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Conservation Agriculture and Its Applications in South Asia

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Although agriculture is an essential occupation needed to feed the world's population, it often has negative environmental impacts when practiced without regard to the condition of the soils that it depends on. Intensive modern food production systems are often accompanied by numerous adverse impacts on soil systems: loss of soil organic matter (SOM), erosion by wind and/or water, reduced soil biological diversity, physical degradation, poor nutrient-use efficiency, groundwater pollution, declining water tables, salinization and waterlogging, greenhouse gas emissions, with accelerating effects on global warming, air pollution, loss of biodiversity, and decline in factor productivity.

The challenge in the next few decades will be to keep pace with the still-growing demand for food, giving attention to the food security needs of the underfed and undernourished, while adopting technologies that are more efficient at using natural resources and have minimal adverse impacts on the environment. In addition, the profitability of agriculture needs to be increased so that farmers around the world, both better-endowed and resource-poor, can make enough income to improve their livelihoods. This chapter considers a set of innovations grouped under the rubric of conservation agriculture (CA) and how they are being adopted by farmers as a way to achieve these goals. It draws on data presently being generated within rice-wheat rotational farming systems in the Indo-Gangetic Plains of South Asia as an example of what can be done, and what more needs to be done, to ensure sustainable intensive agricultural production**.**

1. CONSERVATION AGRICULTURE DEFINED

Conservation agriculture, a term introduced in the 1970s, was adopted by the U.N. Food and Agriculture Organization (FAO) in Rome in the 1990s (FAO CA web site, 2004). This term has often been used interchangeably with other terms like conservation tillage, no-tillage, zero-tillage, direct seeding/planting, *planto directo*, and *siembra directa*. These share some features with conservation agriculture, but it should be understood as more than just a particular method of cultivation or crop establishment technique. CA is different from conventional agriculture in that it retains crop residues on the soil's surface as a cover, not incorporating them into the soil by tillage. The essential features of conservation agriculture are:

- **Little or no soil disturbance.** The native soil microorganisms and soil fauna and the roots of crops and cover crops take over the tillage function and soil nutrient mobilization and balancing. Mechanical tillage disturbs this process. Therefore, zero-tillage is an essential element of CA.
- **Utilization of green manure cover crops (GMCCs), other cover crops, and residues from previous crops for permanent or semi-permanent organic soil cover.** When cover crops are used, they are cut or otherwise killed so they do not compete with crop plants. The dead-residue biomass functions as mulch, protecting the soil physically from sun, rain and wind and also feeding soil biota. Mineralization and loss of nutrients are reduced, and more satisfactory levels of soil organic matter are built up and maintained. This also moderates soil temperatures in favor of biological activity that is important in tropical and sub-tropical areas.
- **Use of crop rotation to help control pests, diseases, weeds and other biotic factors.** Well-balanced crop rotations can neutralize many of the possibly negative aspects of no-till, such

as pest build-up, as they increase the diversity of favorable insects and organisms that can help maintain checks on the spread and impact of pests and diseases.

- **Use of other integrated pest management principles.** Like IPM, CA enhances biological processes. With conservation agriculture, IPM practices of crop and pest management are expanded into total land husbandry. Indeed, without the use of IPM practices, sufficient build-up of soil biota for biological tillage would not be possible.
- **No burning of crop residues since they are made part of the permanent soil cover.** Air pollution is reduced where burning is stopped.
- **Efficient use and possible reduction in agrochemicals and a definite reduction in the use of fossil fuels.** Use of herbicides such as glyphosate is often increased to handle weed control and cover crop control, but this should be compared to the amount of herbicide and pesticide use of traditional tillage systems. As more experience is gained with rotation systems, it is becoming more common to use biological rather than chemical means of weed and pest control.

The goal of conservation agriculture is agricultural sustainability, conserving, improving and making more efficient use of natural resources through the integrated management of available soil, water and biological resources, combined with judicious use of external inputs. CA contributes to environmental conservation as well as to enhancing and sustaining agricultural production. CA aims to be a more resource-efficient/resource-effective form of agriculture.

2. REASONS FOR REDUCING OR STOPPING TILLAGE

Traditionally, tillage has been recommended as a necessary component of agriculture, serving the following functions:

- Incorporating the residues of the previous crop and any amendments (fertilizers, organic and inorganic) into the soil.
- Preparing a seedbed so that normal seeding equipment can penetrate the soil and place the seed at the proper depth into moist soil.
- Controlling any weeds that have germinated or carried over from the previous crop.
- Helping release nutrients through the mineralization and oxidation of soil organic matter, and
- Giving relief from compaction by breaking up any compaction layers.

