Conservation Agriculture: Global Perspectives and Developments[1]

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Summary

The global research and development community in general as well as most of the farmers worldwide are at a crossroad, and must decide on the question: which way forward with agriculture in the 21st century? The empirical evidence provided by the farming communities as presented in this paper tells us that farmer-led transformation of agricultural production systems based on Conservation Agriculture (CA) is already occurring and gathering momentum globally as a new paradigm for the 21st century.

CA, comprising minimum mechanical soil disturbance and direct seeding, organic mulch cover from residues and cover crops, and crop species diversification through rotations and associations, is now practiced globally on about 117 M ha in all continents and all agricultural ecologies. During the last decade, cropland under CA has been increasing at the rate of some 6 million hectares per annum, mainly in North and South America and in Australia, and more recently in Asia where large increases in the adoption of CA are expected.

There is worldwide scientific evidence from research and empirical evidence from 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. Indeed, a range of environmental services from agriculture landscapes is possible based on good quality CA systems. For example, if agricultural land use is to serve as a significant carbon sink and to drastically reduce greenhouse gas emissions, this can be done cost-effectively through the large-scale adoption of CA based protocols. Such protocols can form a base upon which further reductions in production costs, and in energy and fertilizer use can be built through the use of energy-efficient equipment technology and the adoption of precision farming techniques.

CA represents a fundamental change in production system thinking and is counterintuitive, novel and knowledge intensive. The roots of the origins of CA lie in the farming communities, and its spread has been largely farmer-driven. Experience and empirical evidence across many countries has shown that the rapid adoption and spread of CA requires a change in commitment and behaviour of all concerned stakeholders. For the farmers, a mechanism to experiment, learn and adapt is a prerequisite. For the policy-makers and

[1] The views expressed in this paper are those of the co-authors and not of FAO

institutional leaders, transformation of tillage systems to CA systems requires that they fully understand the large and longer-term economic, social and environmental benefits CA paradigm offers to the producers and the society at large. Further, the transformation calls for a sustained policy and institutional support role that can provide incentives and required services to farmers to adopt CA practices and improve them over time.

Key words: Conservation Agriculture, no-tillage, mulch cover, crop rotation, soil health, sustainability, adoption, policy support, institutional support,

Introduction

The challenge of agricultural sustainability has become more intense in recent years with the sharp rise in the cost of food, energy and production inputs, climate change, water scarcity, degradation of ecosystem services and biodiversity, and the financial crisis. The expected increase in population and the associated demands for food, water and other agricultural products will bring additional pressures. Consequently, the development community, including politicians, policy makers, institutional leaders as well as academics, scientists and extension workers, has been highlighting the need for the development of sustainable agricultural production systems that are compatible with the management of all ecosystem services and also permit the restoration of degraded agricultural lands.

In response to this, action has been promoted internationally at all levels and yet, as witnessed in the Millennium Ecosystem Assessment (MEA, 2005), the World Development Report 2008 (WDR, 2008) and the IAASTD reports (McIntyre *et al.*, 2008), some agricultural systems are still being promoted with unacceptably high environmental, economic and social costs, albeit with the promise of further gains in output. Consequently, business-as-usual with regards to agricultural development is increasingly considered inadequate to deliver sustainable production intensification to meet future needs in terms of food security, poverty alleviation and economic growth and ecosystem services (Friedrich *et al.*, 2009a; Kassam *et al.*, 2009).

The degradation of agricultural soils in the world, and the consequent loss in soil health and their productive capacity, are the result of intensive tillage-based farming practices that pay inadequate or no attention to managing the soils and the landscapes as part of living biological and ecosystem resource base (Montgomery, 2007; Huggins and Reganold, 2008). Thus, most agricultural soils have low organic matter with poor soil aggregate structure, and there is little effort made by farmers to develop organic soil cover or mulch from crop residues, stubbles and green cover crops to feed the soil microorganisms, or to maximise rainfall infiltration, or to protect the soil from water and wind erosion.

There is no doubt that it has been possible to feed the world's growing population and improve the nutritional status of a large majority with the help of modern intensive tillage-based crop production practices, genetically enhanced modern cultivars and increased inputs of agro-chemicals. However, the ecological, economic and social foundations of such mainstream practices and the various philosophies and actions of the public and private sector organisations that support and promote such practices, are now under serious scrutiny in all regions as new and more environmentally sustainable and less costly approaches to meet future societal need are demanded and sought. The severe degradation of the resource base and environment and other negative externalities associated with mainstream tillage-based agricultural practices is occurring in all parts of the world. In the industrialised nations such practices rely increasingly on specialised and less diversified cropping systems supported by genetically enhanced cultivars and high levels of agro-chemicals inputs and heavy machinery for high production. In the developing nations, agricultural development and the research, extension and education support services have been pushed by most national institutions, international organizations and donor agencies towards the adoption and spread of similar harmful practices whose long-term economic and environmental sustainability is questionable as well as their ability to adapt to and mitigate climate change and deliver all the required environmental services. In addition the degrading effects of this kind of agriculture in developing countries, located mostly in tropical and subtropical climate zones, are accelerated compared to temperate climatic regions.

