

Conservation agriculture for sustaining resources in rainfed agriculture

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Conservation agriculture (CA) is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment (FAO, 2007). CA is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes. CA is characterized by four principles that are linked to each other. The three principles along with the most important functions they serve are:

1. Minimum mechanical soil disturbance

Erosion control
Soil C buildup

2. Permanent organic soil cover

Erosion control
Biodiversity and environment

3. Diversified crop rotations in the case of annual crops or plant associations in case of perennial crops

Pest and disease control
Soil infrastructure
Biodiversity

4. Controlling in-field traffic

Reducing compaction

The key features of conservation agriculture are

- No ploughing, disking or soil cultivation (i.e., no turning over of the soil)
- Crop and cover crop residues stay on the surface
- No burning of crop residues
- Permanent crop and weed residue mulch protects the soil
- The closed-nutrient cycling of the forest is replicated
- Continuous cropland use

- Crop rotations and cover crops to maximize biological controls (i.e., more plant and crop diversity)
- Specialized equipment

Although conservation agriculture has several benefits, it is not without limitations, which mainly include possible reduction in crop yields and need for change in farm equipment. However, with continuous adoption, in time the crop yields in conservation agriculture are at least as good as in conventional agriculture and in many cases they are higher.

The first principle of CA - Minimum mechanical soil disturbance

Conventional "arable" agriculture is normally based on soil tillage as the main operation. The most widely known tool for this operation is the plough, which has become a symbol of agriculture. Soil tillage has in the past been associated with increased fertility, which originated from the mineralization of soil nutrients as a consequence of soil tillage. This process leads in the long term to a reduction of soil organic matter. Soil organic matter not only provides nutrients for the crop, but it is also, above all else, a crucial element for the stabilization of soil structure. Therefore, most soils degrade under prolonged intensive arable agriculture. This structural degradation of the soils results in the formation of crusts and compaction and leads in the end to soil erosion. The process is dramatic under tropical climatic situations but can be noticed all over the world. Mechanization of soil tillage, allowing higher working depths and speeds and the use of certain implements like ploughs, disk harrows and rotary cultivators has particularly detrimental effects on soil structure. Tillage and current agricultural practices result in decline of soil organic matter due to increased oxidation over time, leading to soil degradation, loss of soil biological fertility and resilience (Lal, 1994). No-tillage minimizes SOM losses and is a promising strategy to maintain or even increase soil C and N stocks (Bayer *et al.*, 2000).