These functions are increasingly being questioned, however, by farmers who have experimented with zero-tillage and who are finding that with some adaptation of other practices, tillage may not be necessary. The following comparisons can be made between tillage and zero-tillage systems:

- Tillage done by tractors consumes large quantities of fossil fuels that add to costs while also emitting greenhouse gases (mostly CO_2) and contributing to global warming. Animal tillage is also expensive since farmers have to maintain and feed a pair of animals for a year in order to undertake tillage operations. Zero-tillage reduces these costs and emissions.
- Tillage often delays timely planting of crops, with subsequent reductions in yield potential. By reducing turnaround time to a minimum, zero-tillage can get crops planted on time and thus increase yields without greater input cost.
- Tillage results in decline of soil organic matter due to increased oxidation over time, leading to soil degradation. Although this SOM mineralization liberates nitrogen and can lead to improved yields over the short term, there is always some mineralization of nutrients and loss by leaching into deeper soil layers. This is particularly significant in the tropics where

organic matter reduction is processed more quickly, with low soil carbon levels resulting after only one or two decades of intensive soil tillage. Zero-tillage, on the other hand, especially with permanent soil cover, has been shown to result in a build-up of organic carbon in the surface layers (see Figure 1; and Campbell et al., 1996).

[Figure 1 about here]

- Although tillage does afford some relief from compaction, it is itself a major cause of compaction, especially when repeated passes of a tractor are made to prepare the seedbed or to maintain a clean fallow. Zero-tillage reduces dramatically the number of passes over the land and thus compaction.
- Use of deep-rooted cover crops and biological agents (earthworms, etc.) can also help to relieve compaction under zero-tillage systems. In some cases, higher bulk densities have been reported under zero-tillage (Gantzer and Blake, 1978), which can lead to yield loss, but this can be corrected by using a permanent soil cover (Sayre and Hobbs, 2004). Even when bulk density is higher in some no-till systems, the infiltration of water is higher.
- Tillage leaves the soil bare, and when this is pulverized excessively and exposed to wind and rain, this leads to soil erosion, especially on sloping land. The loss of topsoil results in significant soil degradation. Runoff and erosion start with raindrop impact on a bare soil surface. This disaggregates the soil into finer particles that clog soil pores and create a surface seal that impedes rapid water infiltration. Most of the rainwater then runs off the land carrying precious topsoil with it. Soil crusting can also occur upon drying and restrict seedling emergence. The permanent crop cover with zero-tillage absorbs the energy of the raindrops and allows more infiltration of water, significantly reducing erosion (Lal, 1989). In Paraguay, topsoil losses of 46.5 t/ha have been recorded with conventional tillage on sloping

land after heavy rain compared to 0.1 t/ha under no-till cultivation (Derpsch and Moriya, 1999).

- Tillage disrupts the root channels left by previous crops, with resulting reduction in water infiltration. It also destroys the channels and nests that are built by soil biota, which results in lower soil microbial populations. In zero-tillage systems, more and greater diversity of earthworms, arthropods (acarina, collembolan, insects, etc.), fungi and mycorrhiza are found than under conventional tillage (Kemper and Derpsch, 1981; Clapperton, 2003). Zero-tillage thus results in a better balance of microbes and other organisms and thus in healthier soil.
- An added, economic consideration is that tillage results in more wear-and-tear on machinery and higher maintenance costs for tractors than under zero-tillage systems

3. WHY MAINTAIN PERMANENT SOIL COVER

Conservation agriculture is distinguished from conventional agriculture by the presence of permanent soil cover. The benefits of this essentially complement those from zero-tillage as noted above. Evidence on this from Brazil was already presented in Chapter 22. An example of such cover is shown in Figure 2. Main reasons for the use of groundcover include:

[Figure 2 about here]

- Groundcover increases water infiltration into the soil by negating the energy of raindrops, preventing clogging of soil pores, and allowing percolation of water into the profile. This protects the soil against water and wind erosion.
- Soil mulch reduces water evaporation, conserves moisture, and helps moderate soil temperature, making conditions more hospitable for belowground biota.

- A cover crop helps reduce weed infestation through competition, and also results in weeds being killed at the same time that the cover crop is cut, rolled flat or killed.
- Cover crops contribute to the accumulation of organic matter in the surface soil horizon.
- Mulch also helps with the recycling of nutrients, especially when GMCCs are used, through the association with belowground biological agents and by providing food for microbial populations.
- The presence of the cover crop and minimal soil disturbance leads to an improvement in soil structure and aggregation over time compared to a tilled soil.
- Cover crops and surface mulch help promote biological soil tillage through their rooting but also by support for earthworm, arthropods and microorganisms belowground. Groundcover promotes an increase in biological diversity both below- and aboveground. The numbers of beneficial insects, for example, has been seen to be higher where there is groundcover and mulch (Jaipal et al., 2002).

