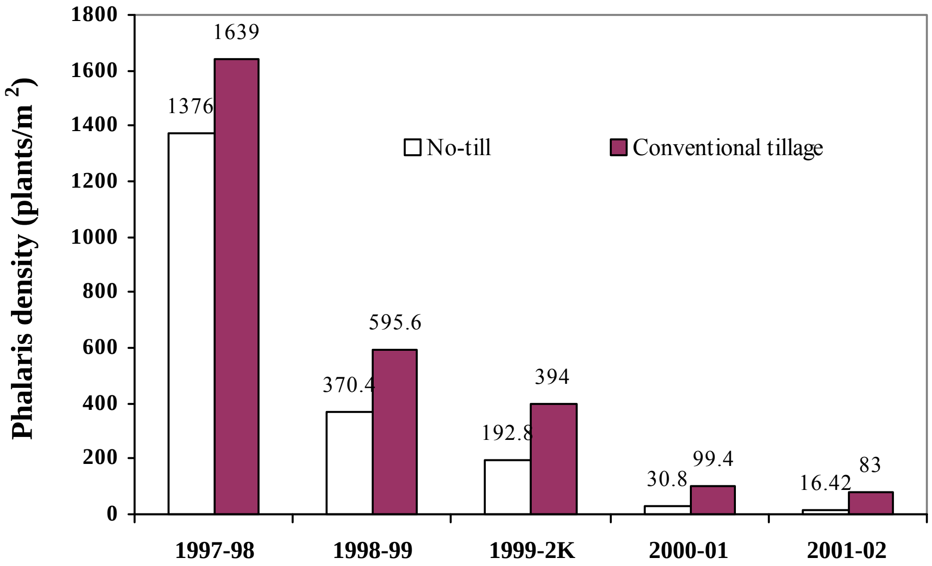

Figure 3. Density of *P. minor* under continuous no-till and continuous conventional tillage wheat, both with annual grass herbicide, and grown in rotation with puddled rice, averaged over six long-term sites in Haryana.

Wheat yield under no-till
Many on-farm comparative studies in Haryana have shown that the combination of no-till with earlier sowing can improve the profitability of wheat production. Due to the absence of tillage operations under no-till, farmers can plant their wheat crops early. Time taken by the various tillage operations after rice harvesting is considered to be the main cause of late planting of wheat under conventional tillage. Late planting of wheat affects input use efficiency and flattens the nitrogen response curves as well as reducing overall crop yield (Saunders 1990). Yield increases of the order of 30 kg/day/ha may be attained with timely sowing allowing large-scale productivity gains across many parts of India.

Some concerns have been raised about the long-term effects of no-till on the biotic and abiotic properties of the soil. The uncertainty of long-term effects is unlikely to disappear until its long-term effects are demonstrated by local research undertaken on farmer fields. Scientists at the Haryana Agricultural University established long-term sites under no-till under the ACIAR-funded project (Figure 4) which are now being managed under the NATP project of the Indian Council of Agricultural Research (ICAR). Studies conducted so far have shown that after six years at these permanent sites, wheat yields under no-till are consistently greater than under the conventional tillage system (Figure 4). At all of these sites, the planting time for the two tillage systems was either the same or the conventional was sown no more than 4-7 days later than the no-till. No-till technology appears to have solved several problems without creating any new ones.

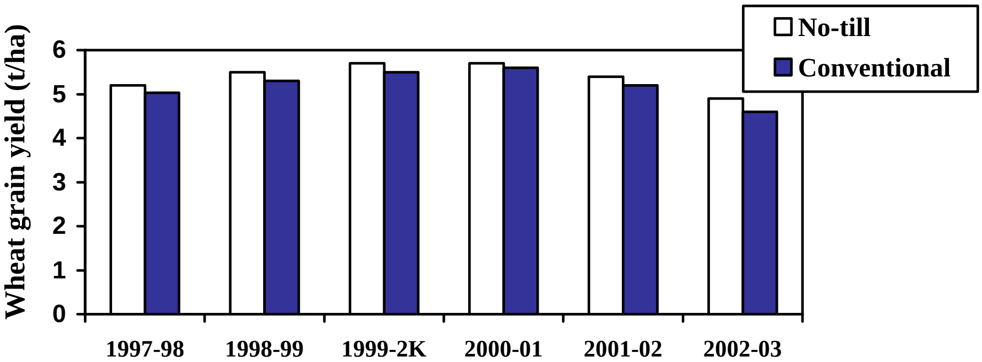

Figure 4. Grain yield of wheat grown in rotation with puddled rice and averaged over 6 long-term sites under continuous no-till and continuous conventional tillage in Haryana (India).