This, so called 'modern' agriculture paradigm based on genetics, agro-chemicals and intensive tillage, is beginning to run out of steam and being increasingly challenged and replaced by a different paradigm as represented by the practice of good quality Conservation Agriculture which offers optimal resource use with high productivity and enhanced ecosystem services. This alternative paradigm has been shown to work in many parts of the world, and is biologically and ecologically as well as economically more efficient in producing the required outputs of goods such as edible and non-edible biological products and of water while at the same time taking care of other essential ecosystem services that regulate soil, crop and ecosystem health, protect habitats and biodiversity, drive carbon, nutrient and hydrological cycles as well as conserve stocks of carbon, nutrients and water, and protect soils and landscapes from erosion and other forms of degradation.

Conservation Agriculture (CA) represents one of the new 'biological and ecosystems' paradigms for sustainable agricultural intensification that can include arable and perennial crops, pastures as well as trees and livestock (Landers, 2007). CA complements other systems such as agro-forestry (Sims et al., 2009) and organic farming that can benefit from integration with CA practices, and CA-based crop-livestock systems offer high sustainable animal carrying capacity (Landers, 2007; Friedrich *et al.*, 2009a). CA experience worldwide over the past four decades has demonstrated how the simultaneous application of a set of practices of minimal mechanical soil disturbance, organic soil cover and diversified cropping can lead to greater and stable yields, better use of production inputs and therefore greater profitability while reducing production costs, enhanced crop, soil and ecosystem health as well as the associated ecosystem services, and improved climate change adaptability and mitigation.

Indeed, CA now spearheads an alternative 'biological and ecosystems' paradigm that can make a significant contribution to sustainable production intensification (including agricultural land restoration) and in meeting agricultural and food needs of the future human populations (Uphoff *et al.*, 2006; FAO, 2008; Pretty, 2008; Friedrich *et al.*, 2009a; Kassam *et al.*, 2009, FAO, 2010). In essence, CA addresses the missing ecological sustainability or the resilience components in the intensive tillage-based standardized seed-fertilizer-pesticide approach to agriculture intensification that has been the hallmark of much of the industrial agricultural development in the industrialized nations, and characteristic of the so called Asian 'Green Revolution' in the seventies in the irrigated rice and wheat systems.

The origins and early roots of discovery, inventions and evolution of CA principles and practices are embedded in the farming communities and civil societies in North and South America who, out of necessity, had to respond to the severe erosion and land degradation problems and productivity losses on their agricultural soils due to intensive tillage-based production practices. Initially, this occurred in North and South America, and later in other parts of world such as Australia, and more recently Asia and Africa. Thus CA has largely evolved and spread bottom up, unlike the intensive tillage-based 'Green Revolution' practices whose evolution has largely followed a top down approach with the international and national scientific community setting largely a reductive research agenda and strongly influencing what innovations and technologies can be and are actually delivered to the farmers in the developing nations through a linear research-extension-farmer approach. Thus, as a consequence, the international and national scientific community has yet to fully embrace the new agricultural production paradigm including the CA concepts and principles, into their research agenda and actual field-based investigations. The few recent exceptions include CIMMYT, ICRAF, ICARDA, ACSAD, CIRAD, EMBRAPA and there are only a handful of industrialised and developing nations whose governments have given explicit policy, legal and institutional level recognition to CA as a preferred agricultural production system paradigm for sustainable rural resource management and development.

Over the past 40 years, farmer-led empirical evidence and scientific evidence from different parts of the world has been accumulating to show that CA concepts and principles have universal validity, and that CA practices, devised locally to address prevailing ecological and socio-economic constraints and opportunities, can work successfully to provide a range of productivity, socio-economic and environmental benefits to the producers and the society at large (Goddard *et al.*, 2008; Reicosky, 2008; Derpsch & Friedrich, 2009a; 2009b; Kassam *et al.*, 2009; FAO, 2008, 2010). This is also true for the semi-arid and humid temperate and subtropical agricultural environments (Stewart *et al.*, 2007; Goddard *et al.*, 2008; Derpsch & Friedrich, 2009a, 2009b; Friedrich *et al.*, 2009a; Kassam *et al.*, 2009; ECAF, 2010). In the USA and Canadian Prairies, farmers have adopted CA practices at a provincial scale, and in the provinces of Alberta, Saskatchewan and Manitoba significant economic and environmental co-benefits have been documented (Baig & Gamache, 2009).

Concepts and Principles of Conservation Agriculture

The concepts that underpin CA are aimed at resource conservation while profitably managing sustainable production intensification and ecosystem services. At its core, CA translates into three practical principles that can be applied simultaneously through contextualised crop-soil-water-nutrient-ecosystem management practices in space and time that are locally devised and adapted to capture simultaneously a range of productivity, socioeconomic and environmental benefits of agriculture and ecosystem services at the farm, landscape and provincial or national scale (FAO, 2010; Friedrich *et al.*, 2009a; Kassam *et al.*, 2009).

