UNDERPINNING CONSERVATION AGRICULTURE'S BENEFITS: THE ROOTS OF SOIL HEALTH AND FUNCTION

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TABLE OF CONTENTS

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"Despite the artistic pretensions, sophistication and many accomplishments of mankind, we owe our existence to a six-inch layer of topsoil and the fact that it rains".

?Confucius

"Without regular and dependable supplies of food, other agricultural products and water, our whole economic structure will collapse, and no amount of accounting, book-keeping, reckoning, buying or selling will sustain it".

Cormack & Whitelaw, 1957

"Some are predicting that water will replace oil as the resource of greatest concern to the global community – there are alternative fuels, but there are no alternatives to water".

Craig Cox (SWCS) in testimony to the US Senate 17.1.07,
Quoted in JSWC (USA) Mar/Apl.2007, p.23a

ABSTRACT

This paper considers features underlying conservation-effective agricultural systems' impacts, because they can explain present successes, suggest guidelines for future initiatives, and indicate criteria for judging their effectiveness. Once farmers have made the transition in awareness, thinking and practice of Conservation Agriculture (CA), positive benefits which attract farmers include savings in time, labour, energy and expenditure, with increased productivity and profit margins, greater stability of production, opportunities for diversification. These are accompanied by agro-ecologic improvements to the physical catchments in which such farms are aggregated, and additional socioeconomic and environmental benefits to the wider community that surrounds them. CA protects and enhances the roots of sustainability whereas conventional tillage agriculture adversely affects soil quality and productivity. CA can offer significant advantages to producers in all agricultural environments including in suboptimal and marginal ecologies. The paper highlights the need to think unconventionally and not to be constrained by the dogma underpinning conventional tillage agriculture. To maximize the opportunity and benefits offered by CA, key areas of further investigations by the scientific and development community are elaborated.

1. INTRODUCTION

In many landscapes, we expect three-dimensional catchments which are clothed in soil to yield sufficient vegetation of various types, including crops, and volumes of clean water regularly on an annual basis. It is becoming widely acknowledged that Conservation Agriculture ('CA') systems, when fully expressed, can improve catchments' (often damaged or degraded) capacities to provide these essential biological and ecosystem service products on a sustainable basis. CA simulates formerly-sustainable systems but at higher levels of productivity.

Optimal CA systems are based on at least three practices: no disturbance of the soil; permanent cover of the soil with organic matter provided by mulch and cover-crops; and diversified crop rotations, which preferably include N-fixing legumes in the sequence.

In many areas, to date, satisfying the needs of expanding human populations for water has resulted in increasing rates of draw-down of subsurface groundwater from wells and boreholes, though without other actions to ensure equal rates of replenishment by infiltrated rainfall water. The consequences are all too often a need to deepen the boreholes, and an increased incidence of streams ceasing to flow ever earlier after the onset of the dry season.

Increased demands for plant products including food have been addressed through both intensification of inputs per unit area - particularly of agrochemicals and energy - more fertilizer and pesticides, and expansion of agriculture onto ‘virgin’ land. In many situations, the resulting increased frequency of physical tillage, more fertilizers and pesticides, and/or expansion onto more ‘fragile’ types of land have resulted in dynamic re-adjustments of the original ecosystems to altered, less-productive states and, as evidenced - particularly in the tropics and subtropics, but also in temperate regions - by increased soil erosion and surface runoff, and the degradation of soil and water quality and of biodiversity. Soil erosion signifies loss of land quality, of soil porosity and of soil depth, while surface runoff signifies wastage of volumes of potentially-usable water. Neither of these wastages, nor other environmental degradation, are acceptable features of an agriculture which attempts to be productive, efficient and sustainable.

Human populations and their associated demands from the land - to yield plant products and water - continue to rise even as productive potentials of much land continue to fall (or can only be maintained with rising costs of production per unit of output) due to past and ongoing damage to the environment.

1.1 Challenge

The challenge is to reverse the observable trend of what is commonly accepted as ‘conventional agriculture’ - towards declining sustainability of land’s productivity accompanied by increasing costs to farmers, to the environment and to society at large. As additional challenge this reversal in trend has to be combined with an increase in production.

2. COMPONENTS OF SOIL PRODUCTIVITY

Soil plays a central role in agricultural production. It determines the production but also the efficiency of many other production factors and inputs. The productivity of a soil, evidenced by yields of plants and input factor productivities, is derived from four components which interact dynamically in space and over time:

1. **Physical**: its ‘architecture’, made up of the arrangement of spaces and solid particles and organic materials, including the forces holding the elements together, and a soil’s depth, defined in three dimensions; the special arrangement of the elements is as important as their quantitative distribution.

2. **Hydric***:* its capacity to absorb, transmit and retain water received at the surface; the supply of soil water to plants is determined by the range of pore-sizes which determine the water's availability to them. In considering 'soil fertility' rather than 'soil productivity' this feature generally becomes obscured (even though implied) beneath acknowledgement of the physical and biologic components. In CA, 'soil productivity' is the preferred term, because of this stress on soil moisture availability.

3. **Chemical**: dissolved substances which serve as plant nutrients; organic (= C-based) chemical complexes as by-products of organisms' metabolic activities which, with active clays, contribute much to soils' capacities of cation-exchange and of slow nutrient release (broadly equivalent to the importance of a soil's pore-size distribution in 'slow release' of water to roots).

4. **Biologic***:* soil-inhabiting organisms - bacteria, fungi, plants, animals, and their non-living residues. The non-living fractions provide energy and nutrients for the activities of the living fractions.

All four components interact under the influences of climate, gravity, available species, and the stability of care and management. As long as undisturbed, the plant/soil ecosystem tends towards a condition of dynamic equilibrium. But, as expression of an ecological principle, under the overriding influences of weather and gravity, changes to one component of soil productivity provoke re-adjustments between all four of them, which may prove beneficial or detrimental in terms of plant production and/or water provision. It is to such disturbance that the detrimental effects of tillage agriculture can be related.

3. SOME ADVERSE EFFECTS OF 'CONVENTIONAL' TILLAGE AGRICULTURE

From the description of the elements for soil productivity it becomes obvious that the common practice of tilling the soil does not favour particularly the physical and biologic characteristics of a soil. The nature of 'conventional' agriculture, based on tillage, fails to provide together the three integrated bases of conservation-effective agriculture: (a) no soil disturbance; (b) permanent cover to the soil; (c) rotations of diverse crops, including legumes.

Tillage destroys soil organic matter through two interrelated processes. Organic matter at depth in the soil is slower to decompose as soil temperature and moisture levels vary more slowly at depth and oxygen partial pressure can be lower also. Ploughing brings this OM to the surface and decomposition is speeded up.

The second process is that, when there is no physical disturbance, soil macro-aggregates "occlude" particulate undecomposed residues. The break up of the macro-aggregates exposes this occluded particulate OM (or light fraction) to decomposition. This process has been well described by Six *et al.* (2000) and shown to be true for Ferrasols by Denef *et al*. (2007) and Zotarelli *et al.* (2007).

- Tillage agriculture generally aims to remove or bury all cover except that provided by the crop itself.

- Under increasing demands and lessening of available land space, conventional tillage agriculture tends towards favouring lesser crop diversity, even to monocropping, as well as to limiting or eliminating regular periods in rotation for soil restoration by the widely-penetrating root systems of appropriate species – such as perennial grasses – which, to an extent, can simulate the effects of former long-rotation 'bush fallows' including shrubs and trees.

- Tillage interferes with the habitat of soil life and disrupts the physical structure of this habitat, replacing the structuring effects of soil life with mechanical restructuring of soil aggregates. This leads to a disruption of continuous pore systems, less structural stability and a clear separation of the tilled topsoil from the not tilled subsoil.

Thus, tillage agriculture results in significant disruptions to the functioning of the living soil/plant system and the interactions between the four components of soil productivity.