Effect of no-till on soil properties
The effect of continuous no-till and conventional tillage in wheat on soil physico-chemical properties was studied at the six long-term tillage sites discussed above. These permanent sites had tropical arid brown and seirozem soils (Kumar et al. 2002). The bulk density (BD) of 0-7.5 cm soil depth was greater in no-till as compared to the conventional tillage in the first year (BD 0.12-0.46 t/m^3 higher) and third year (0.08-0.26 t/m^3 higher). There was no detrimental effect of increased bulk density on wheat germination and plant growth. Furthermore, the difference in BD between the two tillage systems tended to diminish with time. The initial and basic water intake rates were higher in conventional tillage (initial rate 6 - 48 mm/ha higher, basic rate 0.41 - 2.11 mm/ha higher) as compared to no-till. Slower water intake in no-till may be a reflection of the destructive influence of puddling in the rice phase. The moisture retention, defined as the moisture content in the 0-15 cm layer of soil at 7 days after first irrigation, was higher in no-till (up to 13.6% higher) as compared to the conventional tillage system. Four years after the start of this multi-site study, organic carbon (%) and available K in the 0-15 cm soil depth were higher in no-till (OC 0.09-0.24% higher, and available K 8-36 kg/ha higher) as compared to conventional tillage (Figure 5). The soil pH, electrical conductivity (1:2 soil:water) and available P were not affected by the tillage treatments. The P contents (%) in wheat plants were higher in no-till (0.05 - 0.1 % higher) as compared to the conventional tillage and this may be related to greater root growth under no-till.

Savings in irrigation water use are also an important feature of no-till systems. The RW Consortium in collaboration with HAU undertook a detailed investigation of the savings in irrigation water use under no-till (Gupta, 2003). Fields under no-till and conventional tillage systems were selected along an irrigation channel in Haryana to determine irrigation water use. Studies showed that irrigation water used was 13-

33% lower in the fields under no-till, which was attributed to lower water infiltration rate under no-till. The overall assessment of irrigation water use by 4 villages in this irrigation scheme showed about 10% saving in water due to the adoption of no-till. Average water use efficiency (kg grain produced/mm water used) was estimated to be 18.3 kg/ha/mm in no-till fields as compared to 12 kg/ha/mm in the conventional tillage fields, an increase of 35%. This improvement in water use efficiency is likely to be related to avoidance of transient water-logging after the first irrigation which is a common feature of wheat crops grown with conventional tillage in rice-wheat rotation. Savings in irrigation water can also arise in some seasons when soil moisture content after rice harvest is adequate to sow wheat without any pre-sowing irrigation.