Not much research has been done in South Asia on belowground changes in soil biota and associated changes in soil physical and chemical properties. However, it is likely that the same kinds of results are occurring with CA as have been documented in the USA. Brady and Weil (2002: 891-892) report the results of comparison trials in two different locations:

- In the Mid-Atlantic States, six pairs of adjacent fields were evaluated. In one field of each pair, conservation practices (reduced tillage, greater crop diversity, rotation and/or organic nutrient sources) had been used, while conventional practices (more tillage, less crop diversity, etc.) were used in the other. An average of measurements made for coastal plain and piedmont soils showed CA practices giving greater microbial biomass C (2.5 vs. 1.8% of total organic C), more total organic C (16.1 vs. 11.9 g kg^{-1}), more active organic C (126 vs.

94 mg kg^{-1}), greater aggregate stability (73.5 vs. 62%), and a higher N mineralization rate constant day^{-1} (40 vs. 34.5) (Islam and Weil, 2000).

- In three locations in the state of Nebraska, conservation practices (crop rotations including legumes, crop residues and manure) were compared with conventional systems (deep plowing and inorganic fertilizers) for continuous maize or maize-soybean rotation. With conservation practices, microbial biomass averaged much higher (928 vs. 590 kg C ha^{-1}) as well as organic C (61.3 vs. 50.4 Mg ha^{-1}) and water holding capacity (0.19 vs. 0.16 m^3 m^{-3}); pH was more neutral (6.43 vs. 5.87), and bulk density was less (1.17 vs. 1.30 Mg m^{-3}) (Liebig and Doran, 1999).

These are the kinds of changes that we expect are occurring in South Asia with conservation agriculture.

4. GLOBAL USE OF CONSERVATION AGRICULTURE

CA is gaining popularity among farmers throughout the world. Although it is difficult to get an accurate estimate of the total area covered, Derpsch and Benites (2003) calculate that in 2002, CA covered 72 million hectares (Table 1). One of the main reasons for this tillage revolution has been the greater profitability of CA over conventional systems as a result of lower input costs (less fossil-fuel use and more efficient input use) coupled in most cases with an increase in yield. The multiple benefits listed above add to the economic and time benefits that have attracted farmers to this technology initially, and they result in more sustainable crop production for the future.

[Table 1 about here]

5. CURRENT FARMING PRACTICES IN SOUTH ASIA

The major cropping system in the Indo-Gangetic Plains (IGP) of South Asia, covering much of North India, Southern Nepal, and major parts of Pakistan and Bangladesh, is alternating rice-wheat, with rice grown in the wet, humid monsoon season and wheat in the dry, cool winter. Tillage has been and still is promoted as an essential component of management of these two crops in South Asia. For rice, the soils are plowed, flooded and then puddled (plowed when wet). This is done to reduce the percolation of water and promote ponding; the standing water helps control weeds. Rice seedlings from separately raised seedbeds are transplanted into the softened soil in the main rice field.

The puddling of rice fields degrades the soil physical properties and probably has significant negative impacts on the biological population. The land requires repeated plowings (more on heavier, finer textured soils) after the rice is harvested to bury the rice residues and to obtain a fine seedbed suitable for planting the next crop, usually wheat. This plowing is costly, consumes large quantities of fossil fuels, emits large quantities of greenhouse gases, and delays the planting of wheat, whose yield is affected by delayed crop establishment. The poor physical condition of the soil leads to poor crop stands and to waterlogging after irrigation, with aeration stress and yellowing of the young wheat plants. All these factors take their toll on yield potential, natural resource use efficiency, and environmental quality.

These standard practices are now being replaced by new practices focused on more ecologically-sound management of plants, soil, water and nutrients, supporting beneficial soil biological processes. The whole concept and practice of CA has not been adopted by all farmers, but the main elements of zero-tillage and maintaining residue cover on the soil are gaining wide acceptance. More comprehensive management strategies are still evolving.

6. ZERO-TILLAGE WHEAT AFTER RICE HARVEST

Zero-tillage was initially introduced into Pakistan in the Indo-Gangetic Plains in 1983 for wheat cultivation. It had been tried in the Indian Punjab in the 1970s but without any substantial adoption because of the non-availability of suitable equipment. A drill imported into Pakistan from Aitchison Industries (New Zealand) changed the attractiveness of zero-till. This equipment worked very well following manual harvesting of rice since the anchored residue (stubble) did not pose any problem; there were no loose residues to entangle the fixed inverted-T openers. A similar drill was imported into India in 1988 to Pantnagar University, and following these original equipment imports, local manufacturers started making drills at much reduced cost, more affordable to farmers.

