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An ecologically sustainable approach to agricultural production intensification: Global perspectives and developments

Une approche écologiquement durable de l'intensification de la production agricole : perspectives globales et développements

Un enfoque ecológicamente sostenible de la intensificación de la producción agrícola: perspectivas globales y avances

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An ecologically sustainable approach to agricultural production intensification: Global perspectives and developments[1]

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Abstract. The root cause of agricultural land degradation and decreasing productivity–as seen in terms of loss of soil health–is our low soil-carbon farming paradigm of intensive tillage which disrupts and debilitates many important soil-mediated ecosystem functions. For the most part agricultural soils in tillage-based farming without organic surface residue protection are becoming de-structured and compacted, exposed to increased runoff and erosion, and soil life and biodiversity is deprived of habitat and starved of organic matter, leading to decrease in soil's biological recuperating capacity.

Conservation Agriculture (CA) is a cropping system based on no or minimum mechanical soil disturbance, permanent organic mulch soil cover, and crop diversification. It, is an effective solution to stopping agricultural land degradation, for rehabilitation, and for sustainable crop production intensification. CA is now adopted by large and small farmers on some 125 million hectares across all continents and is spreading at an annual rate of about 7 million hectares.

Advantages offered by CA to farmers include better livelihood and income, decrease in financial risks, and climate change adaptability and mitigation. For the small manual farmer, CA offers ultimately up to 50% labour saving, less drudgery, stable yields, and improved food security. To the mechanised farmers CA offers lower fuel use and less machinery and maintenance costs, and reduced inputs and cost of production (including labour when CA involves the use of integrated weed management.

In pro-poor development programmes, every effort should be made to help producers adopt CA production systems. This is because CA produces more from less, can be adopted and practiced by smallholder poor farmers, builds on the farmer's own natural resource base, does not entirely depend on purchased derived inputs, and is relatively less costly in the early stages of production intensification.

Keywords. Conservation Agriculture, paradigms, no-till system, ecosystem approach.

1 Introduction

Challenges arising from global economic and population growth, pervasive rural poverty, degrading natural resources in agriculture land use, and climate change are forcing ecological sustainability elements to be integrated into agricultural production intensification. The situation has been exacerbated by the fact that the quality and direction of the dominant, tillage-based, agricultural production systems world-wide, and the agricultural supply chains that support them, have moved dangerously off course onto a path of declining productivity and increasing negative externalities (MEA, 2005; WDR, 2008; McIntyre *et al.*, 2008; Foresight, 2011). This path is considered to be unsustainable ecologically as well as economically and socially, and is being driven by the consequences of unquestioned faith and reliance on the dominant 'industrialised agriculture' mentality of technological interventions of genetics and agrochemicals in tillage-based agriculture (DEFRA, 2002, 2008; Kassam, 2008). Now increasingly known as the 'old paradigm', this way of farming since WWII was seen as the best option for production intensification and agricultural development to keep hunger and famine at bay after WWII. Subsequently, this paradigm was thought to be a partial solution also for poverty alleviation in the developing countries.

This version of agriculture, whether industrialised or not, in which the soil structure, soil life and organic matter are

[1] The views expressed in this paper are those of the author and not of FAO.

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mechanically destroyed every season and the soil has no organic cover, is no longer sufficiently adequate to meet the agricultural and rural resource management needs and demands of the 21st century. The future requires farming to be multi-functional and at the same time ecologically, economically and socially sustainable so that it can deliver ecosystem goods and services as well as livelihoods to producers and society. Farming needs to effectively address local, national and international challenges. These challenges include: food, water and energy insecurity, climate change, pervasive rural poverty, and degradation of natural resources.