The main criterion for CA systems is the provision of an optimum environment in the root-zone to maximum possible depth. Roots are thus able to function effectively and without restrictions to capture plant nutrients and water as well as interact with a range of soil microorganisms beneficial for crop performance. Water thus enters the soil so that: (a) plants never, or for the shortest time possible, suffer water stress that would limit the expression of their potential growth; and so that (b) residual water passes down to groundwater and stream flow, not over the surface as runoff. Beneficial biological activity, including that of plant roots, thus occurs in the soil where it maintains and rebuilds soil architecture, competes with potential in-soil pathogens, contributes to soil organic matter and various grades of humus, and contributes to capture, retention, chelation and slow release of plant nutrients. Thus, 'conservation-effectiveness' encompasses not only conserving soil and water, but also the biotic bases of sustainability (Shaxson, 2006; Uphoff *et al.*, 2006; Pretty, 2008).

The key feature of a sustainable soil ecosystem is the biotic actions on organic matter in suitably porous soil (Flaig *et al.*, 1977; Uphoff *et al.*, 2006; Kassam *et al.*, 2009). This means that, under CA, soils become potentially self-sustainable, provided sufficient biomass is produced and returned to maintain the soil life. In CA systems with the above attributes there are many similarities to resilient 'forest floor' conditions (Blank, 2008; Kassam *et al.*, 2009):

- 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 exceed the rates of rainfall. Soil organic matter is neither just a provider of plant nutrients nor just an absorber of water (Flaig *et al.*, 1977). 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 hydrological components of soil productive capacity are effectively 'activated' by the fourth, the biological component. This variously provides metabolic functions, acting on the nonliving organic materials (Wood, 1995; Doran & Zeiss, 2000; Lavelle & Spain, 2001; Coleman *et al.*, 2004; Uphoff *et al.*, 2006) to:
- Retain 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.
- Break down and transform the complex molecules of varied dead organic matter into different substances, both labile and resistant, according to the composition of the substrate.
- Leave behind transformed materials with differing degrees of resistance to 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.

- Produce 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.
- Provide organic molecules as transformation products which contribute markedly to soil's CEC; this also augments the soil's buffering capacity to pH changes and to excesses or deficiencies of nutrient ions available to plants.
- Provide humic gums which, together with fungal hyphae and clay bonds, make for different sizes of rough-surfaced aggregates of individual soil particles that in turn provide the permeability of the soil in a broad distribution of pore sizes.
- Increase the burrowing activities of mesoorganisms such as earthworms, and of roots (leaving tubes after they have died and been decomposed).

Principle components of optimum Conservation Agriculture

The three principle components of optimum CA are (see www.fao.org/ag/ca):

(1) Minimizing soil disturbance resulting from mechanical tillage and thus seeding or planting directly into untilled soil, eliminating tillage altogether once the soil has been brought to good condition, and keeping soil disturbance from cultural operations to the minimum possible;

(2) Maintaining year-round organic matter cover over the soil, including specially introduced cover crops and intercrops and/or the mulch provided by retained residues from the previous crop;

(3) Diversifying crop rotations, sequences and associations, adapted to local environmental conditions, and including appropriate nitrogen fixing legumes; such rotations and associations contribute to maintaining biodiversity above and in the soil, contribute nitrogen to the soil/plant system, explore different soil zones with different rooting characteristics, and help avoid build-up of pest populations.

The soil capacity to favour root growth and water transmission is maintained through the activity of soil organisms sufficiently provisioned with organic matter, water and nutrients. A consequence of their activity is soil aggregation interspersed with voids (pores), depending on organisms' production of roots, exudates, gums, hyphae and on their proliferative burrowing and distributive activities. Multiple attributes of organic matter in soil – dynamized by the soil biota – therefore make it a key factor for improving and maintaining yields (of plants and of water). Management actions which increase/optimize organic matter content of soils tend to be beneficial; those that result in depletion of organic matter content tend to be detrimental.

Tillage tends to engender accelerated oxidative breakdown of organic matter with accelerated release of increased volumes of CO_2 to the atmosphere through explosive increase of soil bacterial population, beyond those from normal soil respiration processes. Combining the retention of crop residues (rather than export or burning off) with direct seeding of crops without 'normal' tillage leads to retention and increase of organic matter, as a substrate for the activity of soil biota and for the soil's capacities to retain carbon, and to better provide water and nutrients to plant roots 'on demand' over sustained periods. The relationship between components of CA and desired soil conditions are listed in Table 1 (Friedrich *et al*., 2009a; Kassam *et al.*, 2009).

Farmers worldwide have long used soil tillage to loosen the topsoil, make a seedbed and control weeds, and tillage intensity has increased many-fold as a result of agriculture becoming mechanised with increasingly heavier machines and equipment (Kassam *et al.*, 2009). But not all tillage outcomes are positive, especially when considered over long timescales. Wheels, implements and even feet can compact soil. Too-frequent (and/or too severe) tillage results in disruption of the aggregates making up a soil's biologically induced architecture. Since the sustainability of a soil's productive capacity depends on the influence of the soil biota on soil crumb/aggregate re-formation, the soil aerating effects of undue tillage can accelerate the rate of biotic activity and the consequent more-rapid oxidation of their substrate organic matter. If the mean rate of soil's physical degradation exceeds the mean rate of its recuperation due to the soil biota, its penetrability by water, roots and respiration gases diminishes, productivity declines, and runoff and erosion ensue (Montgomery, 2007).