By 2003, about 1.5 million hectares of wheat were being planted this way in the IGP. There are now 20,000 drills available with farmers made by 68 manufacturers. Zero-tilled wheat saves about 50 liters of diesel ha^{-1}, or 75 million liters annually, worth US$37 million. It also reduces CO_2 emissions by 2 million tons. Farmers have adopted zero-tilled wheat quickly after overcoming their mindsets regarding tillage and after experimenting with the technology in their own fields. They realized that they could get more yield by earlier planting, and the lower cost of production adds to their incomes. There are still some in the Pakistan extension service who remain cautious about using zero-till, but with time, these staff also accept that the technology works well.

Zero-till offered an attractive solution to the problem of late planting. Late planting can be caused by late harvest of the previous rice crop, or by the extensive tillage that farmers must do to convert their physically degraded, puddled rice soil into a suitable seedbed tilth for wheat

(Hobbs and Gupta, 2003). Data from the South Asian region show a 1-1.5% loss in yield potential for every day's delay after the optimum seeding date of November 15. In Pakistan, the majority of the rice grown in the Punjab is a photosensitive, high-quality *basmati* variety that matures in November. Farmers usually make 6-8 passes with a soil tillage implement (disk harrow and/or 9-tyne cultivator) to prepare the seedbed for wheat. This takes 20-30 days and uses 50 liters per hectare of diesel to accomplish. The large quantity of rice residue left in combine-harvested fields (50-60% of the farms are now harvest this way in Pakistan and NW India) creates a problem for the traditional winter-season (*rabi*) wheat drill, and the majority of farmers will burn the loose residue, and instead of drilling wheat, they then sow by broadcast. This creates air pollution problems and poorer plant stands than when seed is drilled.

The approach that worked best for accelerating adoption of zero-till wheat was to supply zero-till drills to innovative farmers and let them experiment in their own fields. As they became more confident about the outcome, they became the best extension channels for the technology to spread to other farmers. Field days and farmer visits were organized to advertise the technology to other farmers.

The main reason given for adoption of zero-tillage since its introduction was the extra yield obtained by planting closer to the optimal sowing time and the cost savings in land preparation and planting (Khan and Hashmi, 2004). Farmers welcome higher yield at less cost. Over time, farmers have realized other environmental and resource-use efficiency benefits. These other benefits have been described in farmer surveys and also by monitoring farmer fields (zero-till vs. conventional paired plots) over time. Emerging assessments include:

1. Higher yields with zero-till compared to normal tilled wheat. A comparison of the yield of zero-tillage wheat and farmers' practice averaged over 6 farmer sites with paired plots

showed a 41% (3.67 vs 2.60 t/ha) increase for zero-tilled plots mainly due to an average 24 days earlier planting in zero-till (Hobbs and Gupta 2003). Similarly, surveys conducted in Pakistan to assess the impact of zero-tillage wheat showed a 13, 16 and 18% increase in zero-till compared to farmer practice in 1991-92, 1995-96 and 2000-01, respectively (Khan and Hashmi, 2004). These data showed an increase in zero-till yields over time, assumed to be a result of increased skill with the zero-tillage drill. In another survey, by the same authors in 2001-02, a 14% increase in yield with zero-till was obtained. In India, similar data showed a 400 kg/ha increase, with 5.2 and 4.8 t/ha yields for zero-till and farmer practice, respectively (Singh et al., 2002). In these permanent plots, yields increased for both zero-tillage and farmer practice with time to 5.4 and 5.1 t/ha, respectively. Improved weed control was suggested as the main reason for this increase.

2. Less irrigation was needed with zero-till wheat, especially less in the first irrigation application. In many cases farmers planted directly after their rice harvest with zero-till, not applying any pre-planting irrigation that is usually needed for conventional tillage. Water savings have been calculated as 10-18% using zero-till over conventional (RWC 2004). There is faster movement of water over the soil surface of zero-till fields compared to plowed ones. Savings in water pumping costs, including fossil fuel use, can add to this benefit. There was also less waterlogging after irrigation and thus less yellowing of young wheat seedlings.
3. Fewer weeds germinated in the zero-till plots because the winter crop weed seeds were exposed less in zero-tilled plots than in tilled ones. If a farmer followed good weed management in zero-tilled plots, using the same herbicide as in conventional plots and preventing the weeds from setting seeds, herbicides were not needed after 4-5 years of zero-tillage (Malik et al., 2004).

4. Farmers observed less lodging in the zero-tilled plots, with improved rooting apparently the main cause of this.
5. By leaving the anchored rice stubble in the field, populations of beneficial insects increased and controlled pests as their habitat was not destroyed by burning or by plowing under the stubble. This could be why there have been no reported outbreaks of rice stemborer in fields using zero-till wheat (Jaipal et al., 2002).
6. Fertilizer efficiency has been increased with zero-till since basal fertilizer can be placed more precisely in a band with the seed drill. In conventional cultivation, the fertilizer is often broadcast and then plowed under because seed drills have difficulty functioning in the loose incorporated stubbles.
7. Plant stands were better and early growth was more vigorous because of the more uniform depth of planting by drill.
8. Environmental benefits have included less air pollution (less burning, although many farmers still do a partial burn) and less greenhouse gas emissions (mostly CO_2) through less use of diesel (Grace et al., 2003).