It is now clear that the root cause of our agricultural land degradation and deceasing productivity–as seen in terms of loss of soil health–is our low soil-carbon farming paradigm of intensive tillage which disrupts and debilitates many important soil-mediated ecosystem functions. The decrease in soil carbon due to tillage occurs even more rapidly in the tropics due to higher temperatures compared with temperate zones. For the most part our soils in tillage-based farming without organic surface residue protection are becoming de-structured, our landscape is exposed and unprotected by organic mulch, and soil life is deprived of habitat and starved of organic matter. Taken together, this loss of soil biodiversity, increase in soil organic matter decease, destruction of soil structure and its biological recuperating capacity, increased soil compaction, runoff and erosion, and infestation by pests, pathogens and weeds, reflect the current degraded state of the health of many of our soils globally (Montgomery, 2007).

Further, the condition of our soils is being exacerbated by: (a) applying excessive mineral fertilisers on to farm land that has been losing its ability to respond to inputs due to degradation in soil health, and (b) reducing or doing away with crop diversity and rotations (which were largely in place around the time of WWII) due to agrochemical inputs and commodity-based market forces. The situation is leading to further problems of increased threats from insect pests, diseases and weeds against which farmers are forced to apply ever more pesticides and herbicides, and which further damage biodiversity and pollute the environment.

However, we also know that the solution for sustainable farming has been known for a long time, at least since the mid-thirties when the mid-west of USA suffered massive dust storms and soil degradation due to intensive ploughing and harrowing of the prairies. For instance, in 1943, Edward Faulkner wrote a book '*The Ploughman's Folly*' in which he stated that there is no scientific evidence for the need to plough. More recently, David Montgomery in his well-researched book '*Dirt: The Erosion of Civilizations*' shows that generally with any form of tillage including non-inversion tillage the rate of soil degradation (loss of soil health) and soil erosion is greater than the rate of soil formation. According to Montgomery's research, tillage has caused the destruction of agricultural resource base and of its productive capacity nearly everywhere throughout human history, and continues to do so.

For these natural science writers as far back as 1943, tillage is not compatible with sustainable agriculture. We only have to look at the various international assessments of the large-scale degradation of our land resource base and the loss of productivity globally to reach a consensus as to whether or not the further promotion of any form of tillage-based agriculture is a wise development strategy. We contend that to continue with intensive tillage agriculture now verges on irresponsibility towards society and nature. Thus we maintain that with tillage-based agriculture in all agro-ecologies that can meet climatic, soil and terrain requirements for crop growth, no matter how different and unsuitable they may seem for no-till farming, crop productivity (efficiency) and output *cannot be optimized* to the full potential. There might be environments and situations, for example water logging, where no-tillage would not work satisfactorily. But if the root problems in those cases cannot be addressed differently, for example by drainage, it is questionable whether tillage based farming would be advisable under these conditions as alternative. Crop farming in such places should better be abandoned. Further, agricultural land under tillage is not fully able to deliver the needed range and quality of environmental services that are mediated by ecosystem functions in the soil system. Obviously, something must change.

2 Farming paradigms

Essentially, we have two farming paradigms operating, and both aspire to sustainability. (1) The tillage-based farming systems, including intensive tillage with inversion ploughing during the last century, aims at modifying soil structure to create a clean seed bed for planting seeds and to bury weeds or incorporate residues. This is the *interventionist paradigm* in which most aspects of crop production are controlled by technological interventions such as soil tilling, modern varieties, protective or curative pest, pathogen and weed control with agrochemicals, and the application of mineral fertilizers for plant nutrition. (2) The no-tillage farming systems, since the forties or so, allow for a predominantly ecosystem approach, and can be productive and ecologically sustainable. This is the *agro-ecological paradigm* characterised by minimal disturbance of the soil and the natural environment, use of traditional or modern adapted varieties, plant nutrition from a mix of organic and non-organic sources including biological nitrogen fixation, an integrated approach to pest management leaving curative pesticides as a last resort, and the use of both natural and managed biodiversity to produce food, raw materials and other ecosystem services. Crop production based on an ecosystem or agro-ecological approach can sustain the health of farmland already in use, and can regenerate land left in poor condition by past misuse.