Worldwide Experience of Benefits from Conservation Agriculture

CA represents a fundamental change to agricultural production systems, requiring a holistic awareness of nature or ecosystems and the services they offer so that these are least disrupted when ecosystems are altered for agricultural production. The main benefits of CA that can be harnessed by farmers and their communities are described in the following sections and provide an indication why farmers are adopting CA systems and why CA deserves greater attention from the development and research community as well as from the government, corporate and civil sectors (Hebblethwaite, 1997; Kassam *et al.*, 2009). However, the many synergistic interactions between components of CA practices are not yet fully understood. In general, scientific research on CA systems lags behind what farmers are discovering and adapting on their own initiative. This is partly because CA is a complex, knowledge-intensive set of practices that does not lend itself to easy scientific scrutiny through short-term research based on reductionist thinking and approaches.

Conservation Agriculture as a fundamental change in the agricultural production system paradigm

CA is a means of assuring production of plants and water recurrently and sustainably. It does this by favouring improvements in the condition of soils as rooting environments. CA is not a single technology, but a range based on one or more of the three main CA described above. CA functions best when all three key features are adequately combined together in the field. It is significantly different from the conventional tillage agriculture (Hobbs, 2007; Shaxson *et al*., 2008; Friedrich *et al.*, 2009a; Kassam *et al*., 2009). Ideally, CA avoids tillage once already damaged soil has been brought to good physical condition prior to initiating the CA system; maintains a mulch cover of organic matter on the soil surface at all times, for providing both protection to the surface and substrate for the organisms beneath; specifically uses sequences of different crops and cover-crops in multi-year rotations;

and relies on nitrogen-fixing legumes (including forages and trees) to provide a significant proportion of N (Boddey *et al.*, 2006).

CA also relies on liberating other plant nutrients through biological transformations of organic matter. This can be augmented as necessary by suitable mineral fertilizers in cases of specific nutrient deficiencies, but organic matter also provides micronutrients that may not be available 'from the bag' (Flaig *et al.*, 1977). CA can retain and mimic the soil's original desirable characteristics ('forest floor conditions') on land being first opened for agricultural use. Throughout the transformation to agricultural production CA can sustain the health of long-opened land that is already in good condition, and it can regenerate that in poor condition (Doran & Zeiss, 2000). CA is a powerful tool for promoting soil and thus agricultural sustainability.

These multiple effects of CA when applied together are illustrated in Table 1 (Friedrich *et al.*, 2009a; Kassam *et al.*, 2009). In contrast with tillage agriculture, CA can reverse the loss of organic matter, improve and maintain soil porosity and thus prolong the availability of plant-available soil water in times of drought (Stewart, 2007; Derpsch, 2008a; Mazvimavi & Twomlow, 2008). It can also reduce weed, insect pest and disease incidence by biological means, raise agro-ecological diversity, favour biological nitrogen fixation, and result in both raised and better stabilized yields accompanied by lowered costs of production (Blackshaw *et al.*, 2007; Mariki & Owenya, 2007; Gan *et al.*, 2008; Baig & Gamache, 2009). Furthermore, CA can be explored for the purpose of achieving some of the objectives of the International Conventions on combating desertification, loss of biodiversity, and climate change (Benites *et al.*, 2002).

It is important to recognize that the improvements seen at macro-scale (e.g., yields, erosion avoidance, water supplies and farm profitability) are underlain and driven by essential features and processes happening at micro-scale in the soil itself. FAO (2008) indicates that: widespread adoption of CA has been demonstrated to be capable of producing large and demonstrable savings in machinery and energy use, and in carbon emissions, a rise in soil organic matter content and biotic activity, less erosion, increased crop-water availability and thus resilience to drought, improved recharge of aquifers and reduced impact of the apparently increased volatility in weather associated with climate change. It will cut production costs, lead to more reliable harvests and reduce risks especially for small landholders.

Higher stable yields and incomes from Conservation Agriculture with reduced production costs

As an effect of CA, the productive potential of soil rises because of improved interactions between the four factors of productivity: (a) physical: better characteristics of porosity for root growth, movement of water and root-respiration gases; (b) chemical: raised CEC gives better capture, release of inherent and applied nutrients: greater control/ release of nutrients; (c) biological: more organisms, organic matter and its transformation products; (d) hydrological: more water available. The combination of the above features to raise productive potential makes the soil a better

Table 1: *Effects of CA components fully applied together* (Friedrich *et al.* 2009a; Kassam *et al.*, 2009)