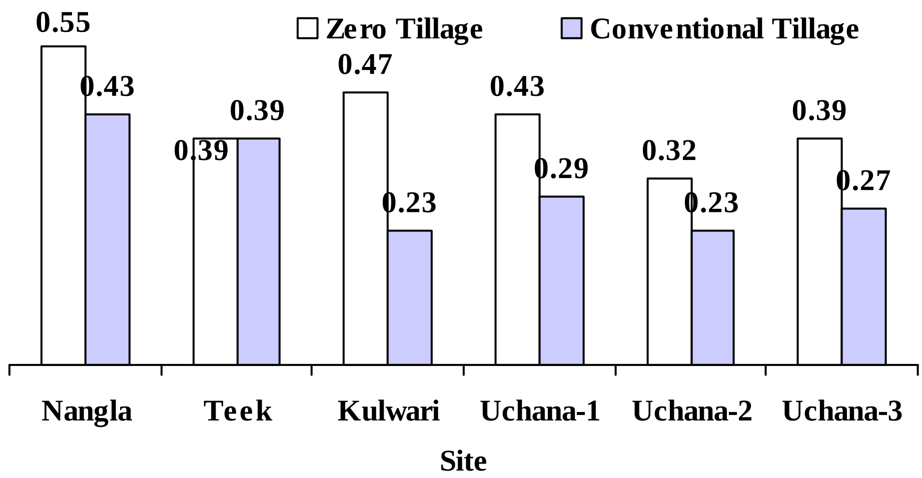

Figure 5. Organic carbon (%) in no-till and conventional tillage in 0-15 cm layer of soil, after 4 years of continuous no-till or continuous conventional tillage wheat.

Effect of no-till on insect and pathogen spectrum

To ensure that the no-till technology serves the long-term interest of farmers and the environment, it is important to establish long-term studies by maintaining permanent sites on farmer fields. So far these studies in Haryana have shown no association between no-till and changes in nematode, insect and fungal populations.

Insect spectrum

In Haryana, Jaipal et al. (2002) studied the effects of tillage practices of sowing wheat on the spectrum of insect species present over 3 years. On-farm sites (n = 24) were sampled every two weeks during the regular growing season of rice and showed the presence of 61 species of insects and spiders. The number of species present was considerably less in the wheat crop. The spectrum of insect fauna present in and around the no-till wheat fields was substantially richer in beneficial fauna than that found in the vicinity of the conventional tillage fields. The rice stubble may have provided shelter to a variety of spiders, ants, earwigs, lady beetles and bugs. These beneficial fauna were also noticed to take refuge in grasses and other weeds growing on the bunds of wheat fields or nearby wastelands. The no-till sites with rice stubble shaved off or burnt *in situ* harboured lower numbers of natural enemies of pests than those with stubble retained. Such fauna in wheat fields sown with conventional tillage or raised-bed methods was, however, almost absent.

Pathogens

Singh et al. (2002) indicated that the population of soil fungi was greater in conventional than no-till fields in Haryana at the Crown Root Initiation (CRI) and dough stage of wheat, while no consistent trend was observed in paddy. *Fusarium* species, *Drechslera rostrata* and *Penicillium* species were predominant fungi in the rhizosphere of wheat and rice. The population of *F. moniliforme* was greater in conventionally sown wheat fields than under no-till. *F. moniliforme*, *F. pallidoroseum*, *D. oryzae* and *D. rostrata* were found to be pathogenic in paddy and *Alternaria triticina* and *Bipolaris sorokiniana* on wheat. There was no significant difference between the tillage systems in the incidence and severity of major diseases of rice-wheat sequence in Haryana.

Effect of no-till on farmer profitability
Faced with ever increasing input costs farmers now consider no-till technology as sustainable and efficient land use. Recent farmer surveys have clearly shown enhanced profitability due to the adoption of no-till (Figure 6). The rapid adoption of no-till is also related to the delivery of benefits to all farmers, irrespective of their land holding. Farmer surveys conducted in Haryana under the ACIAR-project have shown that the benefits from this technology are not dependent on the size of the land holding. In other words, both small and big farmers stand to increase their profitability through the adoption of no-till (Figure 6). Improvements in profitability of the cropping system will be largely responsible for the ongoing demand and adoption of this technology by all categories of farmers.