The post-WWII agricultural policy placed increasing reliance upon 'new' high yielding seeds, more intensive tillage of various types and heavy and more powerful machines, combined with even more chemical fertilizers, pesticides and herbicides, and mono-cropping. According to our reading, factories producing nitrates for manufacturing explosives needed for WWII quickly had to find an alternate market once the war ended. The crop production sector was a sitting target for the explosives salesmen who went around

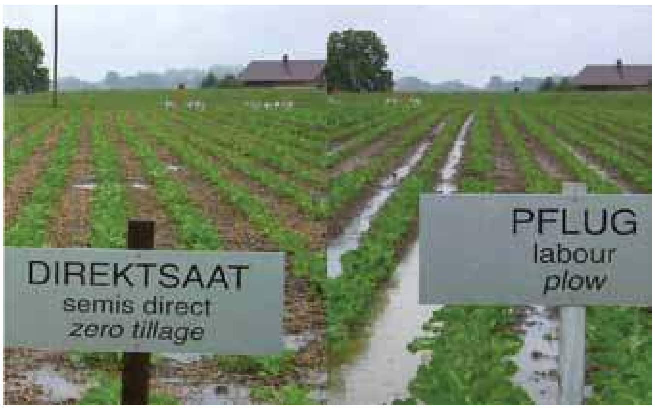

Figure 1. Consequence of intensive-tillage paradigm. Notice that due to soil compaction and loss in water infiltration ability caused by regular soil tillage leads to impeded drainage and flooding after a thunder storm in the ploughed field (right) and no flooding in the no-till field (left). Photograph taken in June 2004 in a plot from a long-term field trial "Oberacker" at Zollikofen close to Berne, Switzerland, started in 1994 by SWISS NO-TILL. The three water filled "cavities" in the no-till field derive from soil samples taken for "spade tests" prior to the thunder storm.
(Credit: Wolfgang Sturny)

convincing farmers that high yields and more profit could be obtained with mineral nitrogen and that there was presumably no real need for crop diversification and rotations with legumes or for adding organic sources of plant nutrients or animal manure. This technological interventionist approach became the accepted paradigm for production intensification, and was promoted globally along with genetically enhanced modern varieties–referred to as the Green Revolution paradigm of the 50's and 60's that included the Asian Green Revolution particularly in the irrigated rice-wheat systems in the Indo-Gangetic Plains of south Asia. While the Green Revolution raised crop yields and total output of food staples, and averted a looming food crisis in south Asia, it also resulted in the following situation in most agricultural landscapes in the tropics and outside in the sub-tropics and temperate environments:

- loss of SOM (soil organic matter), porosity, aeration, biota (=decline in soil health) -> collapse of soil structure -> surface sealing, often accompanied by mechanical compaction, -> decrease in infiltration -> waterlogging -> flooding) (Figure 1);
- loss of water as runoff and of soil as sediment;
- loss of time, seeds, fertilizer, pesticide (erosion, leaching);
- less capacity to capture and slowly release water and nutrients;
- less efficiency of mineral fertilizer: "*The crops have become 'addicted' to fertilizers*";
- loss of biodiversity in the ecosystem, below & above soil surface;
- more pest problems (breakdown of food-webs for micro-organisms and natural pest control);
- falling input efficiency & factor productivities, declining yields;
- reduced resilience, reduced sustainability;
- poor adaptability to climate-change and its mitigation; and
- *higher production costs, lower farm productivity and profit, degraded ecosystem services.*

3 A solution: no-till agro-ecological system

Conservation Agriculture (CA), also known as a 'no-till' farming system, is an effective solution to stopping agricultural land degradation, for rehabilitation, and for sustainable crop production intensification. CA has gained momentum in North and South America, in Australia and New Zealand, in Asia in Kazakhstan and China, and in the southern Africa region. CA has the following three core inter-linked principles (Friedrich *et al*., 2009):

- **No or minimum mechanical soil disturbance** and seeding or planting directly into undisturbed or untilled soil, in order to maintain or improve soil organic matter content, soil structure and overall soil health.
- **Enhancing and maintaining organic mulch cover on the soil surface**, using crops, cover crops or crop residues. This protects the soil surface, conserves water and nutrients, promotes soil biological activity and contributes to integrated weed and pest management.
- **Diversification of species**–both annuals and perennials - in associations, sequences and rotations that can include trees, shrubs, pastures and crops, all contributing to enhanced crop and livestock nutrition and improved system resilience.