CA COMPONENT ► TO ACHIEVE ▼	MULCH COVER (crop residues cover-crops, green manures)	NO TILLAGE (minimal or no soil disturbance)	LEGUMES (as crops for fixing nitrogen and supplying plant nutrients)	CROP ROTATION (for several beneficial purposes)
Simulate optimum 'forest-floor' conditions	√	√		
Reduce evaporative loss of moisture from soil surface	√			
Reduce evaporative loss from soil upper soil layers	√	√		
Minimise oxidation of soil organic matter, CO_2 loss		√		
Minimise compactive impacts by intense rainfall, passage of feet, machinery	√			
Minimise temperature fluctuations at soil surface	√			
Provide regular supply of organic matter as substrate for soil organisms' activity	√			
Increase, maintain nitrogen levels in root-zone	√	√	√	√
Increase CEC of root-zone	√	√	√	√
Maximise rain infiltration, minimise runoff	√	√		
Minimise soil loss in runoff, wind	√	√		
Permit, maintain natural layering of soil horizons by actions of soil biota	√	√		
Minimise weeds	√	√		√
Increase rate of biomass production	√	√	√	√
Speed soil-porosity's recuperation by soil biota	√	√	√	√
Reduce labour input		√		
Reduce fuel-energy input		√	√	
Recycle nutrients	√	√	√	√
Reduce pest-pressure of pathogens				√
Re-build damaged soil conditions and dynamics	√	√	√	√

environment for the development and functioning of crop plants' roots. Improvements in the soil's porosity have two effects: a greater proportion of the incident rainfall enters into the soil; and the better distribution of pore-spaces of optimum sizes results in a greater proportion of the received water being held at plant-available tensions. Either or both together mean that, after the onset of a rainless period, the plants can continue growth towards harvest – for longer than would previously been the case – before the plant-available soil water is exhausted.

In addition, increased quantities of soil organic matter result in improved availability, and duration of their release into the soil water, of needed plant nutrients – both those within the organic matter and those from off-farm. Thus the availability of both water and plant nutrients is extended together. Under these conditions, plants have a better environment in which to express their genetic potentials, whether they have been genetically engineered or not. Yield differences have been reported in the range of 20–120 per cent between CA systems and tillage systems in Latin America, Africa and Asia (Derpsch *et al.*, 1991; Pretty *et al.*, 2006; Landers, 2007; Erenstein *et al.*, 2008; FAO, 2008; Hengxin *et al.*, 2008; Rockstrom *et al.*, 2009). In Paraguay, small farmers have been able to successfully grow crops that initially were thought not to be appropriate for no-till systems, such as cassava. Planting cassava under CA in combination with cover crops has resulted in substantial yield increases, sometimes double the yields compared to conventional farming systems (Derpsch & Friedrich, 2009a).

FAO (2001a) indicates that: machinery and fuel costs are the most important cost item for larger producers and so the impact of CA on these expenditure items is critical. Most analyses suggest that CA reduces the machinery costs. Zero or minimum tillage means that farmers can use a smaller tractor and make fewer passes over the field. This also results in a lower fuel and repair costs. However, this simple view masks some complexities in making a fair comparison. For example, farmers may see CA as a complement to rather than as a full substitute for their existing practices. If they only partially switch to CA (some fields or in some years), then their machinery costs may rise as they must now provide for two cultivation systems, or they may simply use their existing machinery inefficiently in their CA fields.

No-till, or a significantly reduced proportion of the area treated with tillage (e.g., planting basins or zai/tassa/likoti, and strip tillage), requires less input of energy per unit area, per unit output, and lower depreciation rates of equipment. Over time, less fertilizer is required for the same output (Lafond *et al.*, 2008). Production costs are thus lower, thereby increasing profit margins as well as lessening emissions from tractor fuel (Hengxin *et al.*, 2008). Better soil protection by mulch cover minimizes both runoff volumes and the scouring of topsoil, carrying with it seeds and fertilizers. Such losses represent unnecessary cost, wasted rainwater and wasted energy. Their avoidance increases the margin between profits and costs, which formerly, under tillage agriculture, were accepted as 'normal' expenses to be anticipated.

CA systems are less vulnerable to insect pests, diseases and drought effects because better soil and plant conditions include also greater biotic diversity of potential predators on pests and diseases, while crop rotations break insect pest build-ups. Here, much of the cost of avoiding or controlling significant pest attacks is diminished because of it being undertaken by healthier plants, breaks in pest life cycles and natural predators (Settle & Whitten, 2000; Evers & Agostini, 2001; Blank, 2008). Research conducted by Kliewer *et al*. (1998) in Paraguay and Sorrensen and Montoya (1984) in Brazil has shown that crop rotation and short-term green manure cover crops can reduce the cost of herbicides drastically, due to reduction in weed infestation over time (Blackshaw *et al*., 2007). While many still think that green manure cover crops are economically not viable, farmers in Brazil and Paraguay have learned that the economics of CA can be substantially increased with their use (Derpsch, 2008a).

As a result, the financial benefits for farmers in Latin America and North America who have adopted CA have been striking (Landers, 2007; Baig & Gamache, 2009). However, these take time to fully materialize. Sorrenson (1997) compared the financial profitability of CA on 18 medium- and large-sized farms with conventional practice in two regions of Paraguay over 10 years. By year 10, net farm income had risen on CA farms from USD 10,000 to over USD 30,000, while on conventional farms net farm income fell. Medium- and large-scale CA farmers had experienced:

- Less soil erosion, improvements in soil structure and an increase in organic matter content, crop yields and cropping intensities.
- Reduced time between harvesting and sowing crops, allowing more crops to be grown over a 12-month period.
- Decreased tractor hours, farm labour, machinery costs, fertilizer, insecticide, fungicide and herbicide, and cost savings from reduced contour terracing and replanting of crops following heavy rains.
- Lower risks on a whole-farm basis of higher and more stable yields and diversification into cash crop (FAO, 2001b).