3.1 Primary Effects

Primary effect can be seen as:

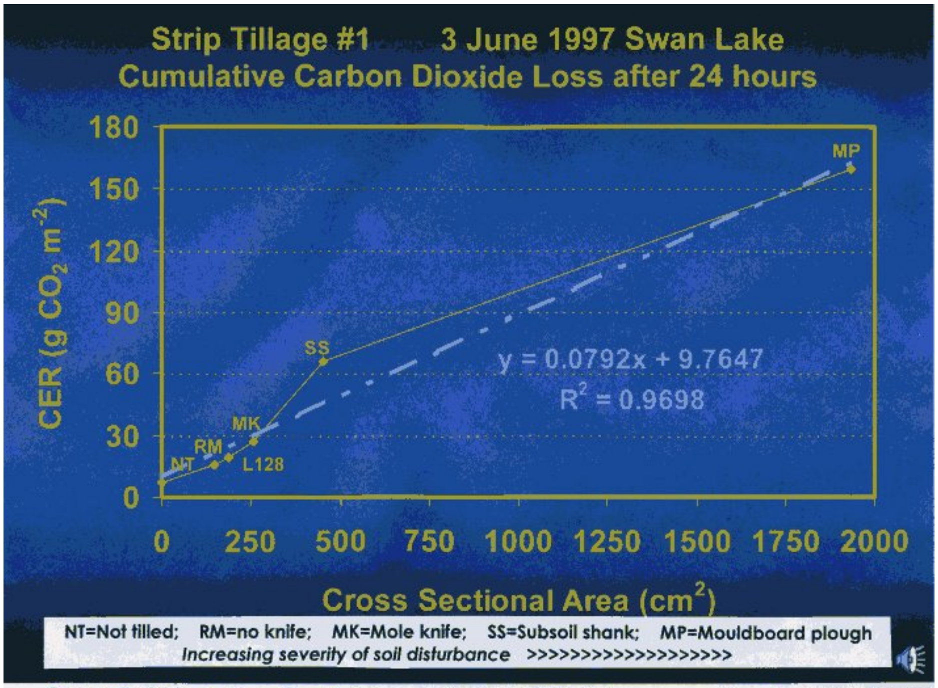
- Physical disruption of, and degradation of, existing soil pores – stirring, compacting, pulverising, losing organic 'glues' between particles;

- Net loss of organic matter by its accelerated oxidation of carbon compounds and emission of CO_2 to the atmosphere, following tillage operations (Figures 1-4). If soil is basically purely inorganic because its soil organic matter reserves have been severely depleted, then applied P fertiliser is usually immobilised almost immediately. The higher the amount of P that can be retained in organic (C-linked) form in residues on the soil surface to act as slow-release fertiliser, the lower is the necessity for high P inputs, and P-fertiliser efficiency improves.

3.2 Secondary Effects

As a source of plant nutrients, organic–matter additions (manures, composts) are commonly substituted by manufactured fertilizers, because the latter are less bulky and easier to transport and spread.

Where tillage agriculture then continues, the remaining soil organic matter is further depleted by oxidation, until so little remains (only that most resistant to transformation) that the soil's buffering capacity is exhausted and plants then become more or less wholly dependent on applied nutrients alone.

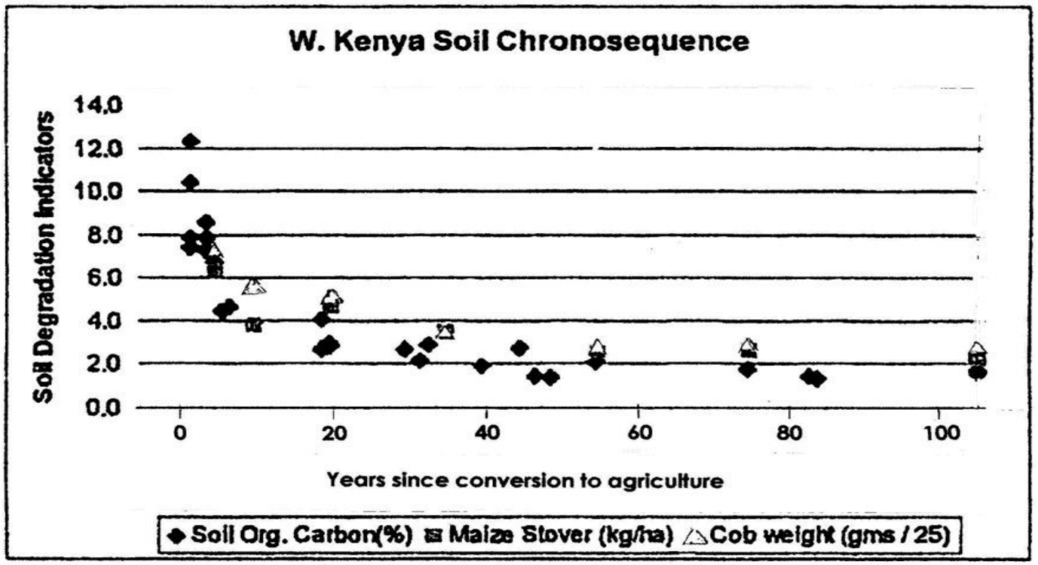


Strip Tillage #1 3 June 1997 Swan Lake
Cumulative Carbon Dioxide Loss after 24 hours

NT=Not tilled; RM=no knife; MK=Mole knife; SS=Subsoil shank; MP=Mouldboard plough
Increasing severity of soil disturbance >>>>>>>>>>>>>>>>>>>>

Source: Reicosky D. PowerPoint/CD presentation at 1st World Congress on Cons. Ag. Madrid 2001

Figure 1: Cumulative carbon dioxide loss from soil subjected to different depths and severities of tillage, according to accelerated rates of oxidation of soil organic matter, and possibly to release of CO_2 trapped in soil pores.

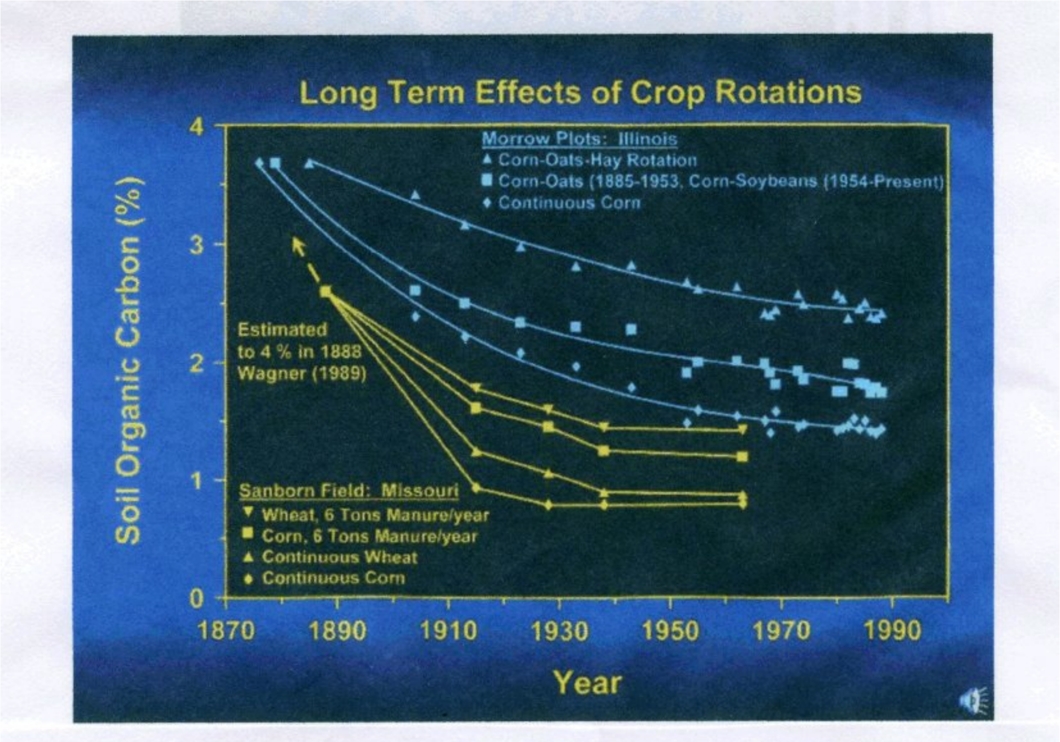


Decline in percent soil organic carbon, weights of maize stover, and maize-cob weights over time since the land's conversion to agriculture
(7 villages in Vihiga and South Nandi Districts in western Kenya).

(After Marenya P.P., Barrett C.B., 2007: 'State-conditional fertilizer yield response on western Kenyan farms'. July 2007, revised draft.

Figure 2: Soil organic carbon, yields of maize stover, maize-cob weights decline rapidly during initial years after bringing the soil into tillage agriculture in western Kenya, then continue to decline at slower rates for as much as 100 years.
(From Marenya & Barrett: diagram reversed laterally)

The trend of loss is seen to be rapid initially, followed by slower long-term decline, the shape of the curve being characterised by a Decomposition Constant. This feature was discussed by Nye and Greenland in 'The Soil under Shifting Cultivation' (C.A.B., 1960, p.51+). The diagram below shows a comparable trend over about 100 years 1880-1990 at two locations in the US Midwest between about 1880 and 1990.