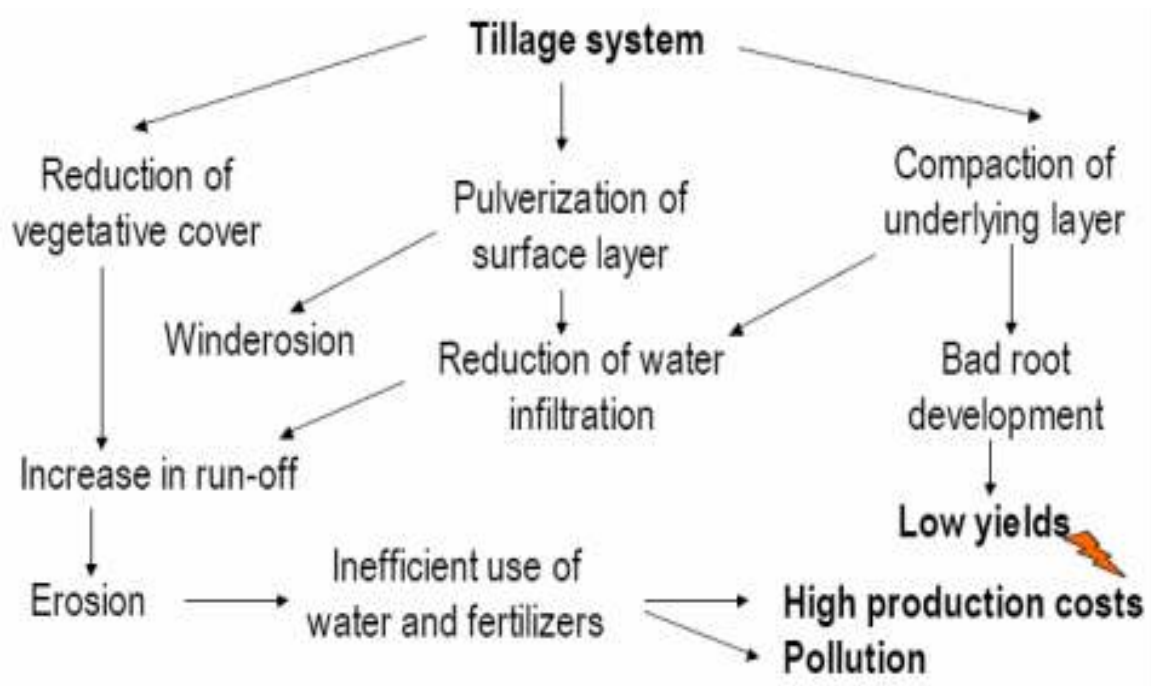
The harmful effects of tillage

- ✘ drastically alters original structure
- ✘ breaks up aggregates
- ✘ buries crop residues
- ✘ bares/exposes soil to the elements
- ✘ reduces biodiversity
- ✘ increases CO₂ emissions
- ✘ creates compact subsoil layers

Soil erosion resulting from soil tillage has forced us to look for alternatives and to reverse the process of soil degradation. Topsoil losses of 46.5 t/ha have been recorded with conventional tillage on sloping land after heavy rain in Paraguay compared to 0.1 t/ha under no-till cultivation (Derpsch and Moriya, 1999). The logical approach to this has been to reduce tillage. This led finally to movements promoting conservation tillage, and especially zero-tillage, particularly in southern Brazil, North America, New Zealand and Australia. Over the last two decades the technologies have been improved and adapted

for nearly all farm sizes; soils; crop types; and climatic zones. Experience is still being gained with this new approach to agriculture and FAO has supported the process for many years. No-till plus mulch reduces surface soil crusting, increases water infiltration, reduces runoff and gives higher yield than tilled soils (Thierfelder *et al.*, 2005). Similarly, the surface residue, anchored or loose, protects the soil from wind erosion (Michels *et al.*, 1995). The dust bowl is a reminder of the impacts of wind and water erosion when soils are left bare.

Effects of poorly chosen tillage



Experience has shown that conservation agriculture (CA) methods are much more than just reducing the mechanical tillage. In a soil that is not tilled for many years, the crop residues remain on the soil surface and produce a layer of mulch. This layer protects the soil from the physical impact of rain and wind but it also stabilizes the soil moisture and temperature in the surface layers. Thus this zone becomes a habitat for a number of organisms, from larger insects down to soil borne fungi and bacteria. These organisms macerate the mulch, incorporate and mix it with the soil and decompose it so that it becomes humus and contributes to the physical stabilization of the soil structure. At the same time this soil organic matter provides a buffer function for water and nutrients. Larger components of the soil fauna, such as earthworms, provide a soil structuring effect producing very stable soil aggregates as well as uninterrupted macropores leading from the soil surface straight to the subsoil and allowing fast water infiltration in case of heavy rainfall events. This process carried out by the edaphon, the living component of a soil, can be called “biological tillage”. However, biological tillage is not compatible with mechanical tillage and with increased mechanical tillage the biological soil structuring processes will disappear. Certain operations such as mouldboard or disc ploughing have a

stronger impact on soil life than others as for example chisel ploughs. Most tillage operations are, however, targeted at loosening the soil which inevitably increases its oxygen content leading in turn to the mineralization of the soil organic matter. This inevitably leads to a reduction of soil organic matter which is the substrate for soil life.

Thus agriculture with reduced, or zero, mechanical tillage is only possible when soil organisms are taking over the task of tilling the soil. This, however, leads to other implications regarding the use of chemical farm inputs. Synthetic pesticides and mineral fertilizer have to be used in a way that does not harm soil life.

Historically, tillage has resulted in loss of soil organic carbon. It is estimated that about 55 giga tons (Gt) of carbon has been lost from 1600 m ha of arable cropland around the globe. Organic matter contents of most soils in the US have been reduced to half of what they were when they were under their original land use. IPCC estimates that at 22 – 29 Gt of the C lost from soils can be sequestered through proper management. Conservation tillage accounts for about 50% of the potential for C sequestration in soils. Studies show that improved soil management can sequester 0.2 to 1.0 t/ha of C in soil. Some no till farms in Brazil have been shown to sequester more than 1 t/ha of C for over 22 years. One estimate is that global conversion of all cropland to conservation tillage can sequester 25 Gt C over 50 years. West and Post (2002) analysed global database of 67 long term experiments and found that Change from conventional to no till sequesters 570 kg C/ha/yr. The sequestration rates peak in 5-10 years and a new equilibrium C level is reached in 15-20 years. Long term tillage studies at CRIDA have shown that reduced tillage can sequester 277 kh C/ha/yr.