Such effects are cumulative over space, and can accumulate over time from degraded condition to improved stabilized condition, with yields and income rising over time, as in this example of large-scale wheat production under CA in Kazakhstan. Work reported by Fileccia (2008) shows the development of wheat yields and financial benefits after changing from conventional tillage to no-till agriculture on mechanized farms in northern Kazakhstan. The internal rate of return to investment (IRR) is 28 per cent. Thus, farmers should turn away from the struggle to reach the highest yield. Instead they should aim for the best economic yield. Fileccia (2008) indicates that CA can achieve this goal even under the relatively marginal conditions prevailing in northern Kazakhstan. Further, in Paraguay, yields under conventional tillage declined 5–15 per cent over a period of 10 years, while yields from zero-till CA systems increased 5–15 per cent. Over the same period, fertilizer and herbicide inputs dropped by an average of 30–50 per cent in the CA systems (Derpsch, 2008a). In Brazil, over a 17-year period, maize and soybean yields increased by 86 and 56 per cent respectively, while fertilizer inputs for these crops fell by 30 and 50 per cent respectively. In addition, soil erosion in Brazil decreased from 3.4–8.0 t/ha under conventional tillage to 0.4 t/ha under no-till, and water loss fell from approximately 990 to 170 t/ha (Derpsch, 2008a).

Climate change adaptation and reduced vulnerability

Reduced vulnerability to effects of drought, less erosion, and lesser extremes of soil temperatures represent a managed adaptation of CA systems to climate change effects such as, for example, more intense rainstorms, increased daily ranges of temperatures, and more severe periods of drought. Overall, CA systems have a higher adaptability to climate change because of the higher effective rainfall due to higher infiltration and therefore minimum flooding and soil erosion as well as greater soil moisture-holding capacity. The advantage of CA over tillage agriculture in terms of the greater soil moisture-holding capacity and therefore duration of plant-available soil moisture is illustrated by Derpsch *et al.* (1991), who show that soil moisture conditions in rooting zones through growing seasons under CA are better than under both minimum and conventional tillage. Thus crops under CA systems can continue towards maturity for longer than those under conventional tillage.

In addition, the period in which available nutrients can be taken up by plants is extended, increasing the efficiency of use. The greater volume and longer duration of soil moisture's availability to plants (between the soil's field capacity and wilting point) has significant positive outcomes both for farming stability and profitability. The range of pore sizes that achieves this also implies the presence of larger pores that contribute to through-flow of incident rainwater down to the groundwater (Shaxson, 2006; Shaxson *et al.*, 2008).

Infiltration rates under well-managed CA are much higher over extended periods due to better soil porosity. In Brazil (Landers, 2007), a 6-fold difference was measured between infiltration rates under CA (120 mm per hour) and traditional tillage (20 mm per hour). CA thus provides a means to maximize effective rainfall and recharge groundwater as well as reduce risks of flooding. Due to improved growing season moisture regime and soil storage of water and nutrients, crops under CA require less fertilizer and pesticides to feed and protect the crop, thus leading to a lowering of potential 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 (Flaig *et al.*, 1977). Good mulch cover provides 'buffering' of temperatures at the soil surface which otherwise are capable of harming plant tissue at the soil/atmosphere interface, thus minimizing a potential cause of limitation of yields. By protecting the soil surface from direct impact by high-energy raindrops, it prevents surface-sealing and thus maintains the soil's infiltration capacity, while at the same time minimizing soil evaporation.

In the continental regions of Europe, Russia and North America, where much annual precipitation is in the form of snow in the winter, CA provides a way of trapping snow evenly on the field which may otherwise blow away, and also permits snow to melt evenly into the soil. In the semi-arid areas of continental Eurasia, one-third or more of the precipitation is not effectively used in tillage-based systems, forcing farmers to leave land fallow to 'conserve' soil moisture, leading to extensive wind erosion of topsoil from fallow land, and to dust emissions and transport over large distances (Brimili, 2008). Under CA, more soil moisture can be conserved than when leaving the land fallow, thus allowing for the introduction of additional crops including legume cover crops into the system (Blackshaw *et al.*, 2007; Gan *et al.*, 2008). In the tropics and subtropics, similar evidence of adaptability to rainfall variability has been reported (Erenstein *et al.*, 2008; Rockstrom *et al.*, 2009).

Reduced greenhouse gas emissions

No-till farming also reduces the unnecessarily rapid oxidation of soil organic matter to CO_2 that is induced by tillage (Reicosky, 2008; Nelson *et al.*, 2009). Together with the addition of mulch as a result of saving crop residues in situ as well as through root exudation of carbon compounds directly into the soil during crop growth (Jones, 2007), there is a reversal from net loss to net gain of carbon in the soil, and the commencement of long-term processes of carbon sequestration (West & Post, 2002; Blanco-Canqui & Lal, 2008; CTIC/FAO, 2008; Baig & Gamache, 2009). Making use of the above-ground crop residues, the root organic matter (higher under CA because of the larger root systems) and the direct rhizospheric exudation of carbon into the soil represents the retention of much of the atmospheric C captured by the plants and retained above the ground. Some becomes transformed to soil organic matter of which part is resistant to quick breakdown (though still with useful attributes in soil), and represents net C-accumulation in soil, eventually leading to C-sequestration. Tillage, however, results in rapid oxidation to CO_2 and loss to the atmosphere. Expanded across a wide area, CA has the potential to slow/reverse the rate of emissions of CO_2 and other greenhouse gases by agriculture.