Source: PowerPoint presentation by Don Reicosky to 1st World Congress on Conservation Agriculture, Madrid, 2001

Figure 3: Comparable example of decline in soil organic carbon, from the U.S. Midwest
Even under rotations, and with manure applied, soil organic matter levels still show long-term decline under tillage agriculture, again falling rapidly at first, more slowly in later decades.

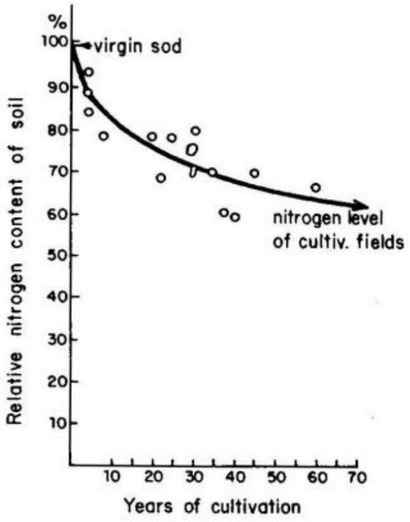


Fig. 5 Decline of soil nitrogen with length of cultivation periods under average farming practices in the Middle West (from Jenny, 1933)
(copied from: Flaig W. et al. 1977: 'Organic Materials and Soil Productivity'. FAO Soils Bulletin 35, p.10)

Figure 4: Comparable decline, in soil nitrogen level relative to that in virgin land_(N-levels closely related to organic matter levels)

3.3 The 'Elephant in the Back Room'

Other investigations suggest that, after s.o.m. has become depleted to very low levels the result has been lower efficiency and eventually minimal effectiveness of mineral fertilizers to contribute to soil fertility and eventually to further enhance yields. This end result has been observed by small farmers: after they could no longer obtain fertilizers (for whatever reason) the subsequent crop yields had become so poor that they have reported: "*The crops have become 'addicted' to fertilizers";* "(After we stopped using fertilizers), w*e suddenly realised that something bad had happened to our soil*"[1]; *"[It] slowly kills the soil"*[2]. Comparable comments by farmers have also been noted in parts of China[3]. A similar problem occurs if blanket applications of only one fertiliser are applied because, if applied in ever-increasing quantities of e.g. N, eventually other nutrients become limiting and the soil can become effectively sterilised.[4]

"*Using data from maize plots* [some known to have been cultivated for more than 100 years] *operated by small farmers in western Kenya, we find a von Liebig-type relationship between soil organic matter, a broad proxy for soil fertility status, and maize yield response to nitrogen application. On a third of the plots, degraded soils limit the marginal productivity of fertilizer such that it becomes unprofitable at prevailing prices. Since poorer farmers most commonly cultivate SOM-deficient soils, stand-alone fertilizer interventions might therefore be less pro-poor than is widely assumed".*[5]

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[1] Shaxson, pers comms. (Malawi)

[2] Tamang, D, 1993, (Nepal) quoted in FAO Soils Bulletin 75, 1999, p.47.

[3] Douglas, pers. comm.(1451).

[4] Twyford, pers. comm.(1644)

[5] Marenya P.P., Barrett C.B., July 2007. 'State-conditional fertilizer yield response on western Kenyan farms'. Revised draft, July 2007. Permitted quotation from authors' abstract.

If these interpretations reflect the reality, and the situation is widespread across the lands occupied by resource-poor small farmers in the tropics and sub-tropics, it poses a serious challenge to the assumption that inorganic fertilisers plus improved seeds are all that are needed (with adequate rainfall, and/or irrigation) in tillage-agriculture to reverse the observed declines in soil productivity over the years.

Until this problem is resolved, the long-term decline of soil organic matter, illustrated above (Figure 4), is like ‘an elephant in the back room’, capable of causing and repeating serious problems.

3.4 Consequences

The loss of soil organic matter caused by repeated soil tillage has a number of consequences:

- Raised risks of losses of water as runoff; of soil as ‘sediment’; of applied inputs – energy, seeds, fertilisers, pesticides;
- Diminished capacities for capture and slow release of both plant nutrients and water;
- Diminished quality of the soil as a rooting environment;
- Diminishing yields, at level costs, year by year; conversely, level yields maintained at rising costs;
- Diminished activity and diversity of soil organisms;
- Lowered resilience of the soil/plant system to adverse conditions;
- Reduced output/input ratios, indicating falling efficiencies of use of inputs;
- Diminished sustainability of farming enterprises.

CA systems (based on the combination of no-till + permanent organic soil-cover + crop-rotations, which induce net increase in soil organic matter, and in conjunction with provision of sufficient plant nutrients) offer an entirely-appropriate type of solution, potentially able to slow and reverse these damages, and to minimise/avoid their repetition on newly-opened lands.

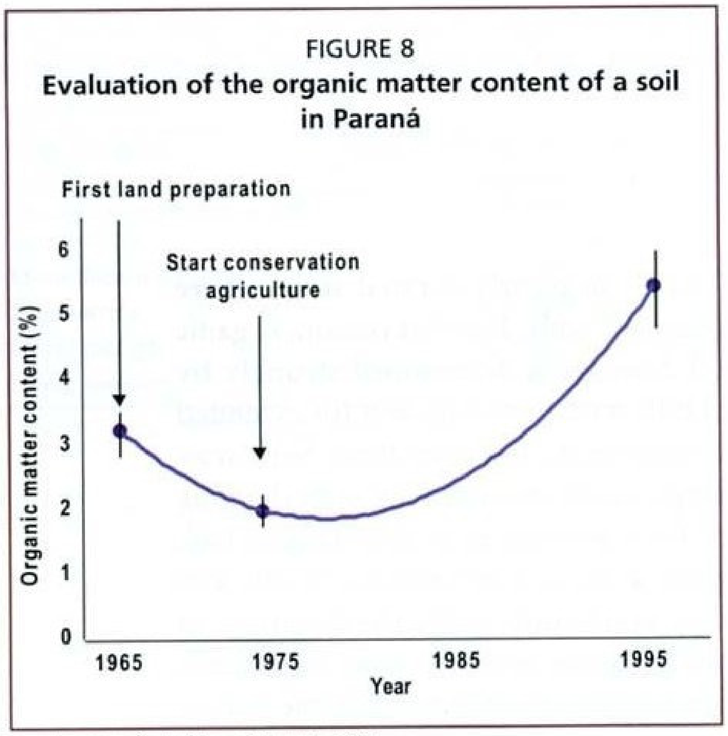
FIGURE 8

Evaluation of the organic matter content of a soil in Paraná

Source: adapted from Derpsch, 1997.

Figure 5: Reversal of s.o.m. decline by adoption of CA in Paraná, Brazil.
Source: Bot A., Benites J., 2005:'The Importance of Soil Organic Matter'. FAO Soils Bulletin 80, p.20.

4. KEY FEATURES OF OPTIMUM CONSERVATION AGRICULTURE

Conservation Agriculture reaches its full potentials for sustainable yields of vegetation and water when three features are functioning together:

1. No physical disturbance of the soil
2. Permanent organic cover to the soil
3. Rotation of crops

4.1 No physical disturbance of the soil

No disturbance of the soil - once it has been brought into good condition for rooting and for water-entry and -retention - is achieved by direct seeding through the mulch cover without tillage. This feature:

- Enables the living parts of the varied members of the soil/plant system to optimise the arrangement, over time, of the four components of soil productivity (as above) to mutual benefit. It avoids disruptive disturbance of the ensuing self-layering of activity and characteristics from the surface downwards into the profile.

- Preserves the integrity of large pores into the soil made by meso-organisms such as worms, termites etc. and by roots now decayed, along which both water and gases can move fairly rapidly to depth, including balanced exchange of respiration gases between the atmosphere and the zone of rooting .

- By avoiding break-up of larger soil aggregates, prevents exposure of their internal micro-aggregates within which occluded small fragments organic matter are sheltered.

- Permits time for biological transformations of organic matter to build up more soil aggregates which have degrees of resistance to slaking and/or mechanical breakdown by compaction.

In a sense, the soil architecture that develops over time under no till can be equated to the architecture of a building (Figure 6). The functional usefulness of the building depends on the nature and organization of the space within the building.

The loss of voids within the soil's architectural units results in a decline in its productivity, stability and usefulness for the chosen purpose.

