Conservation Agriculture: What Is It and Why Is It Important for Future Sustainable Food Production?

Peter R. Hobbs

Department Crops and Soil Sciences, Cornell University
Ithaca NY, 14853 USA

Abstract
This paper focuses on conservation agriculture (CA), defined as minimal soil disturbance (no-till) and permanent soil cover (mulch) combined with rotations, as a more sustainable cultivation system for the future. The paper first introduces the reasons for tillage in agriculture and discusses how this age-old agricultural practice is responsible for natural resource and soil degradation. The paper goes on to introduce conservation tillage (CT), a practice that was borne out of the American dust bowl of the 1930s, before comparing CT with CA, a suggested improvement on CT, where no-till, mulch, and rotations significantly improve soil properties (physical, biological, and chemical), and other biotic factors, and enables more efficient use of natural resources. Recent data is presented showing how CA can improve agriculture through improvement in water infiltration and reduced erosion, improved soil surface aggregates, reduced compaction through promotion of biological tillage, increased surface soil organic matter and carbon content, moderated soil temperatures, and weed suppression. CA also helps reduce costs of production, saves time, increases yield through timelier planting, reduces diseases and pests through stimulation of biological diversity, and reduces greenhouse gas emissions. Availability of suitable equipment is a major constraint to successful CA, but advances in design and manufacture of seed drills by local manufacturers is enabling farmers to experiment and accept this technology in many parts of the world. Estimates of farmer adoption of CA are close to 100 million hectares in 2005, indicating that farmers are convinced of the benefits of this technology. The paper concludes that agriculture in the next decade will have to sustainably produce more food from less land through more efficient use of natural resources and with minimal impact on the environment in order to meet growing population demands. This will be a tall order for agricultural scientists, extension personnel, and farmers. Promoting and adopting CA management systems can help meet this complex goal.

Introduction
The challenge for agricultural scientists to increase food production to meet food security needs and more still persists 40 years after the start of the Green Revolution as population growth continues to increase in many developing countries. However, today such production increases must be accomplished sustainably, by minimizing negative environmental effects and, equally important, providing increased income to help improve the livelihoods of those employed in agricultural production. There are several key issues in this equation on which there is almost unanimous consensus.

- The demand for food is still increasing, not only to meet food security for a growing population, but also to provide more nutritious food that makes protein quality, vitamins, and some essential minerals (iron and zinc) more available.

There is also increasing demand for meat products and hence the grains and fodder needed to feed livestock.
- The land available to produce this extra food is shrinking because of urbanization and use of agricultural land for other purposes. Expansion is possible in some parts of the world, but the quality of this new land may be less than that already in use for agriculture.
- Most of the sources of productivity growth used in the last 40 Green Revolution years are already being utilized—improved varieties, fertilizer, and water. Future sources of productivity growth will be more complex and harder to find.
- Competition for water resources, especially surface and groundwater, will be more severe as domestic and industrial needs will compete for it.
- Fossil fuels will be more costly, adding to production costs through higher diesel prices but also higher fertilizer and other input costs.
- Greenhouse gas emissions such as carbon dioxide, methane, and nitrous oxide that have inherent warming effects on the atmosphere will increase with subsequent effects on climate, especially an increase in severe climatic events such as drought, floods, etc.

This will make the challenge more difficult and complex. One obvious way to accomplish this sustainable food production objective is to make more efficient use of the natural resources that are needed to produce food; this includes water, soils, air, inputs, and people. This paper discusses how promotion and adoption of conservation agriculture (CA) by farmers should be considered as one avenue to pursue in meeting the challenge.

Benefits and Problems Associated with Tillage

One agricultural practice that has been adopted by farmers since the move from hunters and gatherers to more settled food production systems ten thousand years ago is tillage. Tillage is the act of disturbing the soil through use of an implement powered manually or by animals or tractors. Other names for tillage include plowing, cultivation, digging, etc. There are many reasons for adopting tillage with some of the main reasons listed below:

- It is used to incorporate the previous crop residues, weeds, or amendments added to the soil, such as inorganic or organic fertilizers.
- It is the first step in the preparation of a seedbed, essentially the name for soil that is prepared to receive the seed of the planted crop. For most seeding systems, manual or tractor powered, some soil loosening and residue management is needed to allow the seed to be placed at a proper depth for germination in the soil.
- It helps aerate the soil organic matter, which in turn helps release and make available to plants nutrients tied up in this important soil component.
- It is a recommended practice for controlling several soil and residue borne diseases and pests, since residue burial and soil disturbance have been shown to help alleviate this problem.
- It provides compaction relief, maybe only temporarily, a physical property of soil that restricts root and water penetration and reduces production.
- Lastly, tillage is aesthetically pleasing in terms of look and smell.