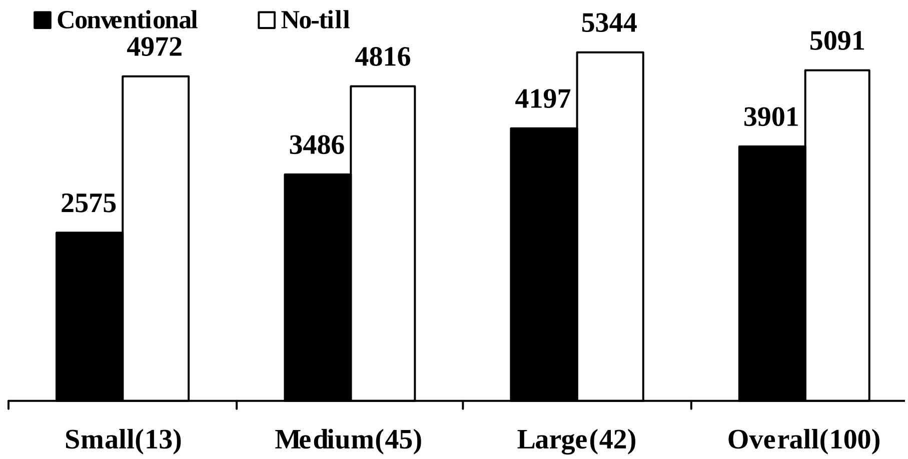

Figure 6. Profitability of wheat (Rs/ha) under conventional and no-till on small, medium and large farms in Haryana.

Expansion of area under no-till
The combination of yield gains and reduced production costs are driving the adoption of no-till by the Indian farmers. During the last three years, the ICAR under its National Agricultural Technology Project (NATP) has also concentrated on resource conservation technologies such as no-till. This has helped in achieving adoption of this technology in western and eastern Uttar Pradesh, Uttranchal and Bihar, states adjoining Haryana and Punjab where original research and development took place (Figure 7). The local farm machinery manufacturers were quick to respond to the challenge of rapidly growing demand for no-till seeding machines and have made a significant contribution to the tillage revolution. These machines sow 8-10 rows, have good seed placement control and can be pulled with an average sized tractor (35 hp). The machinery manufacturers have also collaborated with the local researchers working in the public sector; consequently the quality of the no-till seeders has been steadily improving. Government policy has also contributed to the adoption of no-till. Availability of a subsidy from Haryana and Punjab governments on the purchase of new no-till seeders convinced many growers of the merit of investing in this technology. The convergence of excellent field performance, good quality and affordable machinery and government subsidies have all contributed to the impressive rate of adoption of no-till in the IGP.

In a survey of farmers in Karnal district of Haryana, similar or higher grain yield under no-till as well as fuel and labour savings were given as the three main reasons for the adoption of no-till in wheat (Nagarajan et al. 2002). Other factors considered important in the adoption of no-till by the local farmers included lower *P. minor* infestation, water saving and less lodging of the crop. An impact assessment undertaken by Vincent and Quirke (2002) showed that the Indian economy would gain around A$1800 million in net present value over the next 30 years from the adoption of no-till in the rice-wheat areas of north-western India.

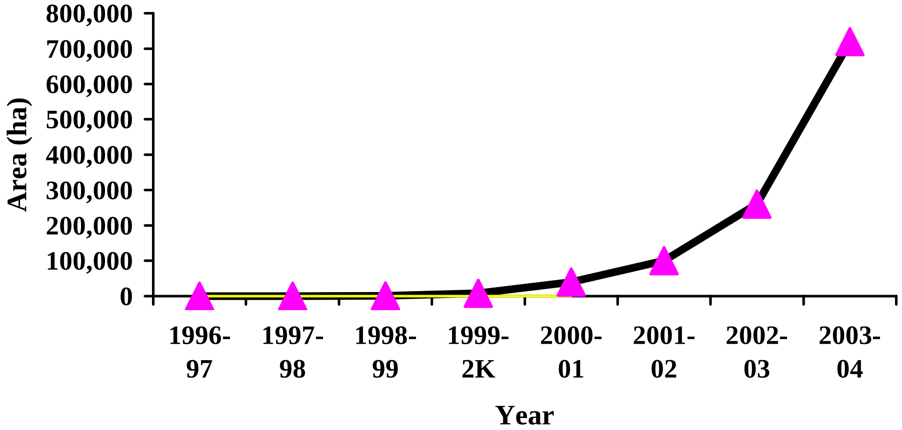

Figure 7. Increase in area under no-till (ha) in India

The research and development campaign on no-till in Haryana has improved the knowledge of local farmers about no-till. Surveys undertaken have also shed some light on the adoption process itself. There were significant differences in the knowledge, attitude and satisfaction between the adopters and non-adopters of no-till (Table 1). It seems that the non-adopters with large holdings are somewhat complacent about the potential benefits of this technology and this attitude may be related to their relative financial security. Ongoing extension programs and greater adoption by their neighbours may eventually achieve adoption in this group but future no-till programs could also specifically target these farmers.