(Photo-sequence from the UK newspaper 'The Independent Saturday Review', 23.7.98)

Figure 6: Controlled demolition of twin apartment-blocks. The interesting things happen in the spaces of soil architecture, as in a building. If the spaces are lost, the usefulness is lost, even though the physical parts remain.

4.2 Permanent organic cover to the soil

Permanent organic (= carbon-rich) cover to the soil is derived from retained plant residues from crops and cover-crops which have been retained *in situ,* sometimes augmented with manures, composts etc. from elsewhere. This feature:

- Protects the soil surface from:

  - high-energy rainfall impact, thereby avoiding the associated crusting and compaction of the surface that occurs on bare soils;
  - extremes of daily temperature fluctuations in uppermost soil layers, which otherwise could be inimical to plant functions in bare soils;

- Provides a regularly replenished organic substrate for the metabolic processes of the soil biota, whose transformative actions on dead organic matter lead to the enhancement of soil aggregation and of a wide range of pore-size distribution within the resulting soil porosity. For root function and water movement the spaces within the pore matrix are as significant as the solids that surround them.

The transformative processes also result in enhancement of the soil's cation exchange capacity (CEC), providing retention and slow-release of plant nutrients, whether derived from organic matter and/or applied 'from the bag'.

4.3 Rotation of Crops

This involves rotation in sequence of several species of crops, including legumes as symbiotic (plant x Rhizobia) sources of plant-fixed atmospheric N, and other usable green manure cover crops, for maintaining soil cover at all times, as well as provision of labile organic residues both at and below the surface. It is important that the nutrient balances in the soil are maintained from one cycle of a rotation to the next. C-accumulation seems only to occur when there is a legume in the system which fixes more N than is removed in the crop products or otherwise lost from the system[6].

This feature results in:

- The placement of organic root-residues at a range of different <u>depths</u> in the soil profile according to each crop's characteristics;

- The provision of various <u>qualities</u> of residues in the soil, from the most labile and readily-transformed to the more-lignified types resistant to decomposition, depending on the plant types. The more-labile/less-lignified forms contribute less to cation-exchange capacity than more-lignified root materials. A wide range of types provided by the different crops increases the range of buffering capacities of the soil with regard to soil pH and nutrient imbalances with respect to plant requirements.

Mixed sequences of crops, plus the presence of permanent soil cover, tend to inhibit the build-up of specific weed species which would thrive under less-varied or monocrop conditions.

The greater the range of plants grown, in mixtures or in sequence, the more varied will be the biodiversity of associations of organisms above-ground and inhabiting the rooting-depth, and the greater the competition which can suppress those which may be detrimental to root function and thus be considered weeds/pests. A crop rotation will further help interrupting the infection chain for diseases and might have other pest-repellent and -suppressing characteristics. For the

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[6] Boddey R., pers. comm.

alterations in copping systems to be worthwhile to farmers, there need to be local uses and/or markets for outputs generated by improved crop sequences.

4.4 Simulation of Forest-floor Conditions

In CA systems with the above attributes there are many similarities with resilient 'forest-floor' conditions:

- Organic materials are added both as leaf-and-stem residues from above the surface and as root-residues beneath the surface where the soil biota are active and carbon is accumulated in the soil.

- Carbon, plant nutrients and water are recycled.

- Rainwater enters the soil complex readily, since rates of infiltration – (maintained by surface protection and varied soil porosity) usually far exceed the rates of rainfall income.

The ongoing relative stability of such conditions depends more on the dynamic biological characteristics of the soil/plant ecosystem than on its static physical attributes.

4.5 Soil Organic Matter

Soil organic matter is neither just a provider of plant nutrients in low concentrations nor just an absorber of water, as is sometimes supposed. The combined living and non-living fractions together form a key part of the dynamics of soil formation, resilience and self-sustainability of CA systems.

In the functioning of soil as a rooting environment, the integrated effects of the physical, chemical and hydric components of soil productivity are effectively 'activated' by the fourth, the biological component.

The varied component species of the living fraction of soil organic matter may inhabit the above-ground mulch and/or the soil below.

They variously provide metabolic functions, acting on the non-living organic materials, which include:

- Retaining potential plant-nutrient ions within their own cells, with liberation on their death, acting as one form of slow-release mechanism; mycorrhizae and rhizobia, as well as free-living N-fixing bacteria, make nutrients available to plants in symbiotic arrangements.

- Breaking down and transforming the complex molecules of varied dead organic matter into different substances, both labile and resistant, according to the composition of the substrate;

- Leaving behind transformed materials with differing degrees of resistance to, and thus of speed of, subsequent breakdown by biotic process of other soil organisms. Over the long term, this leaves some residues less changed than others, providing long-lasting and slowly-released remnant reserves of the nutrient and carbonaceous materials of which they were composed.

- Producing organic acids which, by leaching, contribute to soil formation from the surface downwards by acting to break down mineral particles as part of the soil 'weathering' process. Organic acids also help with transporting lime into the soil profile and mobilizing nutrients like phosphates.

- Providing organic molecules as transformation products which contribute markedly to soil's CEC; this also augments the soil's buffering capacity with respect to pH/acidity changes and to excesses or deficiencies of nutrient ions available to plants.

- Providing humic gums which, together with fungal hyphae and clay bonds, make for different sizes of rough-surfaced aggregates of individual soil particles which, within and between them in continuous channels, provides the permeability of the soil in a broad distribution of pore-sizes.

- Burrowing activities of meso-organisms such as worms, and of roots (leaving tubes after they have died and been decomposed), also contribute to the macro-porosity of the soil, with similar effects.

The soils which are most vulnerable to tillage-stimulated rapid loss of soil organic matter are those of coarse texture and where the clay fraction is dominated by low-activity clays. Such soils (e.g., ferralsols) are widely distributed in the tropics and sub-topics, and total over 750 million ha. in these regions.

4.6 The Roots of Sustainability

Sustainability of land's capacities to continue yielding both plant products and water year after year depends primarily on maintaining the soil in fit condition for active life processes of the whole soil/plant system. This relates to the ongoing generation and re-generation of the porous soil architecture – the soil's 'self-recuperation capacity' – with respect to repair of damaged soil and to its physical resilience in the face of adverse shocks of weather and/or of poor management.

It is clear that maintaining the vitality of the soil, notably of the number, diversity and activity of the living components of its organic matter, is a key factor in sustaining the land's capacity to go on yielding vegetation and water through maintenance of soil porosity.

The advantage of CA over TA in terms of the duration of plant-available soil moisture is clearly illustrated by the graph in Figure 7, which shows the situation with respect to soil moisture conditions throughout growing-season under three experimental treatments: 'Direct drill' (= no-till conservation agriculture); 'Minimum tillage' (= non-inversion tillage with tines); and 'Conventional tillage' with heavy discs.

"Soil-moisture available to plants at different depths during the period of vegetative growth of wheat in 1981, under three different systems of soil preparation

..... Direct drill = no-till
---- Minimum tillage
___ Conventional tillage (heavy discs)

X axis: Available water in soil % of available-water capacity
Y axis: Months May, June, July, August, September"

from: Derpsch R, Roth C H, Sidiras N, Kopke U.1991.

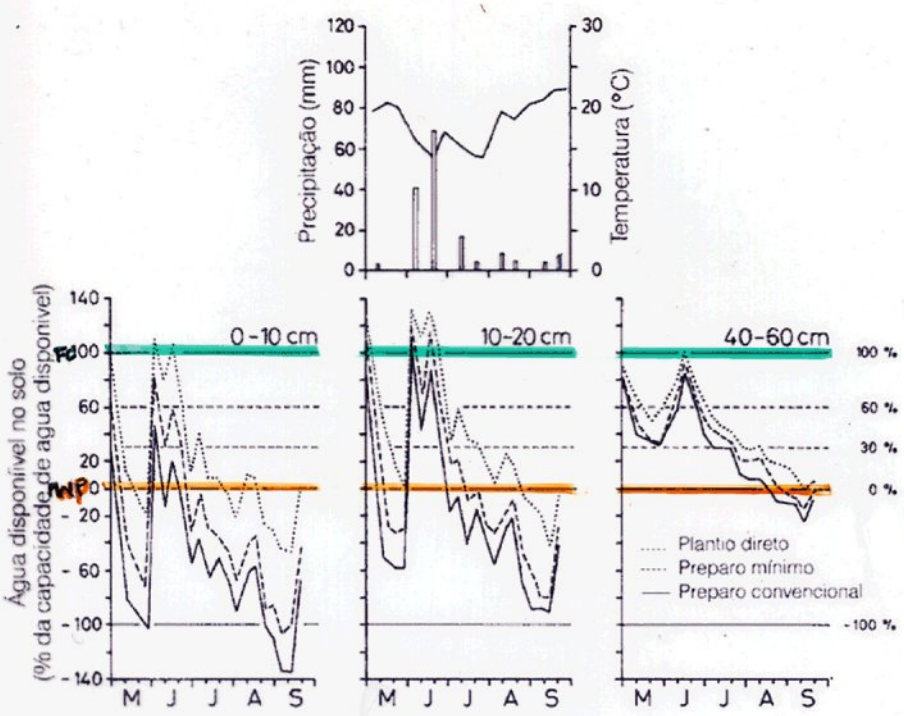

Figure 7: Soil management and plant-available soil water
Source: Derpsch, Roth, Sidiras, Kopke, 1991. *`Controle da erosão no Paraná, Brasil: sistemas de cobertura do solo, plantio direto e preparo conservacionista do solo'*. GTZ, Eschborn. p.76.