Tillage also has detrimental affects on both the environment and farmers:

- Tillage costs money in the form of fuel for tractors, wear and tear on equipment, and the cost of the operator. If animals are used as the power source, the costs of feeding and caring for the animals over a full year are also high.
- Greenhouse gas emissions from the burning of the diesel fuel add to global warming.
- Soil organic matter is oxidized when it is exposed to the air by tillage with resulting declines, unless organic matter is returned to the soil as residues, compost, or other means.
- Tillage disrupts the pores left by roots and microbial activity. What is less known is what effect this has on below ground soil biology?
- The bare surface exposed after tillage is prone to breakdown of soil aggregates as the energy from raindrops is dissipated. This results in clogging of soil pores, reduced infiltration of water and runoff, which leads to soil erosion. When the surface dries, it crusts and forms a barrier to plant emergence.
- The bare surface after tillage is prone to wind erosion
- The tractor wheels compact the soil below the surface.

Figure 1 is a representation of the negative effects stemming from badly chosen tillage practices.

What Is Conservation Tillage and Agriculture?

One of the more famous results of poor tillage choice is the Dust Bowl of the 1930s in the in the U.S. Great Plains. This resulted from excessive tillage and exposure of soil to wind. The tragic dust storms of that time and place served as a wakeup call about how man's interventions in soil management and plowing can lead to unsustainable agricultural systems. In the 1930s it was estimated that 91 million hectares of land was degraded by severe soil erosion (Utz et al. 1938); this area has been dramatically reduced today. For the next 75

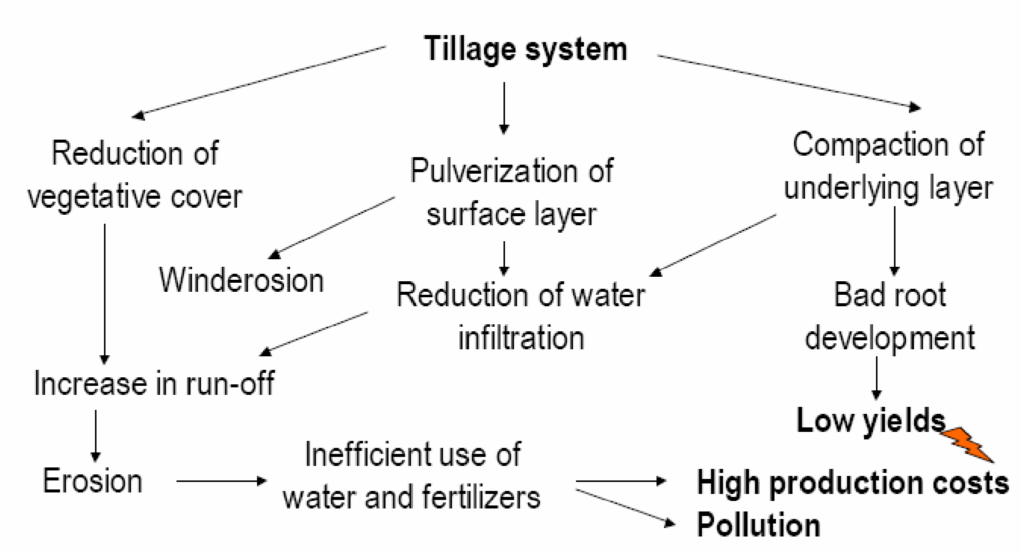


Figure 1. The effects of badly chosen tillage practices.

years, farmers have been adopting conservation tillage practices that reduce tillage and maintain a residue cover on the soil. This is called *conservation tillage* (CT) and is defined as follows:

> "Conservation tillage is the collective umbrella term commonly given to no-tillage, direct-drilling, minimum-tillage and/or ridge-tillage, to denote that the specific practice has a conservation goal of some nature. Usually, the retention of 30% surface cover by residues characterizes the lower limit of classification for conservation-tillage, but other conservation objectives for the practice include conservation of time, fuel, earthworms, soil water, soil structure and nutrients. Thus residue levels alone do not adequately describe all conservation tillage practices." (Baker et al. 2002)

This has led to confusion among the agricultural scientists and, more importantly, the farming community. To add to the confusion, the term conservation agriculture has recently been introduced by the FAO (Food and Agriculture Organization website) and others and its goals defined by FAO as follows:

> "Conservation agriculture (CA) aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. It contributes to environmental conservation as well as to enhanced and sustained agricultural production. It can also be referred to as resource efficient or resource effective agriculture." (FAO)

This encompasses the *sustainable agricultural production* need that all humankind obviously wishes to achieve. But this term is often not distinguished from conservation tillage. FAO mentions in its CA website that

> "Conservation tillage is a set of practices that leave crop residues on the surface which increases water infiltration and reduces erosion. It is a practice used in conventional agriculture to reduce the effects of tillage on soil erosion. However, it still depends on tillage as the structure forming element in the soil. Nevertheless, conservation tillage practices such as zero tillage practices can be transition steps towards Conservation Agriculture."

In other words conservation tillage uses some of the principles of conservation agriculture, but has more soil disturbance. FAO has characterized conservation agriculture as follows:

> "Conservation Agriculture maintains a permanent or semi-permanent organic soil cover. This can be a growing crop or dead mulch. Its function is to protect the soil physically from sun, rain and wind and to

> feed soil biota. The soil micro-organisms and soil fauna take over the tillage function and soil nutrient balancing. Mechanical tillage disturbs this process. Therefore, zero or minimum tillage and direct seeding are important elements of CA. A varied crop rotation is also important to avoid disease and pest problems." (FAO website)

Conservation agriculture does not just mean not tilling the soil and then doing everything else the same. It is a holistic system with interactions among households, crops, and livestock since rotations and residues have many uses within households; the result is a sustainable agriculture system that meets the needs of farmers. The rest of this paper looks at the various benefits of CA in terms of the environment and soil health, some equipment needs, and how CA is being adopted in the world. Note that CA can be done on the flat or on raised beds; in both cases the three pillars of CA are followed. The paper will not indicate which system is used, although other papers at this conference will look specifically at bed planting, which is used to further improve water-use efficiency (Sayre and Hobbs 2004).

Benefits of Conservation Agriculture

The benefits will be looked at in relation to minimal soil disturbance, permanent ground cover, and rotation since they all interact to provide the benefits, which include the following:

a) Yields in the rice-wheat (RW) systems of the Indo-Gangetic Plains in South Asia are higher with no-till because of timelier planting and better stands. Yields of 200-500 kg/ha are found with no-till wheat in this system (Hobbs and Gupta 2004). Yield gains are also reported in other systems.
b) One of the major benefits of CA, which makes it popular with farmers, is it costs less in terms of money but also time. Once again in the RW systems of South Asia (Hobbs and Gupta 2004), no-till wheat significantly reduced the costs of production; farmers estimate this at about 2,500 rupees/ha (US$ 60/ha), mostly due to using less diesel fuel, less labor, and less pumping of water. Since planting can be accomplished in one pass of the seed drill, time for planting was also reduced, thus freeing farmers to do other productive work.
c) Water-use efficiency increased in the RW system because often the first irrigation could be dispensed with, and when the first irrigation was given the water flowed faster across the field. Water savings of 15-50% have been calculated with the greater savings occurring when crops are planted on beds. Other systems using no-till and permanent ground cover show reduced water runoff (Figure 2), better water infiltration (Figure 3), and more water in the soil profile throughout the growing period (Figure 4).