It took 15 years in Pakistan and 10 years in India to reach significant adoption of the zero-tillage component of CA with wheat. This was mainly because of mindset problems and the fear of failure; CA contravened the conventional wisdom built up over many years about the benefits of tillage. Farmers had to experiment with no-till to convince themselves that it works. Today in South Asia, there is spreading adoption, and farmers are financially better off. A main factor that facilitated extensive adoption was the willingness and availability of local artisans to build the necessary drills. Without such equipment, the success would not have been possible.

7. PERMANENT-BED PLANTING IN RICE-WHEAT SYSTEMS

An improvement upon zero-tillage can come if crops are grown on the ridges of a ridge-and-furrow planting configuration (Sayre and Hobbs, 2004). This is, however, profitable only if farmers shift to a permanent bed system, i.e., zero-tilled crops on raised beds. After the wheat harvest, rice can be either direct-sown on the beds or transplanted onto wet beds. There are many advantages to the bed system:

1. Water savings are in the order of 30-40% using beds compared to wheat grown on flat soil surfaces. Since water will become increasingly a major limiting resource in the future, this is a critical benefit. Farmers in NW Mexico, in the Yaqui valley where CIMMYT undertakes its wheat research in the winter, 90% of the farmers are now growing wheat and other crops on beds because of the limitations of irrigation water (Aquino, 1998).
2. Controlled traffic in the furrows can prevent compaction in the beds. This can be a significant benefit over time, especially in zero-tilled fields. It also results in more compaction at the bottom of the furrow, which restricts vertical water flow (seepage) and helps wet the adjacent beds through better horizontal flow.
3. It offers farmers an alternative to herbicide use for weed control since most weeds can be controlled by mechanical cultivation by driving down the furrows. Herbicide application is also much easier with beds, since nozzles can be prepared to apply the herbicide uniformly over the bed and by using the bed as a guide for the applicator.
4. Similarly, this system offers an opportunity to band basal and top-dress fertilizer applications, instead of broadcasting them, which improves efficiency.
5. The beds permit more diversity in cropping systems during the summer season, as better drainage can be maintained for crops on beds during the wet monsoon period.

6. In addition, permanent beds offer all the other benefits listed above for zero-tillage.

Local manufacturers in India and Pakistan are now making suitable bed formers-cum-planters for practice of this system. There are still some design flaws that need to be corrected, but many farmers have had success in their experiments with this system.

8. CONSERVATION AGRICULTURE IN RICE-WHEAT SYSTEMS

Zero-tillage is just one of the three pillars of conservation agriculture. The others are permanent ground cover and crop rotation. Work is now being done to promote more use of ground cover in the wheat cycle. First, farmers are encouraged to stop burning their loose residues left after combine-harvesting. A lack of seeding implements that allow planting into loose residue is one of the main limitations at the moment, but local engineers and manufacturers are working together to solve this issue. The following are some promising approaches:

1. Manage the crop residues better during combine harvesting; essentially build a mechanism in the combine to chop and evenly spread the straw on the field after it leaves the combine. The presently-used inverted-T opener for seeding is not affected by anchored straw and will have less clogging if the straw is cut into small pieces and spread evenly.
2. Evaluate other systems of planting besides the inverted-T opener. Cutting disks, trash removers, and other systems used in Europe and the U.S. are being tried in South Asia, but the costs of these are still high, and the equipment is heavy and needs bigger tractors.
3. A strip-till system where a rotary blade cuts the residue and forms a narrow strip for planting seed and fertilizer is also being tried. There is a Chinese seeder that comes as an attachment for 2-wheel tractors that is easily adapted for this purpose. These implements are a common power source in eastern regions of the IGP.

4. In Australia, equipment called 'Happy Seeder,' which cuts and picks up the loose straw ahead of the planter, sows the seed without tillage into the soil cleared of straw. The straw that was cut is then blown out behind the straw chopper, being distributed evenly on the ground to form residue mulch. Pakistan engineers are working on a prototype.

Equipment being used in other parts of the world such as South America should be obtained and tested in South Asia. Eventually, prototypes have to be made locally and then mass-produced, fitting the lower horsepower tractors found in Asia. Heavy equipment based on disk-type openers has been tried and is not as popular as the inverted-T opener and other options being promoted by the Rice-Wheat Consortium. Equipment designs used in South America by small-scale farmers may be more suitable to the power systems in Asia.