Between the first ('Direct drill') and the third ('Conventional') treatments there is a major difference in the duration of plant-available moisture (between Field Capacity and Wilting Point) in the upper 20cm of the soil between May and September of the study-period. The effects of dry weather would have taken effect on the crop much earlier in the plots damaged by conventional tillage than under those maintained under CA management. Stated another way, the crops under the CA system would have continued towards maturity for longer than those in soil with conventional tillage. In addition, the period in which available nutrients can be taken up by plants is also extended, increasing the efficiency of their use.

The greater the volume and longer duration of soil moisture's availability to plants (between the soil's Field Capacity and Wilting Point) under CA treatment has significant positive indications for farming stability and profitability. The range of pore sizes which achieve this also implies the presence of larger pores which contribute to through-flow of incident rainwater down to the groundwater.

The following two photos (Figures 8a, 8b) indicate the above effects on an experimental field near Foggia, Italy.

Figure 8a: This shows the differing appearance of wheat from part under mulch-based zero-tillage for 3 years (in the top-left quadrant beyond the further figure) vs. (in the top-right quadrant) the same variety and fertilizer-treatment but produced with conventional tillage and non-retention of residues from the previous crop.(Photo: TFShaxson)

Figure 8b: Representative ears of wheat from the above two quadrants (taken on same day as upper photo). Greater availability of moisture in the root-zone of that under CA management enabled the plant on the left to continue photosynthesising for some time after that on the right, which had run out of available water and stopped. Subsequently, after harvest, 14% more wheat yield/ha. was recorded from the CA wheat than from the TA wheat. (Photo: Des McGarry)

Infiltration rates under well-managed CA are much higher over very extended periods than in TA due to better soil porosity. In Brazil, a six-fold difference was measured between infiltration rates under CA (120 mm per hour) and TA (20 mm ph hour). CA thus provides a means to maximize effective rainfall and recharge of groundwater as well as reduce risks of floods, due to improved water infiltration. Due to improved growing-season moisture regime and soil storage of water and nutrients, crops under CA are healthier, requiring less fertiliser and pesticides to feed and protect the crop, thus leading to a lowering of contamination of soil, water, food and feed. In addition, in soils of good porosity anoxic zones hardly have time to form in the root zone, thus avoiding problems of the reduction of nitrate to nitrite ions in the soil solution.

Such types of information from soils in good condition under CA provide a range of ‘yardsticks’ against which to compare the benefits of CA and the health of the soil, as against the damages caused by ‘conventional’ tillage agriculture, as discussed below.

5. IMPACTS OF CONSERVATION-EFFECTIVE AGRICULTURE

CA’s impacts can benefit both people and the wider landscapes that surround them. These benefits attract the interest of others, thus contributing to CA’s autonomous spread.

5.1 Some Realisable Impacts at Farm Level [7]

- ✓ Labour, time and farm power are saved through reduced cultivation and weeding requirements.
- ✓ Lower costs because both operations and external inputs are reduced.
- ✓ Mechanical equipment has a longer life-span, lower repair costs, and consumes less fuel.
- ✓ Better movement in the field; less drudgery of repetitive work.
- ✓ More-stable yields, particularly in dry years because more nutrients and moisture are available to the crops.
- ✓ Labour savings provide opportunities for diversification of enterprises and into other activities.
- ✓ Yields are increased even as inputs decrease, to a changed equilibrium state, including lowered demand for fertilisers, pesticides, and energy.
- ✓ Increased profits, in some cases from the beginning; in all cases after a few years, as efficiency of the production system increases.
- ✓ Most or all rainfall is harnessed as effective rainfall, with minimal runoff and soil erosion, leading to longer and reliable moisture regime for crop growth, improved drought proofing, and retention of the upper more-fertile soil layers
- ✓ Increase in biological nitrogen fixation (BNF), in soil organic matter at all levels of the root-zone, (possibly sufficient to sequester carbon at depth after root senescence), as well as in CEC, soil moisture holding capacity, soil biota and general agro-biodiversity.

When increasing areas of land become covered by effective CA, such benefits as listed above extend onwards to the local community and beyond as ecosystem services, and to the three-dimensional catchments in which the farms are located:

5.2 Some Consequent Impacts at Community or Catchment Level

- ✓ More constant water-flow in rivers/streams, improved recharge of the water-table/groundwater, with re-emergence of water in dried-up wells and water sources.
- ✓ Cleaner water because pollution, erosion and sedimentation of water bodies are reduced.
- ✓ Less flooding because infiltration increases; less damage from droughts and storms.
- ✓ Improved sustainability of production systems and enhanced food security.
- ✓ Increased environmental awareness and better stewardship of natural resources.

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[7] After Pieri, Evers, Landers, O'Connell, Terry: '*No-Till Farming for Sustainable Rural Development*'. WB Agriculture & Rural Devt. Working paper; and authors' own observations.

- ✓ Lower costs of municipal and urban water-treatment.
- ✓ Reduced maintenance costs of rural roads.
- ✓ Increased social interactions between members of the local community
- ✓ Improved livelihoods and rural life.

The rate and nature of such improvements due to CA are in positive contrast with what is generally being achieved with ‘conventional’ tillage agriculture (‘TA’).

5.3 Underlying the improvements

Overall, the characteristics of CA enable it to achieve the amelioration, avoidance, or even reversal, of the detrimental effects of tillage systems across a wide range of places and situations which may differ widely in terms of the characters of the land, of farmers’ resources, of social systems and of other factors.

The positive effects at macro-scale derive from the characteristics of the soil when considered as a biological entity at micro-scale (see also 8.2 below).

Two interlinked features distinguish CA from TA:

- Net increase, rather than ongoing decrease, of soil organic matter.
- Improvement in quantities and duration of soil-moisture at plant-available tensions (soil matrix potentials), minimising effects of atmospheric drought on crops.

Common to both are the need for sufficient nutrients to be available to plants at all times when soil-water supply is not limiting.

Successful and effective CA systems are implemented by individuals’ preferences and decisions. An important motivator in many situations is the farmer’s wish to restore, and make more productive, farmland which has been damaged (often unknowingly) as a result of tillage agriculture over the years, and thus jointly to benefit the land on the one hand and his/her family’s livelihood on the other.

For resource-poor farmers in particular, achieving such soil improvements and benefits may take time to achieve fully, through a series of accumulating small improvements. Measures which enable infiltration of the highest proportion of rainfall and thereby minimise losses of potential soil water, may be a first critical stage, together with P and N additions, in starting the upward spiral of improvement.

6. HINDRANCES TO PROGRESS

Main hindrances to faster spread can be listed under the general headings ‘Ecological’, ‘Historical’, and ‘Intellectual’.

6.1 Ecological Hindrance

Africa has wide range of agro-ecologic situations across which more secure and more-productive agriculture systems are urgently required. They pose a range of agro-ecologic and/or socio-economic challenges. Can CA's best effects be achieved in every situation?

Agriculture usually aims to provide more of what people prefer than what the undisturbed ecosystems can or could provide, provoking many ecosystem adjustments which are foreseeable but often ignored, and which may have disastrous results if managed inappropriately. Soils already seriously damaged by past mis-management are degraded resources on which to plant present and future crops. Their remediation needs adjustments in management for restoration and sustainability of productive capacity. Improvements in levels of P in the soil assists the establishment of N-fixing leguminous plants – preferably quick-growing and suitably-inoculated leguminous trees in the worst situations. The N fixed in this form is more-efficiently used than that applied 'from the bag', and together with the P, begins the provision of those plant nutrients essential for subsequent crop growth and function – and subsequent build-up of soil organic matter - in such degraded soils.