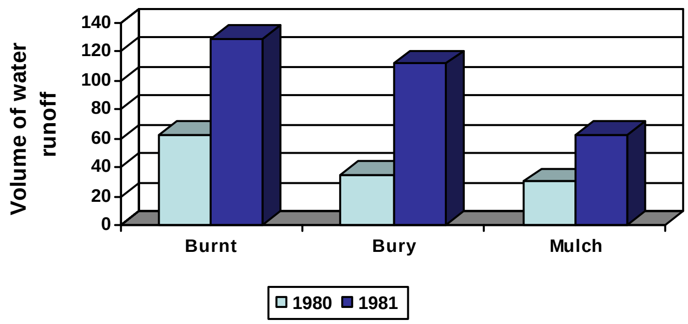
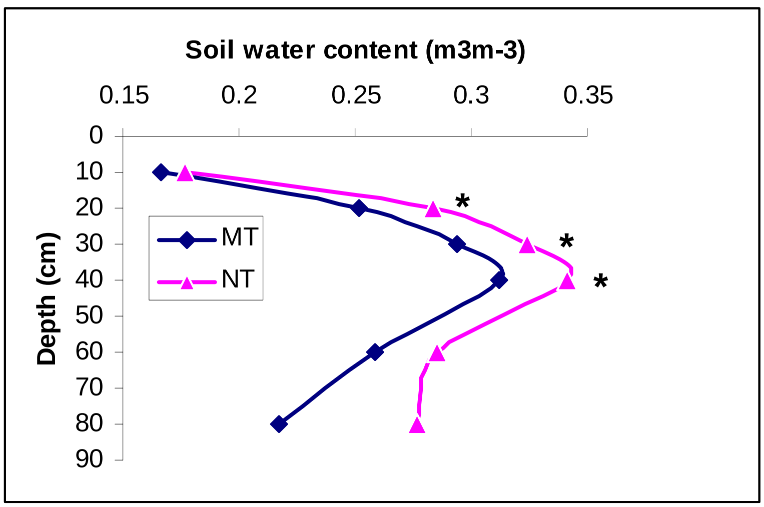


Figure 2. Reduced water runoff from plots managed using different residue treatments (Freebairn et al. 1985).



Values of soil water content at each depth followed by (*) are significantly different ($P \leq 0.05$)

Figure 3. Soil water content by soil depth under minimal and no-till treatments at 11 leaf stage in corn. (Adapted from Fabrizzi et al. 2005)

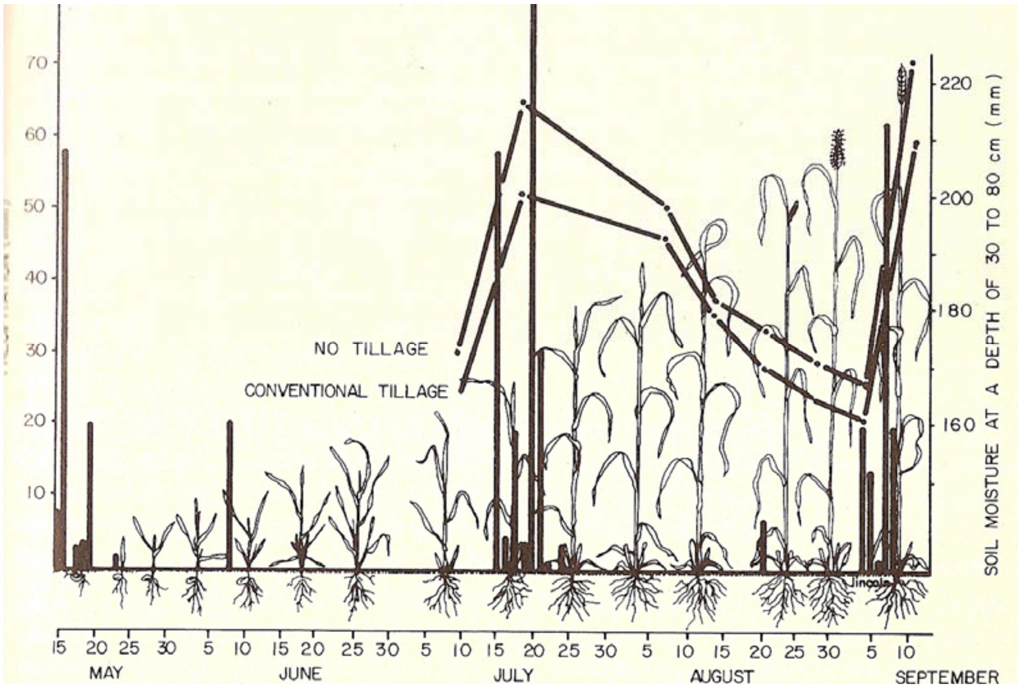


Figure 4: Increased soil moisture available at 30-80 cm under conventional and no-tillage treatments. (Kemper and Derpsch 1981).

d) The mulch helps promote more stable soil aggregates as a result of increased microbial activity and better protection of the soil surface. Table 1 displays data from a 10-year maize trial that shows aggregate stability increased by using more mulch. Interestingly, water-filled pore space increased with just a normal application of mulch, and additional residue did not increase this value.