Studies in southern Brazil show an increase in carbon in the soil under CA. According to Testa *et al.* (1992), soil carbon content increased by 47 per cent in the maize–lablab system, and by 116 per cent in the maize–castor bean system, compared to the fallow–maize cropping system which was taken as a reference. Although exceptions have been reported, generally there is an increase in soil carbon content under CA systems, as shown by the analysis of global coverage by West & Post (2002). In systems where nitrogen was applied as a fertilizer, the carbon contents increased even more. Baker *et al.* (2007) found that crop rotation systems in CA accumulated about 11 t/ha of carbon after nine years. Under tillage agriculture and with monoculture systems the carbon liberation into the atmosphere was about 1.8 t/ha per year of CO_2 (FAO, 2001b).

With CA, reduced use of tractors and other powered farm equipment results in lower emissions. Up to 70 per cent in fuel savings have been reported (FAO, 2008). CA systems can also help reduce the emissions for other relevant greenhouse gases, such as methane and nitrous oxides, if combined with other complementary techniques. Both methane and nitrous oxide emissions result from poorly aerated soils, for example from permanently flooded rice paddies, from severely compacted soils, or from heavy poorly drained soils. CA improves the internal drainage of soils and the aeration and avoids anaerobic areas in the soil profile, so long as soil compactions through heavy machinery traffic are avoided and the irrigation water management is adequate.

The soil is a dominant source of atmospheric N_2O (Houghton *et al.*, 1997). In most agricultural soils biogenic formation of nitrous oxide is enhanced by an increase in available mineral N which, in turn, increases the rates of aerobic microbial nitrification of ammonia into nitrates and anaerobic microbial reduction (denitrification) of nitrate to gaseous forms of nitrogen (Bouwman, 1990; Granli & Bøckman, 1994). The rate of production and emission of N_2O depends primarily on the availability of a mineral N source, the substrate for nitrification or denitrification, on soil temperature, soil water content, and (when denitrification is the main process) the availability of labile organic compounds. These variables are universal and apply to cool temperate and also warm tropical ecosystems. Addition of fertilizer N, therefore, directly results in extra N_2O formation as an intermediate in the reaction sequence of both processes that leaks from microbial cells into the atmosphere (Firestone & Davidson, 1989). In addition, mineral N inputs may lead to indirect formation of N_2O after N leaching or runoff, or following gaseous losses and consecutive deposition of N_2O and ammonia. CA generally reduces the need for mineral N by 30–50 per cent, and enhances nitrogen factor productivity. Also, nitrogen leaching and nitrogen runoff are minimal under CA systems. Thus overall, CA has the potential to lower N_2O emissions (e.g., Parkin & Kaspar, 2006; Baig & Gamache, 2009), and mitigate other GHG emissions as reported by Robertson *et al.* (2000) for the mid-west USA and Metay *et al.* (2007) for the Cerrado in Brazil. However, the potential for such results applying generally to the moist and cool UK conditions has been challenged, for example, by Bhogal *et al.* (2007) and questions have been raised over their validity due to the depth of soil sampled, particularly for N_2O emissions and the overall balance of GHG emissions (expressed on a carbon dioxide (CO_2-C) equivalent basis).

Better ecosystem functioning and services

Societies everywhere benefit from the many resources and processes supplied by nature. Collectively these are known as ecosystem services (MEA, 2005), and include clean drinking water, edible and non-edible biological products, and processes that decompose and transform organic matter. Five categories of services are recognized: provisioning services such as the production of food, water, carbon and raw materials; regulating, such as the control of climate, soil erosion and pests and disease; supporting, such as nutrient and hydrological cycles, soil formation and crop pollination; cultural, such as spiritual and recreational benefits; and preserving, which includes guarding against uncertainty through the maintenance of biodiversity and sanctuaries.

CA's co-benefits to ecosystem services, particularly those related to provisioning, regulating and supporting, derive from improved soil conditions in the soil volume used by plant roots. The improvement in the porosity of the soil is effected by the actions of the soil biota which are present in greater abundance in the soil under CA. The mulch on the surface protects against the compacting and erosive effects of heavy rain, damps down temperature fluctuations, and provides energy and nutrients to the organisms below the soil surface. When the effects are reproduced across farms in a contiguous micro-catchment within a landscape, the ecosystem services provided – such as clean water, sequestration of carbon, avoidance of erosion and runoff – become more apparent. The co-benefits of more water infiltrating into the ground beyond the depth of plant roots is perceptible in terms of more regular stream flow from groundwater through the year, and/or more reliable yields of water from wells and boreholes (e.g., Evers & Agostini, 2001). The benefits of carbon capture become apparent in terms of the darkening colour and more crumbly 'feel' of the soil, accompanied by improvements in crop growth, plus less erosion and hence less deposition of sediment downstream in streambeds.