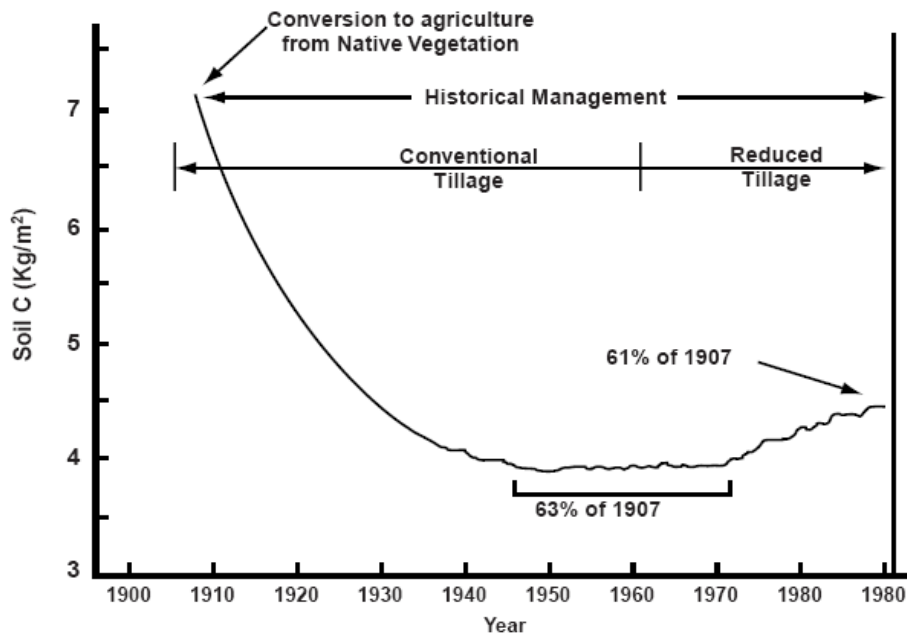


Fig. Simulated total soil carbon changes (0 to 20 cm) from 1907 to 1990 for central US corn belt (Smith, 1999)

The second principle of CA – Maintaining a Permanent organic soil cover

There are two ways in which the soil can be kept permanently covered with organic material, retaining crop residues and growing cover crops. Retention of residues is linked to tillage, and in no till systems, by definition, residues cover >30% of the soil surface, and in reduced till systems, >15% of the soil surface. The other way of maintaining soil cover is by growing cover crops. Cover crops are crops that are grown in the intervals between main crops, so that at no point of time the soil is left fallow. Cover crops serve a variety of purposes.

Cover crops

- ✓ Control erosion
- ✓ Reduce surface runoff
- ✓ Add organic matter
- ✓ Improve soil structure and tilth
- ✓ Fix atmospheric nitrogen (legumes)
- ✓ Recycle unused soil nitrogen (catch crops)
- ✓ Increase soil productivity
- ✓ Enhance ecosystem biodiversity
- ✓ Help control weeds

Fast growing high biomass producing cover crops can sequester considerable amounts of C. Cover crops contribute to the accumulation of organic matter in the surface soil horizon and this effect is increased when combined with NT. However, under dryland conditions the scope for growing cover crops is limited due to non availability of soil moisture. There is some scope for growing post monsoon cover crops such as horsegram after short duration crops such as sorghum, sunflower, etc. Studies at CRIDA showed that horsegram grown in the post monsoon season could sequester 0.34 t C/ha/yr in the soil up to a depth of 30 cm.

Cover crops help promote biological soil tillage through their rooting; the surface mulch provides food, nutrients and energy for earthworm, arthropods and microorganisms belowground that also biologically till soils. Use of deep-rooted cover crops and biological agents (earthworms, etc.) can also help to relieve compaction under zero-tillage systems. There is a lot of literature that looks at burning, incorporation and removal of crop residues on soil properties and much less where mulch is left on the surface. Groundcover promotes an increase in biological diversity below but also aboveground; the number of beneficial insects was higher where there was groundcover and mulch (Kendall *et al.*, 1995) and these help keep insect pests in check.