6.2 Historical Hindrance

Land which has been 'opened' to agriculture for more than a few decades may have had its productive potential significantly reduced by how it has been managed in the past, resulting in increased costs to maintain level outputs, let alone increase them.

In response to demands of rising human populations, land has been 'opened' on a significant scale over more than 150 years from multi-species (vegetation x soil x animal) ecosystems' natural bush/forest to systems based on many fewer species. 'Modern' agriculture has promoted the almost-universal use of tillage equipment, whose use in many situations has been rapidly followed by significant net losses of soil organic matter due to soil disturbance, at precipitous rates initially followed by more gradual further decline from those low residual levels.

The processes, trends and consequences of organic matter degradation, which are seen in both tropical and temperate regions, may be much more pronounced and accelerated in the warm/hot climates of the tropics than where mean temperatures are lower.

6.3 Intellectual Hindrance

Misapprehensions, hallowed by repetition over time, have hindered attempts at avoidance of, and recovery from, damage to land's productivity. Examples include:

- 'Soil erosion' has commonly been assumed to be the culprit for causing yield decline. The 'Battle against erosion', 'Cancer of erosion' etc. approach failed adequately to analyse problems and missed highlighting actual rather than apparent causes.

  This has occasioned much delay and wasted expenditure. In many cases the farmer-led CA revolution began to 'take off' independently over the past thirty years because of dissatisfaction with the relative ineffectiveness of 'conventional' recommendations about Soil & Water Conservation (SWC).

- Concerns about ‘soil fertility’ are commonly related chiefly to levels of plant nutrients alone and the use of manufactured fertilisers, whereas the phrase ‘soil productivity’ broadens it to include all features affecting soil as a porous rooting environment, a habitat for soil micro-organisms, and a storage for water and nutrients.

- Many people have a perception that ‘agriculture’ implies a need for tillage of the soil in order to produce annual and perennial crops. The significant change in attitude required to embrace CA based on no tillage poses an element of resistance to CA’s more-rapid spread in some parts of the world.

- Many people seem to accept that soil erosion and surface runoff are apparently unavoidable concomitants of ‘normal’ agriculture, leading to scepticism that there are solutions to these problems. CA demonstrates that, except in extreme situations, this is not necessarily true.

- The earlier ‘high-input / high-output ‘Green Revolution’ of recent decades in Asia and the heavily mechanised, and energy-, capital- and input-intensive industrialised approach to standardised farming in the developed regions has often been assumed to be the appropriate model for raising and sustaining agricultural productivity on the African continent and across the developing world from now onwards. However, the Green Revolution’s environmental damages – to quality of soils and biodiversity as well as of irrigation waters – appear to have limited its future sustainability. This calls into question its overall validity as a model for sustainable agricultural development both there and elsewhere, even more so when considered against the new 21st century realities of high energy costs, climate change and water scarcity.

- It is an intellectual hindrance that small resource-poor farmers are commonly considered by others as needing teaching different ways of doing things, and that ‘outsiders’ are the ones with the useful answers. Perceptive experience in the field indicates that farm families are keenly aware of problems and potentials, but are unable to access appropriate or sufficient means of resolving the difficulties. Appropriate assistance may often be related to e.g. availability of small amounts of timely ‘seed-finance’ to initiate an improvement, and/or the enactment of laws which facilitate needed improvements. It may also involve removal of those laws etc. which are found to inhibit relevant development which farmers themselves wish to undertake by adapting some action or object the better to suit their situation. Non-farm agriculturists and others may need to re-examine commonly-held (but often hidden) assumptions about the lives and livelihoods of the families they profess to serve before being able to arrive at truly-appropriate modes of assistance. Somewhat as Dr Samuel Johnson wrote in the 1700s: “*The use of travelling is to regulate imagination with reality, and instead of thinking how things may be, to see them as they are*”.

7. CONSERVATION-EFFECTIVE AGRICULTURE IN SUB-OPTIMAL/PROBLEM AREAS

7.1 Limiting factors

Areas which are less than optimal for introducing CA (with all three key features working in concert) will have a greater number and/or severity of adverse factors capable of hindering plant production and groundwater recharge.

In sub-humid and semi-arid climatic zones it may not be possible to apply the precepts of good Conservation Agriculture to an optimum because insufficiency of rainfall may severely limit how much biomass can be grown per unit area. On the one hand this limits the quantity of harvestable crops; on the other it also limits the amount of residues which are available to serve both as a protective cover to the soil, a substrate for soil improvement, and simultaneously as a source of fodder for animals and as domestic fuel. Fortunately, under these conditions, the decomposition rates also are often lower. If a compromise between different uses of organic matter can be struck, the benefits of CA become visible, although the increase in soil organic matter is slower than under optimal supply levels.

In more humid areas, while water may not be a serious limiting factor, scarcity of particular plant nutrients may prove to be the more significant factors. Relief of e.g. P-deficiency may enable better crop responses to given levels of other inputs, whether human or mechanical energy, fertilizers, improved seeds, etc. Also in the case of phosphate deficiencies the higher biological activity in the soil under CA can improve the P-availability in the long term.

It is always important to identify what might be limiting factors and then, over time at appropriate intervals, regularly to rank their relative levels of importance, thus noting which require the most urgent attention – realising that, as one is mitigated, another may come to the fore.

It is worth noting that improvement of the organic-matter status and activity in the soil can have multiple positive effects which may alleviate/eliminate more than one limiting factor at the same time.

7.2 Concentrating Scarce Available Resources

The objectives of improving the soil's content and activity of organic matter remain the same, namely:

- to improve the soil as a rooting-zone for crops;
- for more efficient use of rainfall (a free good) for both crop production and groundwater recharge,
- for more-productive use of labour/energy and applied inputs.

If resources are in short supply – e.g., water, phosphate, manure - it makes sense to concentrate them to adequate levels in limited areas, e.g., at the crop's planting stations, from which the young plants will derive most early benefit, rather than spread widely but sparsely. In drier areas of the African continent, this is illustrated by the plant-production successes of water-collecting 'tassa' or 'zai', into which the limited quantities of available manure and compost are concentrated, and micro-doses of appropriate fertilizers may be locally applied to greatest effect (Figures 9 and 10).

Figure 1. Left: use of planting basins allows farmer to plant early and get better crop. Right: conventional farmer practice, results in late planting and poorer crop establishment.

From: 'Conservation Farming for Agricultural Relief and Develpoment in Zimbabwe' by Mazvimavi K., and Twomlow S, in No-Till Farming Systems. WASWC, 2007, p.169

Figure 9: (rephotographed from Goddard, Zoebisch, Gan, Ellis, Watson, Sombatpanit, (eds.) 2008. No-till farming systems. Bangkok: World Assoc. Soil & Water Conservation. WASWC Special Publicn. No 3, p.169

Figure 13 Burkina Faso: zay concentrate water and nutrients

Figure 10: "Burkina Faso: zai concentrate water and nutrients"
(rephoographed from Critchley, Reij and Turner, 1992. 'Soil and water conservation in sub-Saharan Africa'. Rome, IFAD. p.47, Fig. 13.)

igure 5 Without *tassa* nothing can be harvested on barren degraded land

Figure 11: "Without tassa nothing can be harvested on barren degraded land" (Niger)
(Rephotographed from Hassane, Martin, and Reij, 2000. 'Water harvesting, land rehabilitation and household food security in Niger'. Rome: IFAD. p.21, Fig. 5)

It is therefore becoming increasingly clear that degraded lands, even in the dry tropics such as Niger (Figure 11), can be rehabilitated and soil productive capacity regenerated by applying the principles of CA as with tassa or zai systems.

7.3 Reaching the Groundwater

The greater the proportion of a field's area or, preferably, of a catchment that is treated with these 'small basins of water concentration', the greater will be the proportion of rainfall captured and infiltrated from the surface down to depth, per hectare of land surface, (rather than running off). Then the greater will be the likelihood of such water as is in excess of crop requirements reaching the groundwater and maintaining or raising the level of the sub-surface water-table, which is tapped by wells and boreholes and which also is the source of streams' and rivers' flows.

7.4 Enhancing Fertilizers' Effectiveness

It should be noted that in tillage-agriculture situations, while purchased fertilisers alone may be able to raise crop yields significantly where insufficient plant nutrients have been the major limiting factor, they will not, of themselves, result in sustainable improvements in porosity of the soil and hence of soil moisture conditions. For this, adequate supplies of organic matter need regularly to be provided to 'feed' the soil biota, as is the case with 'classic' Conservation Agriculture systems. On the scale of a stream's catchment this is clearly essential in order to maintain the land's ongoing capacities to yield both vegetation <u>and</u> water every year.