Table 1. Effect of removal and retention of residue, with a single and double application on soil properties in a 10-year maize trial. (D.L. Karlen et al. 1994)

Residue treatment	**Wet aggregate stability**	**Total-C in aggregates**	**Water -filled pore space %**
Removal	41.9	16	76.9
Mulch	45.9	24	86.5
Twice the mulch	60.0	40	88.0
LSD	11.5	6	NS

e) CA resulted in improved fertilizer efficiency (10-15%) in the rice-wheat system, mainly a result of better placement of fertilizer with the seed drill as opposed to broadcasting with the traditional system (Hobbs and Gupta 2004). In some reports, nitrogen fertilizer efficiency was recorded as lower, a result of microoganisms tying up the nitrogen in the residue. However, in other longer-term experiments, release of nutrients increased with time because of more active microbial activity and nutrient recycling (Carpenter-Boggs et al. 2003).

f) No-till uses less diesel fuel and thus results in lower carbon dioxide emissions, one of the gases responsible for global warming. In RW systems, 40-60 liters of diesel fuel are saved because farmers can forego the practice of plowing many times to get a good seedbed after harvesting rice planted after puddled rice in degraded soils (Hobbs and Gupta 2004).

g) Weeds have been shown to germinate less in CA in RW systems (50-60% less) because the soil is less disturbed and less grassy weeds (*Phalaris minor)* germinate than in tilled soils. There is also evidence of allelopathic properties of cereal residues in respect to inhibiting surface weed seed germination (Lodhi and Malik 1987; Steinsiek et al. 1982; Jung et al. 2004). Weeds will also be controlled when the cover crop is cut, rolled flat, or killed by herbicides. Farming practices that maintain soil microorganisms and microbial activity can also lead to weed suppression by biological agents (Kennedy 1999).

h) Less lodging was seen in no-till wheat in RW systems than with conventional tillage, especially on beds. This requires more study but may be related to the crop roots utilizing the root and pore space and other biotic channels left after the previous crop, the result being better rooting.

i) CA results in more biotic diversity in the soil as a result of the mulch and less soil disturbance. This also produces higher surface soil organic carbon than when soils are tilled. There are many references on this issue (Roldan et al. 2003; Alvear et al. 2005; Riley et al. 2005; Madari et al. 2005; Diekow et al. 2005). The results from an oxisol soil in Brazil are used to highlight this issue in table 2. Note the surface mulch also helps moderate soil temperatures and moisture, which is more favorable for microbial activity.

j) Groundcover promotes an increase in biological diversity below and above-ground; there are more beneficial insects where there are groundcover and mulch, (Jaipal et al. 2002; Kendall et al. 1995) and these help keep insect pests in check. The data in table 3 are from a study in Spain that looked at the effect of tillage on soil-borne arthropods (Rodriguez et al. 2006). No-till resulted more arthropods in some cases. Table 4 shows data from Australia where more earthworms were found in no-till treatments. An early paper by McCalla (1958) showed that bacteria, actinomycetes, fungi, earthworms, and nematodes were higher in residue mulched fields than those where the residues were incorporated. Recent studies also show more soil fauna in no-till, residue retained management treatments compared to tilled plots (Buckerfield and Webster 1996; Nuutinen 1992; Karlen et al. 1994; Hartley et al. 1994; Riley et al. 2005; Birkas et al. 2004; Kemper and Derpsch 1981; Clapperton 2003).

k) The role of tillage on soil diseases is discussed by Leake (2003), with examples of the various diseases affected by tillage. He concludes that the role of tillage on diseases is unclear and acknowledges that a healthy soil with high microbial diversity plays a role by being antagonistic to soil pathogens. He also suggests that no-till farmers need to adjust management to control diseases through sowing date, rotation, and resistant cultivars to help shift the advantage from the disease to the crop. A list of the impacts of minimum tillage on specific crops and their associated pathogens can be found in Sturz et al. (1997).