Table. Carbon sequestration potential of some cover crops (Alfisol, western Nigeria)

Cover crop	SOC (%) before	SOC (%) after	C seqstrn. rate*
<i>Brachiara</i>	1.21	1.57	2.41
<i>Paspalum</i>	1.23	1.45	1.49
<i>Cynodon</i>	1.30	1.70	2.60
<i>Pureria</i>	1.27	1.50	1.52
<i>Stylosanthes</i>	1.30	1.63	2.19
<i>Stizolobium</i>	1.30	1.57	1.80
<i>Psophocarpus</i>	1.20	1.57	2.11
<i>Centrosema</i>	1.30	1.53	1.53
<i>Control</i>	1.33	1.37	0.28

* Mg/ha/yr

Source: Lal *et al.* (1998)

The third principle of CA - Diversified crop rotations

As the main objective of agriculture is the production of crops, changes in the pest and weed management become necessary with CA. Burning plant residues and ploughing the soil is mainly considered necessary for phytosanitary reasons: to control pests, diseases and weeds. In a system with reduced mechanical tillage based on mulch cover and biological tillage, alternatives have to be developed to control pests and weeds. Integrated Pest Management becomes mandatory. One important element to achieve this is crop rotation, interrupting the infection chain between subsequent crops and making full use of the physical and chemical interactions between different plant species. Synthetic chemical pesticides, particularly herbicides are, in the first years, inevitable but have to be used with great care to reduce the negative impacts on soil life. To the extent that a new balance between the organisms of the farm-ecosystem, pests and beneficial organisms, crops and weeds, becomes established and the farmer learns to manage the cropping system, the use of synthetic pesticides and mineral fertilizer tends to decline to a level below that of the original "conventional" farming system.

Crop rotation is an agricultural management tool with ancient origins. Howard (1996) reviewed the cultural control of plant diseases from an historical view and includes examples of disease control through rotation. The rotation of different crops with different rooting patterns combined with minimal soil disturbance in zero-till systems promotes a more extensive network of root channels and macro-pores in the soil. This helps in water infiltration to deeper depths. Because rotations increase microbial diversity, the risk of pests and disease outbreaks from pathogenic organisms is reduced, since the biological diversity helps keep pathogenic organisms in check (Leake, 2003). The rotation of crops is not only necessary to offer a diverse "diet" to the soil

microorganisms, but as they root at different soil depths, they are capable of exploring different soil layers for nutrients. Nutrients that have been leached to deeper layers and that are no longer available for the commercial crop can be "recycled" by the crops in rotation. This way the rotation crops function as biological pumps. Furthermore, a diversity of crops in rotation leads to a diverse soil flora and fauna, as the roots excrete different organic substances that attract different types of bacteria and fungi, which in turn, play an important role in the transformation of these substances into plant available nutrients.

The effects of crop rotation:

- Higher diversity in plant production and thus in human and livestock nutrition.
- Reduction and reduced risk of pest and weed infestations.
- Greater distribution of channels or biopores created by diverse roots (various forms, sizes and depths).
- Better distribution of water and nutrients through the soil profile.
- Exploration for nutrients and water of diverse strata of the soil profile by roots of many different plant species resulting in a greater use of the available nutrients and water.
- Increased nitrogen fixation through certain plant-soil biota symbionts and improved balance of N/P/K from both organic and mineral sources.
- Increased humus formation.

Rotations, especially legume-based ones, are generally regarded as extremely valuable for maintaining soil fertility and have a very good potential for sequestering C in dryland systems. It has been estimated that rotations can lead to sequestering of 0.01 - 0.03 Pg C/year in the maize/soybean-growing region of the US. The effectiveness of rotations is greatest when combined with conservation tillage practices. West and Post (2002) analyzed a global database of 67 long-term experiments and found that increasing rotational complexity sequesters 200 kg C/ha/yr and a new equilibrium is reached in 50-60 years.

The third principle of CA - Controlling in-field traffic

The FAO now includes "controlling in-field traffic" as a component of conservation agriculture; this is accomplished by having field-traffic follow permanent tracks. This can also be accomplished by using a ridge-till or permanent bed planting system rather than planting on the flat (Sayre & Hobbs, 2004).

Economics of conservation agriculture

Technology, despite its ideological appeal, is unlikely to be adopted by farmers unless it makes economic sense. More and more farmers are switching to conservation agriculture as it is offering them greater profits. Although there may be initial reductions in profit levels or in extreme situation losses, due to switching from conventional agriculture to CA (mainly due to need for purchase of new equipment, and possible reduced yields in

initial years of conversion), in time CA clearly demonstrates its economic superiority apart from ecological and environmental benefits. The possibility of earning carbon credits under CDM makes CA even more attractive to farmers.