Table 1. Knowledge, attitude and satisfaction from no-till among the adopters and non-adopters of this technology.

	Small[1]	Medium	Large	Overall
	Knowledge (Max. Score = 115)			
Adopters	105.6	108.7	105.9	106.7
Non-adopters	94.4	99.0	55.0	86.4
t-value	2.39*	2.97*	6.58*	5.93*
	Attitude (Max. Score = 95)			
Adopters	90.5	94.6	90.8	90.9
Non-adopters	76.3	75.0	46.6	69.7
t-value	4.30*	9.08*	8.27*	8.92*
	Level of Satisfaction (Max. Score = 95)			
Adopters	83.3	83.2	79.7	81.9
Non-adopters	58.0	83.0	37.0	56.7
t-value	8.14*	0.09	7.57*	10.21*

Knowledge, attitude and levels of satisfaction from no-till technology have been ascertained on the basis of responses on a 5-point scale ranging from strongly agree to strongly disagree. The scores of adopters and non-adopters are the scores obtained by the respondents out of the maximum scores indicated in the table.
Survey was undertaken in villages where no till technology had been introduced. The non-adopters are those who had seen the technology but had not yet adopted it.
[1] Small farmers are those who have operational land holding of <2 ha, while medium and large farmers have operational land holding of 2-4 ha and >4 ha, respectively.

Looking Ahead

Although most of the evidence for the success of no-till presented so far is based on the research and farmer experience in Haryana, there have been other important parallels in other regions. Acceptance of no-till by farmers in the Punjab province of Pakistan has many similarities with the information presented above for Haryana and Indian Punjab. A study by Khan et al. (2001) showed that there was a rapidly growing awareness of the benefits of this technology among the local farmers. Reduced sowing cost and timely planting of wheat were considered two of the major benefits of no-till, a trend similar to that in

Haryana. There was also consistency between the two regions in farmers reporting lower weed infestations and reduced lodging under no-till. According to Khan et al. (2001), positive experience of early adopters of no-till is likely to result in large-scale adoption of this system over the next 3 years. There is emerging evidence that no-till is also gaining acceptance among farmers in the eastern part of the IGP, and over the next few years the area under no-till is expected to increase rapidly in states such as Bihar.

It is fairly likely that two other innovations will soon emerge as part of the resource conservation technologies. Direct seeded rice under no-till and no-till transplanted rice have shown promise in the preliminary work undertaken in Haryana. The success of direct seeded rice depends on the success of weed management. In some places like Bihar, pre-monsoon rain received in June is often inadequate for puddling but can be useful for direct seeding of rice under no-till. Labour and water-shortage are likely to become major constraints to rice production in Haryana and Punjab. Potential benefits from extending the no-till technology into rice are substantial (Piggin et al. 2002). No-till transplanted-rice has been successfully evaluated in Haryana and Punjab on the medium soils and has the potential for large-scale adoption. There are potentially many lessons to be learnt from extensive direct/aerial seeded Australian rice systems. How such systems could be integrated into intensive and high output production systems in India would warrant a major research effort. A starting point in IGP could be the adoption of mechanical transplanting for appropriate soil types. In order to assure the long-term stability of R-W cropping system in the IGP, it is important to target tillage reforms for rice production.

Bed planting in wheat has been successful in achieving up to 30-40% saving in irrigation water but the acceptance of this technology by the local farmers has been low. The significant cost of making beds and then re-shaping them on an ongoing basis has proved to be a major negative in achieving farmer acceptance of this technology in the rice-wheat system. Moreover, bed-planting machinery available at this stage has not shown consistent performance. However, permanent raised beds sown with no till seeders in situations where wheat is rotated with crops other than rice still looks promising. No-till in contrast is a simple technology, which has consistently delivered cost reductions and productivity gains for all farmers irrespective of the size of their land holding.

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