Table 2. Total soil carbon and microbial bio-carbon under different crop rotations with (CT) and without tillage (NT) on an oxisol in Brazil (adapted from Balota et al. 2004)

Crop Rotations[a]	Total C (mg g^{-1})		MBC (μgC g^{-1})	
	CT	NT	CT	NT
Depth: 0-50 mm				
S/W	15.3 b	20.6 a	177 b	347 a
M/W	14.7 b	22.4 a	185 b	367 a
C/W	13.9 a	20.6 a	206 b	326 a
Depth: 50-100 mm				
S/W	13.4	17.3	194 bA	280 aB
M/W	15.3	19.0	209 bA	322 aA
C/W	13.2	19.7	140 bB	232 aC
Depth: 100-200 mm				
S/W	14.4 b	16.3 a	192 bA	214 aB
M/W	15.6 b	17.2 a	182 bAB	272 aA
C/W	13.8 b	16.2 a	163 bB	204 aB

Means within a row followed by a different lower case letter are significantly different at $P \leq 0.05$. Means within a column of the same depth followed by a different upper case letter are significantly different at $P \leq 0.05$

[a/] S: soybean; W: maize; C: cotton. All values represent the mean of data obtained from soil samples collected in 1997 and 1998.

Table 3. Mean number of various arthropods under tilled (CT) and no-tilled (NT) plots in Spain (Adapted from Rodriguez et al. 2006)

Family	2000		2001	
	CT	NT	CT	NT
Araneae	18.3 a	31.4 b	8.4 a	14.5 b
Formicidae	10.8 a	10.2 a	32.7 a	101.7 b
Coleoptera	8.8 a	12.4 a	19.0 a	33.7 a
Parasitoids	7.9 a	11.4 b	4.0 a	5.6 b
Collembola	4.7 a	12.3 b	55.2 a	56.4 a
Diptera	11.1 a	9.5 a	19.7 a	31.9 b
Homoptera	11.4 a	7.0 a	19.6 a	16.2 a
Acarina	0.2 a	3.0 b	24.5 a	15.0 a

Means within a row followed by a different lower case letter are significantly different at $P \leq 0.05$.

Table 4: Earthworm populations under various tillage treatments with and without residue mulch in Australia (Chan and Heenan 1993)

Residue Management	Direct Drilling (NT)	Reduced Tillage (RT)	Conventional Tillage (CT)
Retain Straw residue	17	14	4
Burn Straw residue	18	7	4

l) Interactions between root systems and rhizobacteria effect crop health, yield, and soil quality. Release of exudates by plants activate and sustain specific rhizobacterial communities that enhance nutrient cycling, nitrogen fixing, biocontrol of plant pathogens, plant disease resistance, and plant growth stimulation. Sturz and Christie (2003) review this topic. Groundcover would be expected to increase biological diversity and increase these beneficial effects.

Essentially, CA takes advantage of biological processes in the soil to accomplish *biological tillage;* this improves networks of interconnected pores, nutrient recycling, and soil physical and biological health. Life in the soil is a highly complex and dynamic system that is sensitive to tillage, pesticides, and other toxins. Increasing nutrient availability and plant productivity depends on regaining a healthy soil food web. Following are some key considerations for healthy soils:

- Soil organic matter formation and the multitude of organisms involved—fauna and flora;
- Healthy roots and the synergistic associations with biological organisms, e.g., rhizobia, mycorrhiza, antifungal agents, etc.;
- Soil microbes protect their territory and through microbial competition maintain a balance that stabilizes the population;
- Some microbes help roots control disease—antifungal agents;
- Healthy soils have more microbes than unhealthy soils;
- Mulching helps promote more diversity of microbes through temperature and moisture moderation; and
- It is hypothesized that CA plays a critical role in underground diversity and disease and pest suppression.