7.5 Keep the Carbon-Gains: Avoid Tillage

From studies of effects of tillage on oxidation of soil carbon reserves, it becomes clear that, after a net accumulation of organic matter has been achieved in the previous year, a single severe tillage operation could result in the loss by oxidation of much or all the carbon previously gained.

If, for reasons of e.g. soil compaction by animal trampling, it is necessary to disturb the soil again, such disturbance should be as limited as possible – in both area and severity of disturbance - consistent with achieving the required result, in order to safeguard as much of the soil organic matter as possible from being oxidised. The soil aggregates may have taken many months to build up, but their destruction may take only a few days. Strip-tillage between rows of mulch in the crop-lines may be useful in some situations, such as on moist soils under cold climatic conditions: it is preferable to conventional whole-field tillage, but is has some disadvantages compared with no tillage.

7.6 Minimising Areas of Compaction

If wheeled machinery is to be used in the farming operation and if irreversible soil compaction cannot safely be avoided by lowering the contact pressure on the soil, it is advisable to limit the compaction thus caused into permanent 'tramlines' which are used for every operation, thereby not damaging the surface porosity already achieved on the majority of the area.

8. THINKING UNCONVENTIONALLY

It is helpful not to feel completely constrained by the dogma of conventional approaches to problems encountered. A more free-ranging mind may see unconventional possibilities for solving problems. Here are three examples:

8.1 “Soil Erosion is Not *Caused* by Deforestation, Overgrazing, Excessive Cultivation”

Common responses have been to promulgate laws and other pressures on farmers to abandon such practices, but with almost no lasting success. However, by considering three components that all three ‘causes’ have in common (Figure 12), we can discern other possible ways of tackling the erosion problem.

> SUPPOSED ‘CAUSE’> **RELEVANT v COMPONENT v**	**Deforestation**	**Overgrazing**	**Excessive cultivation**
Loss of organic matter on and in soil	√	√	√
Loss of soil porosity	√	√	√
Loss of plant cover	√	√	√

Figure 12: Re-thinking the supposed causes of erosion

8.2 “For Purposes of Natural Resource Management, Soil Should be Re-defined as a Biological Entity – Rather than a Geological One”

With respect to management of living natural resources, there is a case to be made for re-defining soil primarily as a biological – rather than a geological – entity. This would focus attention on how best to improve its capacities to yield vegetation and water.

‘…Society might take better care of soil if it were considered less as an inorganic physical unit of mineral particles, air, water and nutrient ions that happens to contain life, but more descriptively as a living system, a complex and dynamic subsurface ecosystem of diverse living organisms (including plant roots), non-living organic matter, and biologically-transformed organic/humic products, which inhabits, modifies and interpenetrates an inorganic mix of mineral particles, air, water and nutrient ions, and which changes dynamically over the fourth dimension of time’.[8]

As already indicated, considering soil in this light, and treating it accordingly, can be expected to result in greater profitability of farming enterprises and in rising benefits to the wider society.

Related to this is the concept of ‘soil health’, of which two similar definitions are given in Annex 1. The definitions are readily compatible with the characteristics and objectives of Conservation Agriculture as discussed in this paper.

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[8] Shaxson T.F. 2006 .in*: Re-thinking the conservation of carbon, water and soil: a different perspective*. In: Agronomie/Agron. Sust. Dev., 26, 1-9.

8.3 Working in Farmers' Own Contexts: Dissemination for Adaptation of CA Practices through Farmer Field Schools

CA is knowledge-intensive farming practice requiring farmers to understand and develop capacity to test and integrate CA principles and practices into their own farming systems to fully harness the benefits offered by CA. Through a Farmer Field School approach, it has been possible to introduce and disseminate appropriate CA practices into many countries across Africa, and there have been notable successes. In the context of a Farmer Field School, individual farmers may prove to be the best judges of what could work best for them to put CA principles into practice in their own particular situations. Farmer Field Schools offer an effective mechanism to set up a process of farmer discovery adoption and adaptation learning in order to accelerate CA's positive impact on livelihoods, food security, economic development and the environment.

9. KEY AREAS FOR FURTHER INVESTIGATIONS

9.1 Topics Common to All CA Systems.

Topics that are common to all CA systems are:

- *Rebuilding 'last-resort' resistant reserves of s.o.m.:* What is the best way to rebuild s.o.m. reserves with special reference to the more resistant materials which provide stores of organic complexes with nutrient ions that provide 'last resort' provisions before the soil becomes of very little value for plant production?

- *Characterise the changes in relative ranking of limiting factors over the process/sequence of soil improvement:* At a given site where a soil has become degraded, an understanding is important of what is the relative ranking among the biologic, physical, chemical and hydric factors which currently limit its productivity, so as to know at, a given stage, which to address with priority in actions to improve the situation. This might include some "urgent repair" actions before even starting conversion to CA". Priorities may change as the soil condition improves over time, indicating the nature of what changes in management should follow to optimise the rate of ongoing improvement in soil condition. Undertaking of such investigations in different agroclimatic zones will help to clarify the dynamics of soil improvement as a basis for better-informed decision-making at all levels, from field to national institutions.

- *Characterising effects of induced changes soil conditions which result in improved infiltration and percolation:* Greater understanding and enlightenment is required of the dynamics of soil water with regard to reaching deeper roots and movement down to groundwater once infiltration capacity through the surface layer has been achieved and safeguarded. This would help to link the interests of farm-families – as both agriculturists and as users of water – and those of the wider society concerned about water reserves and streamflow maintenance. Repeats of soil-water 'tracking' over time, as shown in Fig. 7 (above) would enable effective comparison of relative benefits/dis-benefits of adopting one vs. another strategy for improvement the soil and/or management method

- *Contributions of different types of organic-matter input to soil health conditions*: It is clear that different types of organic matter result in different products of microbial breakdown and transformation (e.g., differences in effects of e.g., leaves of *Tithonia sp.*, wheat straw, cattle manure, charcoal, sawdust, etc.) on soil conditions and plant responses.

- *Identifying readily-usable indicators of agro-ecosystem changes and condition:* Farmers and others will want to know whether their CA systems are improving in soil health and having the expected positive effects as time progresses. Such indicators as changes in weed flora, associations of insect species, associations of micro-organisms, condition of soil architecture, frequency and severity of runoff, could facilitate regular monitoring, enabling the plotting of the trajectories of change as CA's effects intensify.

- *How to integrate cattle and other animals with CA crop-production system?:* Livestock might be a problem since it creates competition for the use of residues as forage. On the other side livestock-keeping provides economic benefits in growing forage crops and with this gives opportunities to diversify crop rotations, which makes them healthier and increases the overall productive capacity of the production system. In what ways can balances be struck between the (complementary) needs for feeding animals and feeding the soil?

- *Appropriate support and assistance to farmers using CA:* When, in a particular country, there is sufficient convincing evidence of the benefits to be derived from its wider spread, what administrative and legal arrangements would best serve to support the initial practitioners as they make the transition from TA to CA but also encourage others to join the CA revolution?

- *Quantify and document rates of CO_2 flux to atmosphere* after differing severities and types of tillage, in different *tropical* situations, in comparison with rates from no-till CA systems in the same regions.

9.2 Topics More Specific to Particular Environmental Conditions and Crop Preferences

Topics that are more specific to particular environmental conditions and crop preferences are:

- *Characteristics of sequences of crops, including green manure/cover crops*, to make up manageable rotations in CA systems for particular localities, e.g., humid/subhumid/semi-arid regions; sandy/clayey/silty soil areas; subsistence farming/market-oriented farming etc.

- *Weed management:* Weed-control poses difficulties in many situations, especially where farmers do not have the resources to buy herbicides and equipment appropriate to their particular situations. Ranges of strategies need to be available to farmers which are appropriate to the weed flora, the rotational sequence and system, and the farmer's resource endowments. Crop rotations, permanent soil cover and the avoidance of bringing weed seeds to germination are important parts of the weed management strategies under CA.

- *Pest management:* Comparable comments apply in the case of pest management. For both weeds and pests, the concepts and practices of Integrated Weed / Pest Management appear likely to fit well into CA systems.

- *Determine optimum combinations* of soil organic matter x manufactured fertilisers for soil/plant system nutrition in different agro-ecologic situations.