The cultivation and use of cover crops has not been tried much yet since rice residue leaves considerable biomass. There is also the constraint of time between rice harvest and optimal wheat planting noted above. However, non-photo-sensitive, earlier-maturing rice varieties are now being grown in the Indian Punjab with harvest starting at the end of September. These situations could benefit from the use of a cover crop before planting wheat.

9. ISSUES FOR THE RICE-WHEAT FARMING SYSTEM

The rice-wheat system is a double-cropping system, and in order to obtain the full benefits of CA, the rice cycle should also use zero-till. This will also be a hard mindset for farmers to change. Growing direct-seeded rice without puddling soils has been tried many times in the region, and data suggest that wheat yields after non-puddled rice are higher than after puddled rice (Hobbs et al., 2002). But usually weed growth during the rice cycle has limited the success of this approach. There are a number of issues to be resolved before zero-tilled rice will be acceptable. Many of these are already being researched in a participatory mode with farmers and other stakeholders by RWC partners:

1. **Management of weeds with rice.** Herbicides are probably the simplest way to attain adequate weed control in the early transition years of CA adoption. Hopefully, as weed problems subside over time, these will no longer be needed. The main objective should be to prevent weeds from setting seeds and to use integrated approaches to achieve this. The use of stale seedbeds, where fields are allowed to germinate weeds which are then killed or removed before rice seeding, is one approach. Other integrated methods include use of more competitive rice varieties and selective hand weeding. Many herbicidal products are available for transplanted rice based on many years of testing by rice agronomists. Glyphosate is much less toxic than many herbicides presently used for rice cultivation with quick breakdown on reaching the soil. Persistent use of this herbicide could lead to development of weed resistance, however, as has already occurred with other rice herbicides. With aggressive weed management, the problem should diminish over time.
2. **Development of a suitable planter** for sowing seed into loose residues and placing seeds more precisely at favorable planting depths (rice should be shallow-planted).
3. **Use of cover crops/green manures** between the wheat harvest and rice planting. The GMCC would provide biomass for ground cover and help control weeds. The cover crop could be killed by herbicides, followed by the planting of zero-till rice into the mulch, with no incorporation. Any weeds that germinate along with the cover crop would also be killed. There need to be economic assessments for cover crops to see whether the costs involved are more than the benefits. Data from Parvin et al. (2004) show that no-till cotton following a

wheat cover crop is profitable. In the rice-wheat system, the costs of the seed, planting, nutrients, irrigation and herbicide would all need to be considered.

4. **Selection of more vigorous and competitive aerobic rice varieties.** Most rice grown in South Asia has been selected under puddled, transplanted conditions but for CA, varieties are needed that grow under more aerobic conditions, are more competitive with weeds, and withstand the different insect and disease attacks found under more upland conditions. These are being developed by various agencies, international and national, and should be available for testing under this land management system
5. **Use of crop rotations to help handle weed and other biotic problems.** This would be easier in the wet monsoon season if these crops were planted on beds since waterlogging restricts their use on flat soil surfaces. The discussion of polycropping in Chapter 40 provides some promising data and explanations from China as to how inter-cropping can be practiced within rice-wheat rotations to improve crop performance.
6. **Understanding and using the benefits that can accrue from adopting the system of rice intensification (SRI)**. The increased rice yields achieved with SRI methods, reported in Chapter 28, derive in large part from the deeper, healthier root systems and increased soil biological activity that these methods induce (Uphoff, 2003). These are two factors associated with successful conservation agriculture. Not keeping soils flooded during the rice segment of the rice-wheat rotation would provide more suitable soil conditions for growing wheat afterwards, so there could be indirect benefits for that part of the farming system while achieving more and lower-cost production from the rice cycle. The SRI changes in rice-growing would reduce the requirements for water supply, which is becoming a constraint in some parts of the IGP where the RWS predominates at present. It remains to be seen how

SRI practices will respond to no-tillage, mulch, and non-puddling of rice soils. It is possible that SRI and conservation agriculture could both benefit from combining these strategies for plant, soil, water and nutrient management.

10. DISCUSSION

Conservation agriculture is known to enhance biological activity, but research on this topic is difficult to do and poorly understood. Future research should assess and quantify the impacts of CA on biological populations including species identification and function, how microbial populations check negative outbreaks of pests and diseases, consequences of soil biota for soil physical properties, and their role in nutrient recycling and mineralization. Included in such research would be assessments of the effect of fertilizers, herbicides and pesticides on the viability of the soil biota to give guidance on how these processes can best be enhanced. In the rice-wheat systems of South Asia, introduction of conservation agriculture for entire regions is just beginning. Data are thus not available on the beneficial effects that it will have, if any, on large-scale biological activity. Methodologies are also rudimentary and need to be introduced and refined for such measurements to be taken more easily and accurately.