Equipment Issues

A major requirement of this system is the development and availability of equipment that promotes good germination of crops planted into soil that is not tilled and where residue mulch occurs on the soil surface. It should also be able to place bands of fertilizer for increased efficiency. All countries promoting CA face this challenge. Some advanced countries import or develop heavy, expensive equipment based on disk openers to address these requirements. Less developed countries have smaller power sources that necessitate different designs. The Rice Wheat Consortium (RWC) members are working vigorously in partnership with local manufacturers and farmers to make new equipment available for experimentation at an affordable price, with provisions for after sales service and supply of needed spare parts to make the system successful. Recently, multicrop, zero-till ferti-seed drills fitted with inverted-T openers, disk planters, punch planters, trash movers or roto-disk openers have been developed for seeding into loose residues (RWC Highlights 2004-05) (Figure 5).

The result globally is an array of equipment to suit local conditions with tractor (large and small), animal, and manual power. A book by Baker et al. (2002) (a new edition will be published in 2006, with more details for developing nations) is a good source about the various equipment needs for no-till seeding. This range of equipment means that small- and large-scale farmers can use this technology. In South Asia, where land holdings are small and many farmers do not own a tractor, a system of rental or service providers make the technology available. These farmers were accustomed to using service providers for tillage and with the introduction of no-till, farmers rented custom services utilizing a zero-till drill and tractor to plant their fields.

Figure 5. Various equipment for planting wheat no-till in the RWC: (a) inverted-T coulter; (b) Indian no-till drill using inverted T; (c) disk type planter; (d) star-wheel punch planter (e) “Happy planter,” which picks up straw and blows it behind the seeder; f) disk planter with trash mover.

Farmer Adoption of Conservation Agriculture Worldwide

Data reported by Derpsch (2005) indicates that the extent of no-tillage adoption worldwide is just over 95 million hectares. This figure is used as a proxy for CA, although not all of this land is permanently no-tilled or has permanent ground cover. Table 5 details the extent of no-tillage by country. Six countries have more than 1 million hectares. South America has the highest adoption rates and has more permanent no-till and permanent soil cover. Both Argentina and Brazil had significant lag periods to reach 1 million hectares in the early 1990s, and then expanded rapidly to the present day figures of 18.3 and 23.6 million hectares, respectively. By adopting the no-till system, Derpsch (2005) estimates that Brazil increased its grain production by 67.2 million tons in 15 years, with additional revenue of US$ 10 billion. Derpsch also estimates that at an average rate of 0.51 t/ha/yr, Brazil sequestered 12 million tons of carbon on 23.6 million hectares of no-till land. Tractor use was also significantly reduced, saving millions of liters of diesel fuel.

Table 5: Extent of no-tillage adoption worldwide

Country	**Area under no-tillage (m ha) 2004/2005**
USA	25.30
Brazil	23.60
Argentina	18.27
Canada	12.52
Australia	9.00
Paraguay	1.70
Indo-Gangetic-Plains (**)	1.90
Bolivia	0.55
South Africa	0.30
Spain	0.30
Venezuela	0.30
Uruguay	0.26
France	0.15
Chile	0.12
Colombia	0.10
China	0.10
Others (Estimate)	1.00
Total	**95.48**

Source: Derpsch, 2005.

** Includes area in India, Pakistan, Bangladesh, and Nepal in South Asia

How Long Does It Take to See Benefits

Usually the full benefits of CA take time and, in fact, the initial transition years may present problems that influence farmers to disadopt the technology. Weeds are often a major initial problem that required integrated weed management over time to get them under control. Soil physical and biological health also takes time to develop. Three to seven years may be needed for all the benefits to take hold. But in the meantime, farmers save on costs of production and time and usually get similar or better yields than with conventional systems. Farmers should be encouraged to continue this sustainable practice and correct problems as they arise.

Conclusions

Crop production in the next decade will have to produce more food from less land by making more efficient use of natural resources—and with minimal impact on the environment. Only by doing so can food production keep pace with demand, while the land's productivity is preserved for future generations. This is a tall order for agricultural scientists, extension personnel, and farmers. Use of productive but more sustainable management practices described in this paper can help solve this problem. Crop and soil management systems that improve soil health parameters (physical, biological, and chemical) and reduce farmer costs are essential. Development of appropriate equipment to allow these systems to be successfully adopted by farmers is a prerequisite for success. Overcoming traditional mindsets about tillage by promoting farmer experimentation with this technology in a participatory way will help accelerate adoption. Encouraging donors to support this long-term, applied research with sustainable funding is also an urgent need.

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