These principles and key practices appear to offer an entirely appropriate alternative to most modern and traditional tillage-based agricultural production systems in the tropical, sub-tropical and temperate agro-ecologies, with a potential capacity to slow and reverse productivity losses and environmental damages. In conjunction with other complementary good crop management practices for integrated crop nutrition, pest and water management, and good quality adapted seeds, the implementation of the CA principles provide a solid foundation for sustainable production intensification. These principles can be integrated into most rainfed and irrigated production systems to strengthen their ecological sustainability, including horticulture, agro-forestry, organic farming, System of Rice Intensification (SRI), 'slash and mulch' rotational farming, and integrated crop-livestock systems,

CA is a lead example of the agro-ecological paradigm for sustainable production intensification now adopted by FAO as seen in its recent publication '*Save and Grow*'. Empirical evidence shows that farmer-led transformation of agricultural production systems based on Conservation Agriculture (CA) is gathering momentum globally. CA, comprising minimum

Table 1. Area under CA by continent

Continent	Area (hectare)	Percent of total
South America	55,464,100	45
North America	39,981,000	32
Australia & New Zealand	17,162,000	14
Asia	4,723,000	4
Russia & Ukraine	5,100,000	3
Europe	1,351,900	1
Africa	1,012,840	1
World total	124,794,840	100

mechanical soil disturbance (no-till and direct seeding), organic soil cover, and crop species diversification, is now estimated to be practiced globally on about 125 M ha (some 9% of global arable cropland) across all continents (Table 1) and all agricultural ecologies, with some 50% of the area located in the developing regions. During the last decade, cropland under CA has been increasing yearly at a rate of some 7 million hectares, mainly in the Americas, Australia, and, more recently, in Asia and Africa (Friedrich *et al*., 2012).

For the farmer the initial drivers for adoption of CA are mostly erosion or drought problems, as well as cost pressure. However, drivers of change that are valid for large scale farmers are different from small-scale farmers. Water erosion has been the main driver in Brazil, wind erosion and cost of production in the Canadian and American Prairies, and drought and cost issues in Australia and Kazakhstan. More recently, concern about the economic and environmental unsustainability of traditional approaches to agriculture internationally, including small-scale farming in Africa and Asia, has stimulated governments to seriously consider CA whose principles can be implemented by small or large farmers in most agro-ecologies to raise productivity and harness environmental services, avoid and recuperate from land degradation, and respond to climate change.

In the adoption of or transformation to CA, there are constraints and opportunities that must be addressed in different ways in different places depending on their nature. These include:

- Weeds that can be controlled using integrated management practices involving a combination of surface mulch, cover crops, rotations, mechanical management and herbicides.
- Net labour requirement which by and large is reduced over time with increase in labour productivity (in terms of output per unit input) in all CA systems whether with manual, animal or mechanised farm power.
- Larger farmers are not the only beneficiaries of CA. Small farmers with any farm power source can practice CA and harness a range of benefits. Similarly, field-based horticulture production can also benefit from CA, whether small or large scale.
- Livestock can create a competition for residues but over time CA generates more biomass which can permit effective management of functional biomass to meet the needs of livestock and of soil health. A combination of on-farm livestock management and area integration of crop-livestock with community participation provides a basis for overcoming this constraint.
- Temperate areas of Europe are claimed to be different from other areas where CA has been widely adopted. This appears to be a myth, as seen from the viewpoint of almost a 'wholesale' transformation to CA in some states in Canada and in Western Australia and parts of USA, and more recently the introduction and growing evidence of CA in Finland, Switzerland, UK, France, Italy, Germany and Denmark.