A question often asked is: how long will it take to obtain the benefits of CA? Also: how sustainable will the benefits be? One of the leaders in the development of conservation agriculture, Rolf Derpsch, has commented (Florentin et al., 2001):

> "In our project in Paraguay we showed that we can regain average productivity on extremely degraded soil in about 3 years when converting to zero tillage and green manure crops (pigeon pea the first year, mucuna the second year) + fertilization, when

about 12 t/ha/year of dry matter (crops + GMCC) are produced. Of course this has been possible in a high rainfall area (1600 mm/year)."

There is very little literature on this topic, and for the rice-wheat system, it may be necessary for all, or almost all farmers to use CA practices before major benefits will be seen. It should be assumed for now that time will be required to obtain full benefits and that there may be a transition period of variable length before farmers see significant positive effects. This should be documented and assessed as more data become available on CA.

Much of present-day agriculture that relies completely on tillage is not sustainable over the long term in more intensive production systems because of significant soil degradation, contributions to global warming, and inefficient use of natural resources. Conservation agriculture has potential to help reduce the negative effects of intensive production agriculture: it reduces soil degradation; helps build up soil organic matter in the surface layers; improves soil physical and biological properties; reduces the use of fossil fuels; and improves the efficiency of inputs. The main impediments to accelerated adoption are mindsets that favor the status quo on tillage and the lack of access to suitable equipment for planting into the permanent soil cover.

Experimentation by farmers with this resource-efficient technology together with scientific research will determine the best set of practices for each eco-region. As reported above, at least 72 million hectares of crops were grown around the world with these methods as of 2002, and this number has been growing each year. Other areas have adopted some aspects of this technology, usually zero-tillage, but permanent soil cover needs to be integrated into farming systems to obtain additional benefits. This is the case in the rice-wheat areas of South Asia where farmers are obtaining higher wheat yields at less cost by adopting zero-tillage.

In the next decade, farmers growing rice and wheat in rotation need to find ways to change the way that rice is grown by adopting a planting system like SRI not reliant on puddling soils since this practice negates many of the positive effects obtained with CA in the wheat cycle. Changes in practice will depend in part on having suitable equipment and finding ways to control weeds and convince the farming community that this new set of practices is preferable. Conservation agriculture has potential to benefit farmers in other agro-ecological and cropping-system zones of Asia. Stakeholders in South Asia need to accept that present practices within their intensive food production systems are not sustainable and that a more environmentally friendly and efficient agriculture is needed to produce the extra food needed for the expanding population, doing this in a sustainable way for the benefit of future generations.

REFERENCES

Aquino P. 1998. The adoption of bed planting of wheat in the Yaqui Valley, Sonora, Mexico. CIMMYT Wheat Special Report No. 17a. CIMMYT, Mexico, DF.

Brady NC, Weil RR. 2002. The Nature and Properties of Soils, 13th ed. Prentice-Hall, Upper Saddle River, NJ.

Campbell CA, McConkey BG, Zentner RP, Selles F, Curtin D. 1996. Long-term effects of tillage and crop rotations on soil organic C and total N in a clay soil in southwestern Saskatchewan. Canadian Journal of Soil Science 76: 395-401.

Clapperton MJ. 2003. Increasing soil biodiversity through conservation agriculture: Managing the soil as a habitat. In: Proceedings of the Second World Congress on Conservation Agriculture: Producing in Harmony with Nature, Iguassu Falls, Parana-Brazil, August 11-15, 2003. Food and Agriculture Organization, Rome, published on CD.

Derpsch R, Moriya K. 1999. Implications of soil preparation as compared to no-tillage on the sustainability of crop production: Experiences from South America. In: Reddy MV, ed, Management of Tropical Agro-Ecosystems and the Beneficial Soil Biota. Science Publishers, Enfield, NH, pp 49-65.

Derpsch R, Benites JR. 2003. Situation of conservation agriculture in the world. In: Proceedings of the Second World Congress on Conservation Agriculture: Producing in Harmony with Nature, Iguassu Falls, Paraná, Brazil, August 11-15, 2003. Food and Agriculture Organization, Rome [CD].

Florentín MA, Peñalva, M, Calegari, A, Derpsch, R. 2001. Abonos verdes y rotación de cultivos en siembra directa. Pequeñas propiedades. In: Proyecto Conservación de Suelos MAG - GTZ, DEAG, San Lorenzo, Paraguay, 84 pp

Gantzer CJ, Blake GR. 1978. Physical characteristics of a La Seur clay loam following no-till and conventional tillage. Agronomy Journal 70: 853-857.