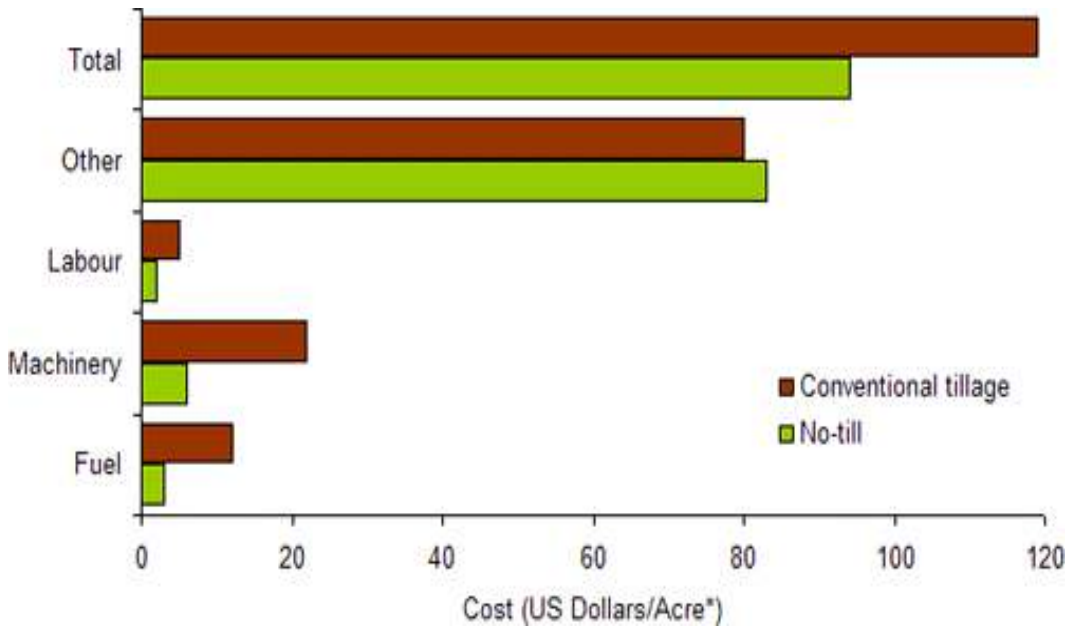
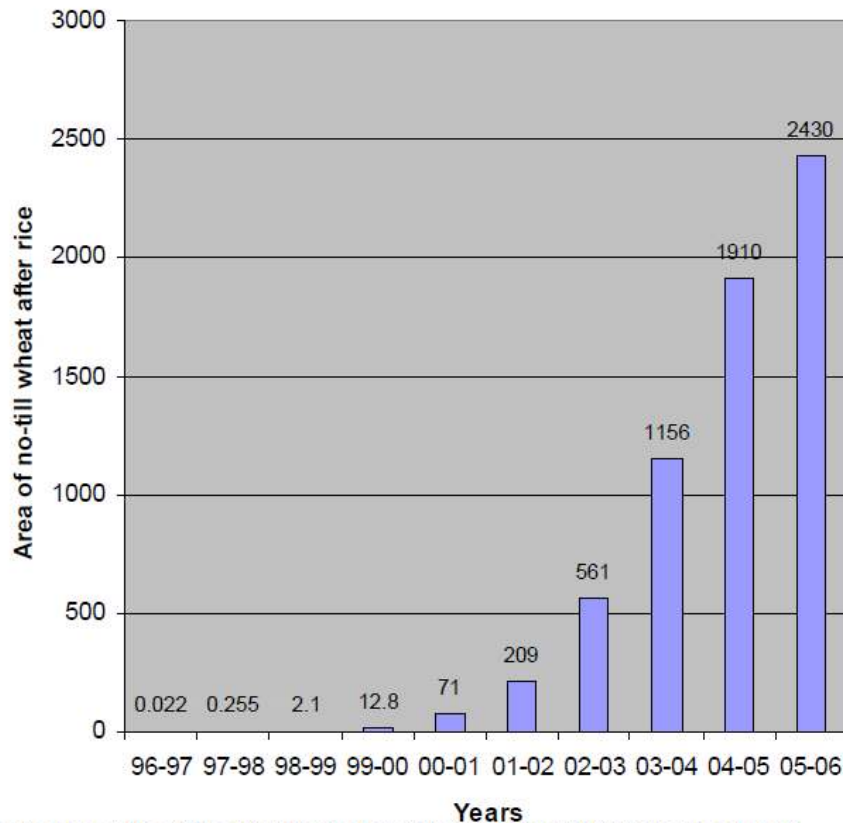


Fig. Economic advantages of no till system over conventional till system

Table. Area under no till in different countries (2004-05)

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)



Source: Rice-Wheat Consortium for the Indo-Gangetic Plains 2006 www.rw.c.cgiar.org

Fig. Estimated area growth of no-till wheat in the Indo-Gangetic Plains for the past 10 years

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