Constraints to CA adoption appear to be surmountable for up-scaling when:

- Farmers are working together in testing and sharing experience and generating new knowledge, and using the innovation network approach as an effective way of CA extension.
- Appropriate and affordable no-till equipment and machinery is available.
- There is relevant and problem solving knowledge generation and technical capacity in the research and extension system to offer advice to farmers, industry and policy makers.
- Eventual risks involved in transforming to no-till systems are buffered through appropriate insurances and/or incentives.
- There is effective policy and institutional support for adoption and widespread uptake.

In the developing regions, especially among larger mechanized farms there has been spontaneous adoption of CA. However, the adoption process more generally, including for small holder farmers, is still slow and has not yet entered into the exponential uptake phase. In recent years the situation has begun to change in Asia and Africa and there is already growing government commitment and programmes in these regions to promote CA, including for small scale farmers. In Africa, the Southern Africa region is at an advanced stage of early adoption with countries such as South Africa, Zambia, Zimbabwe, Mozambique, Malawi and Tanzania leading the way. In Asia, small farmers in China and India and large farmers in Kazakhstan have made significant progress with no-till systems in recent years. However, a more coordinated approach and harmonized policy will be needed for CA to really take off and provide benefits to small holder farmers and bring land degradation under control. Empirical evidence across many countries has shown that the rapid adoption and spread of CA requires a change in behaviour of all stakeholders. For the farmers, a mechanism to experiment, learn and adapt is a prerequisite. Policy-makers and institutional leaders need to fully understand the longer-term productivity, economic, social and environmental benefits of CA for producers and the society at large.

4 CA–an opportunity to save and make money, alleviate rural poverty internationally and to improve the planet

Advantages offered by CA to small or large farmers include better livelihood and income. For the small farmer under a manual system, CA offers ultimately 50% labour saving, less drudgery, more stable yields, and improved food security. To the mechanised farmers CA offers lower fuel use and less machinery and maintenance costs. Reduced cost of production with CA is a key to better profitability and competitiveness, as well as keeping food affordable.

Against the background of rising input, food and energy costs, land degradation and climate change, experience of switching to CA confirms that the known advantages include higher soil carbon levels, microorganism and meso fauna activity over time, minimisation or avoidance of soil erosion, the reversal of soil degradation, improved aquifer recharge due to greater density and depth of soil biopores due to more earthworms and more extensive and deeper rooting. CA advantages also include adaptation to climate change due to increased infiltration and soil moisture storage and increased availability of soil moisture to crops, reduced runoff and flooding, and improved drought and heat tolerance by crops, and climate change mitigation through reduced emissions due to 50-70% lower fuel use, 20-50% lower fertilizer/pesticides, 50% reduction in machinery and use of smaller machines, C-sequestration of 0.20-0.7 or more $t\,ha^{-1}\,y^{-1}$ depending on the ecology and residue management, and no excess CO_2 release as a result of no burning of residues (Kassam *et al*., 2009; Corsi *et al*., 2012).

To the community and society, CA offers public goods that include: less pollution, lower cost for water treatment, more-stable river flows with reduced flooding and maintenance, and cleaner air and less siltation of dams (Mello and Raij, 2006; ITAIPU, 2011). At the landscape level, CA offers the advantages of better ecosystem services including: provision of food and clean water, regulation of climate and pests/diseases, support of nutrient cycles, pollination, cultural recreation, enhancement of biodiversity, and erosion control. At the global level, the public goods are: improvements in groundwater resources, soil resources, biodiversity and mitigation of climate change (Haugen-Kozyra and Goddard, 2009).