- *Put an economic value on saved rainwater:* Rainwater is assumed to be a 'free good' when programmes and projects are put together and their likely costs and benefits calculated. The change from tillage agriculture (TA) to CA systems can result in prolongation of plant-available soil moisture which can translate into more-secure and potentially higher yields (as shown above). Rainfall may be free at point of entry, but it gains a potential measurable positive value once it is in the reach of crops' roots. By contrast, avoidable runoff - as lost potential soil moisture – can similarly be given a negative value.

- *Ensure appropriate climatic and soil variables are recorded* regularly and in sufficient frequency and detail throughout long-term experiments, as an aid to more-detailed interpretation of results than is possible when such data are not available.

10. CONCLUSIONS

10.1 Changes

Both Conservation Agriculture and Tillage Agriculture cause soil changes – but in opposite directions.

Benefits of CA reach far beyond minimising water runoff and soil erosion (though this is often stated as a first reason why farmers adopt it). It has profound ongoing beneficial effects on the soil as a rooting environment and as a receiver, store and downward transmitter of rainwater translating into improved ecosystem services.

The living and non-living components of organic matter together have catalytic effects on the capacity of the soil to provide both vegetation and water. Conversely, insufficiency of organic matter in soils limits soils' productivity and sustainability and diminishes the efficiency of use of applied inputs to agricultural plant/soil systems.

The consequences have positive repercussions on the stability, sustainability and profitability of farming.

10.2 Response

A response to the challenge of reversing the trend of land degradation is to spread the application of better systems of land husbandry – of which well-managed CA is a prime example - which are capable of reversing these adverse trends and of repairing past damages to ecosystem functions caused by tillage agriculture (TA).

CA, in optimum agro-ecologic conditions, has been demonstrated to be capable of causing this reversal of trends, repairing past damage due to tillage agriculture (whether practised without or with heavy use of agrochemicals and energy), and restoring sustainability to soils' productivity.

The fact that autonomous spread of CA occurs outward from farmers who have already made the transition demonstrates that its benefits are both welcomed and repeatable and that the appropriate CA systems are workable by farmers.

The further spread of CA into a wide range of other agro-ecological situations then depends on understanding the principles which underlie CA's successes, and devising appropriate systems for each new situation, in which the practices enable the principles to have fullest positive effect.

10.3 Illuminations

Now it is possible to work with a positive approach:

'How can we make things even better, and in so doing avoid the old problems?' rather than with the old negative approach:

'How can we stop soil erosion?

It is now possible to see:

- How and why well-applied CA works.
- How damaged land can become restored to usefulness and productivity.
- Why and how mismanaged soils degrade.
- How long bush fallows used to have their positive effects in extensive low-intensity agricultural systems, and why short breaks of recuperative grass were important (though not necessarily sufficient) in conventional tillage-agriculture systems.
- Why 'soil erosion' is a consequence, not a primary cause, of soil degradation.
- Why soil 'in good condition' limits the duration of climatic drought's effects.
- What is the real basis of sustainability in agriculture?

10.4 Green Revolution, Blue Revolution

Following its many and widespread successes, the Green Revolution of the 1960s and 1970s based on HYVs and high inputs of fertilizer, pesticides and irrigation water appears to have reached plateaux of crop production, partly, at least on account of degradation of soil and water resources.

Conservation Agriculture appears to have the capacity also to raise but also stabilise yields, to restore productivity of damaged soils, and to improve supplies of usable water. Because water is likely to become increasingly scarce with respect to rising demands, perhaps CA deserves to be called the coming 'Blue Revolution'.

10.5 Think Like a Root, Like a River

Perceiving the soil as a *biotic* entity encourages thinking about not only soil organic <u>matter</u> but also soil biotic <u>processes</u>. Broadening this to considering how these are linked with catchments' yields of plants and of water also suggests '*Think like a root; think like a river'* as a way of working out what features of the soil in a particular situation would be most appropriate for both those yields to be achieved on a recurring basis. If, when both need improvement, they are treated only as separate subjects there is danger that the solutions proposed for one problem – poor crop yields – may become problematic for the achieving; other – water yields, and *vice versa*. This takes you back into the body of this paper with its pointer that, in particular, the porosity of soil and how that is improved and maintained is a key to ameliorating both problems together. For example, construction of big dams as a solution to water-shortage problems almost always has been without giving timely prior attention to improving the conditions of the soil in the catchment, with consequent resulting loss of capacity by sedimentation much faster than assumed. Conversely, application of unnecessarily high quantities of mineral fertilisers to croplands which have poor and unimproved porosity can result in pollution of the streams that flow from the catchment to which they were applied.

10.6 Replacing the 'Tillage Presumption'

The successes of well-managed Conservation Agriculture systems point to the occurrence of a positive revolution in practice, behind which is the revolution in thinking on the part of the farmers involved, and on the part of those who assist and advise them. While much of 'the message' spreads farmer-to-farmer within and between generations, this is not yet necessarily, nor automatically, so in the case of those institutions responsible for pre-and in-service training of future advisers and others serving the farmers. The concepts, key components and effects of Conservation Agriculture need now to form the core of such training, such that the 'tillage presumption' no longer occupies that upper position.

10.7 Reducing the Reasons for Fighting Over Access to Water and Land

The widespread adoption of CA principles and practices will make positive contribution to food supplies and food security and to the greater availability of clean water in groundwater and streams. This will delay and minimise the pressures to fight over access to farmland and water supplies as adverse effects of both population increase and climate change together put increasing pressures on these vital resources.

10.8 Good Land Husbandry

Well-managed and effective systems of conservation agriculture provide excellent examples of good land husbandry, of which a prime effect is re-vitalisation and maintenance of soil health for crop intensification and ecosystem services. The excellent soil conditions which can develop and be maintained with well-managed conservation-effective agricultural systems provide the criteria against which all other forms of soil management should be compared.

11. ENVOI

'Such people [are] driven by a desire to make no-tillage as sustainable and risk-free as possible, and in the process make food production itself sustainable for the first time in history. … The results have been significant and will have far-reaching consequences[9] .

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[9] Baker, Saxton, Ritchie, Chamen, Reicosky, Ribeiro, Justice, Hobbs, (2007): *No-tillage Seeding in Conservation Agriculture – Second edition*. FAO and CABI. The dedication note.

ANNEX 1

SOIL HEALTH

While there is much talk of 'soil quality' as if it were a static and sufficient characteristic, there is less-frequent mention of 'soil health', referring particularly to the biological dynamics of soil quality.

"*Below are 1) the ideas of David Wolfe at Cornell University and 2) Peter Trutmann's comments on Doran and Zeiss' definition of soil health that appeared in Applied Soil Ecology (15:3-11) during 2000:*

'1) Soil health refers to the integration of biological with chemical and physical approaches to soil management for long term sustainability of crop productivity with minimal impact on the environment. "Healthy" soils maintain a diverse community of soil organisms that: help to control plant disease, insect and weed pests: form beneficial symbiotic associations with plant roots (e.g., nitrogen fixing bacteria and mycorrhizal fungi); recycle essential plant nutrients; improve soil structure (e.g., aggregate stability) with positive repercussions for soil water and nutrient holding capacity; and ultimately improve crop production. Examples of management practices for maximizing soil health would include: maintaining vegetative cover on the land year-round to increase organic matter input and minimize soil erosion; more reliance on biological as opposed to chemical approaches to maintain crop productivity (e.g., rotation with legume and disease-suppressive cover crops); and avoiding use of heavy equipment on wet soils to avoid soil compaction.

David W. Wolfe, Ph.D.
Professor, Dept. of Horticulture
Cornell University
Ithaca, NY

'2) *Soil health is the capacity of soil to function as a vital living system, with ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health* (Doran and Zeiss, 2000, Applied Soil Ecology 15:3-11). This definition indicates need of the soil to function as a vital living system to sustain biological productivity, promote environmental quality and maintain plant and animal health. To us 'soil health' emphasizes a unique property of biological systems, since inert components cannot be sick or healthy. Management of soil health thus becomes synonymous with 'management of the living portion of the soil to maintain the essential functions of the soil to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health'.

Dr. Peter Trutmann
Director
International Integrated Pest Management
Cornell University
Ithaca, NY 14853-4203"

Both statements dated 2000 or later.

From: http://ppathw3.cals.cornell.edu/mba_project/moist/TropSCORE.html (seen Feb. 23rd, 2008).'Worldwide Portal to Information on Soil Health' Homepage Index 1C.
TropSCORE –The Consortium for Tropical Soil Cover and Organic Resources Exchange

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ANNEX 2

A FEW, OUT OF MANY, TITLES OF ADDITIONAL RELEVANT REFERENCES:

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