Grace PR, Jain MC, Harrington L, Robertson GP. 2003. The long-term sustainability of the tropical and subtropical rice and wheat system: An environmental perspective. In: Ladha JK, Hill J, Gupta RK, Duxbury J, Buresh RJ, eds, Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts. ASA Special Publication 65. Agronomy Society of America, Madison, WI, pp 27-44.

Hobbs PR, Singh Y, Giri GS, Lauren JG, Duxbury JM. 2002. Direct seeding and reduced tillage options in the rice-wheat systems of the Indo-Gangetic Plains of South Asia. In: Pandey S, Mortimer M, Wade L, Tuong TP, Lopez K, Hardy B, eds, Direct Seeding -- Research Strategies and Opportunities: Proceedings of the International Workshop on Direct Seeding in Asian Rice Systems, Strategic Research Issues and Opportunities, 25-28 January, 2000, Bangkok, Thailand. Philippines: International Rice Research Institute, Los Baños, pp 201-215.

Hobbs PR, Gupta RK. 2003. Resource-conserving technologies for wheat in rice-wheat systems. In: Ladha JK, Hill J, Gupta RK, Duxbury J, Buresh RJ, eds, Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impact. ASA Special Publication 65. Agronomy Society of America, Madison, WI, pp 149-171.

Islam KR, Weil RR. 2000. Soil quality indicator properties in Mid-Atlantis soils as influenced by conservation management. J. Soil Water Cons. 55: 69-78.

Jaipal S, Singh S, Yadav A, Malik RK, Hobbs PR. 2002. Species diversity and population density of macro-fauna of rice-wheat cropping habitat in semi-arid subtropical northwest India in relation to modified tillage practices of wheat sowing. In: Malik RK, Balyan RS, Ashok Yadav, Pahwa, SK. (Eds). Herbicide-Resistance Management and Zero-Tillage in the Rice-Wheat Cropping System: Proceedings of an International Workshop. CCSHA University, Hissar, India, pp 166-171.

Kemper B, Derpsch R. 1981. Results of studies made in 1978 and 1979 to control erosion by cover crops and no-tillage techniques in Paraná, Brazil. Soil and Tillage Research 1: 253-267.

Khan MA, Hashmi NI. 2004. Impact of no-tillage farming on wheat production and resource conservation in the rice-wheat zone of Punjab, Pakistan. In: Lal R, Hobbs PR, Uphoff N, Hansen DO, eds, Sustainable Agriculture and the Rice-Wheat System. Marcel Dekker, New York, pp 219-228.

Lal R. 1989. Conservation tillage for sustainable agriculture: Tropical versus temperate environments. Advances in Agronomy 42: 85-197.

Liebig MA, Doran JW. 1999. Impact of organic production practices on soil quality indicators. J Envir Qual 28: 1601-1609.

Malik RK, Yadav A, Singh S, Sardana PK, Hobbs PR. 2004. No-tillage farming in the rice-wheat cropping system in India. In: Lal R, Hobbs PR, Uphoff N, Hansen DO, eds, Sustainable Agriculture and the Rice-Wheat System. Marcel Dekker, New York, pp 133-146.

Parvin D, Dabney S, Cummings S. 2004. No-till cotton yield response to a wheat cover crop in Mississippi. Online. Crop Management doi:10.1094/CM-2004-0416-01-RS. http://www.plantmanagementnetwork.org/pub/cm/research/2004/cover/

RWC. 2004. RWC Highlights for 2003-2004. See RWC web site.

Sayre KD, Hobbs PR. 2004. The raised-bed system of cultivation for irrigated production conditions. In: Lal R, Hobbs PR, Uphoff N, Hansen DO, eds, Sustainable Agriculture and the Rice-Wheat System. Marcel Dekker, New York, pp 337-355.

Singh S, Yadav A, Malik RK, Singh H. 2002. Long term effect of zero-tillage sowing technique on weed flora and productivity of wheat in rice-wheat cropping zones of the Indo-Gangetic Plains. In: Malik RK, Balyan RS, Yadav A, Pahwa SK, eds, Proceedings of International workshop on Herbicide resistance management and zero-tillage in rice-wheat cropping system. 4-6 March 2002. Haryana Agricultural University, Hisar, India, pp 155-158.

Uphoff N. 2003. Higher yields with fewer external inputs? The System of Rice Intensification and potential contributions to agricultural sustainability. International Journal of Agricultural Sustainability 1: 38-50.

WEB SITES:

FAO Conservation Agriculture -- http://www.fao.org/ag/AGS/agse/main.htm

Rolf Derpsch -- http://www.rolf-derpsch.com/

Conservation Technology Information Center -- http://www.ctic.purdue.edu/CTIC/CTIC.html

Rice-Wheat Consortium (RWC) web site -- http://www.rwc-prism.cgiar.org/rwc

SRI web site -- http://ciifad.cornell.edu/sri/