CA is highly relevant to several elements of the global agenda. It is the base element for combining intensive, highly productive agriculture with sustainability and ecosystem services, which responds to the strategic Objective A of FAO that deals with the promotion of sustainable production intensification based on a new paradigm of agriculture (FAO, 2011), improving the prospects for achieving the UN Millennium Development Goals. For the future of agriculture, CA comprises the best available set of agro-ecological concepts and production practices for climate change adaptation and mitigation, addressing the risks of climate variability, and reducing the vulnerability to drought, flood, heat, frost and wind. There is worldwide evidence from research and farmer practice to show that large productivity, economic, social and environmental benefits for the farmers and for the society can be harnessed through the adoption of CA practices. For example, if agriculture is to provide a significant sink for carbon and to drastically reduce greenhouse gas emissions, this can be done cost-effectively through wide scale adoption of CA, thus contributing to climate change mitigation. Further, CA helps to improve rural livelihoods by contributing to rural poverty reduction and eventually even to reversing the rural-urban migration trends.

However, there is still a need for more concerted and sustained efforts to promote CA globally, requiring the involvement of all sectors and stakeholders, from farmers, research and extension across to input supply industries and output value chain service providers to policy makers and institutional leaders to educational and vocational training institutions. It is this integrated stakeholder engagement that has been responsible for the rapid uptake of CA in large parts of the Americas and Australia.

5 Pro-poor production systems and poverty alleviation

Currently, it is estimated that three-quarter of the bottom billion are rural-based and rely on agriculture for their food security and livelihood. As long as they 'must' remain in agriculture as producers and agriculture workers, every effort should be made to help producers to adopt sustainable production systems such as CA (FAO, 2011, www.fao.org/ag/ca), and System of Rice Intensification (SRI) (Kassam *et al*., 2011b, http://sri.ciifad.cornell.edu) which are effective in pro-poor development for small farmers, as well as have the potential for enabling small farmers to produce 'more from less' and can offer surplus food to the local markets at a lower price. SRI is an alternative agro-ecological approach to rice production in which the soil is not flooded but kept moist, allowing the rice plant to grow a large root system. Together with a different set of crop management practices including transplanting young seedlings in wider spacing, SRI methods lead to increased yield and reduction in the use of production inputs of seeds, water, nutrients, pesticides and even labour. With aerobic soil conditions, SRI system can be integrated into CA systems, offering further productivity and environmental benefits, including reduced methane emission.

A quarter of the bottom billion is urban-based. Their food security will depend on wage employment within the economy, as it grows and diversifies, to be able to purchase affordable food from the market. Any safety-net social support for urban-based as well as rural-based poor families, in terms of cash and access to food rations, would help to improve food security. Similarly, training of youth and adult from the urban and rural poor families for skills development would improve chances of wage employment. Support to educate the children of poor urban and rural families would eventually help them to break out of the downward spirals and poverty traps.

However, in the long run, all stakeholders–farmers, supply and value chain service providers, academics, researchers, extension agents, policy makers, civil servants, consumers–must become engaged in understanding and harnessing the full power of the no-till agro-ecological paradigm. This will contribute to making farming and rural resource management careers an attractive source of livelihood to future generations who must take a custodial view of their role in managing the planet's natural resources for food security and economic development.

6 Concluding Remarks

CA principles appear to be universally applicable because the practice of CA is not a blanket recommendation or recipe for everywhere (also called silver bullet or "panacea") but has to be adapted to the site and farmer circumstances.

CA produces more from less, can be adopted and practiced by smallholder poor farmers, builds on the farmer's own natural resource base, does not entirely depend on purchased derived inputs, and is relatively less costly even in the early stages of sustainable production intensification. More emphasis should be put on the constraints and challenges in overcoming the hindrances in tropical and subtropical small-scale farmer areas in Africa and Asia and the solutions that might be different from the larger scale farmers of Brazil and Argentina.

CA being a new paradigm for most farmers globally, special emphasis must be placed on the need of a change in mindset amongst farmers especially in traditional farming communities in the North and the South and the importance of involving all stakeholders to apply a holistic approach in CA promotion that is just as much farmer driven as it is science driven and supported by public and private sectors and national agriculture development policies.

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