Legumes in CA rotations provide increased *in situ* availability of nitrogen, thus diminishing the need for large amounts of applied nitrogenous fertilizers (Boddey *et al.*, 2006). Also, there is increasing evidence of a significant amount of 'liquid carbon' being deposited into the soil through root exudation into the rhizosphere (Jones, 2007).

Society gains from CA on both large and small farms by diminished erosion and runoff, less downstream sedimentation and flood damage to infrastructure, better recharge of groundwater, more regular stream flow throughout the year with the less frequent drying up of wells and boreholes, cleaner civic water supplies with reduced costs of treatment for urban/domestic use, increased stability of food supplies due to greater resilience of crops in the face of climatic drought, and better nutrition and health of rural populations, with less call on curative health services (ICEPA/SC, 1999; World Bank, 2000; Pieri *et al.*, 2002). In CA systems, the sequences and rotations of crops encourage agrobiodiversity as each crop will attract different overlapping spectra of microorganisms.

The optimization of populations, range of species and effects of the soil-inhabiting biota is encouraged by the recycling of crop residues and other organic matter that provides the substrate for their metabolism. Rotations of crops inhibit the build-up of weeds, insect pests and pathogens by interrupting their life cycles, making them more vulnerable to natural predator species, and contributing development-inhibiting allelochemicals. The same crop mixtures, sequences and rotations provide above-ground mixed habitats for insects, mammals and birds.

Worldwide Adoption and Spread of Conservation Agriculture

Global area and regional distribution

It is well known that only a few countries in the world conduct regular surveys on CA adoption. The data presented in this paper is mainly based on estimates made by farmer organizations, agro industry, well-informed individuals, etc. Table 2 shows an overview of CA adoption in those countries that have more than 100,000 ha being practiced by farmers, and Table 3 shows the area under CA and the percent of adoption by continent.

It is estimated that CA is practiced at present on about 117 M ha worldwide. CA in recent years has become a fast growing production system. While in 1973/74 the system was used only on 2.8 M ha worldwide, the area had grown to 6.2 M ha in 1983/84 and to 38 M ha in 1996/97 (Derpsch, 1998). In 1999, worldwide adoption was 45 M ha (Derpsch, 2001), and by 2003 the area had grown to 72 M ha (Benites *et al.*, 2003). In the last 11 years CA system has expanded at an average rate of more than 6 M ha per year from 45 to 117 M ha showing the increased interest of farmers in this technology (Table 2).

The growth of the area under CA has been especially rapid in South America where the MERCOSUR countries (Argentina, Brazil, Paraguay and Uruguay) are using the system on about 70% of the total cultivated area. More than two thirds of no-tillage practiced in MERCOSUR is permanently under this system, in other words once started the soil is never tilled again.

Table 2. *Extent of Adoption of Conservation Agriculture Worldwide*
(countries with > 100,000 ha)

Country	Area under No-tillage (ha) (2008/2009)
USA [1]	26,500,000
Argentina [2]	25,785,000
Brazil [3]	25,502,000
Australia [4]	17,000,000
Canada [5]	13,481,000
Paraguay [6]	2,400,000
China [7]	1,330,000
Kazakhstan [8]	1,300,000
Bolivia [9]	706,000
Uruguay [10]	655,000
Spain [11]	650,000
South Africa [12]	368,000
Venezuela [13]	300,000
France [14]	200,000
Finland [15]	200,000
Chile [16]	180,000
New Zealand [17]	162,000
Colombia [18]	102,000
Ukraine [19]	100,000
Total	**116,921,000**

Source: Derpsch, R. and Friedrich, T., 2010
Extracted from: http://www.fao.org/ag/ca/6c.html

Information provided by: 1) CTIC, 2007; 2) AAPRESID, 2010; 3) FEBRAPDP, 2005/06; 4) Australian Bureau of Statistics, 2009; 5) Doug McKell, Soil Conservation Council of Canada, 2006; 6) MAG & CAPECO, 2008; 7) Li Hongwen, 2008; 8) Mekhlis Suleimenov, 2007; 9) ANAPO, Bolivia, 2007; 10) Miguel Carballal AUSID, 2007; 11) Emilio González-Sánchez, AEAC/SV, 2008; 12) Richard Fowler, 2008; 13) Rafael E. Perez, 2004; 14) APAD, 2008; 15) Timo Rouhianinen, FINCA, 2008; 16) Carlos Crovetto, 2008; 17) John Baker, 2008; 18) Fabio Leiva, 2008; 19) Estimate by the authors.

As Table 3 shows 47.6% of the total global area under CA is in South America, 34.1% in the United States and Canada, 14.7% in Australia and New Zealand and 3.5% in the rest of the world including Europe, Asia and Africa. The latter are the developing continents in terms of CA adoption. Despite good and long lasting research in these continents showing positive results for no-tillage systems, CA has experienced only small rates of adoption.

Because of the benefits that CA systems generate in terms of yield, sustainability of land use, incomes, timeliness of cropping practices, ease of farming and ecosystem services, the area under CA systems has been growing exponentially, largely as a result of the initiative of farmers and their organizations. A useful overview of adoption of CA in individual countries is given in Derpsch & Friedrich (2009a, 2009b) and Derpsch *et al.* (2010).

Table 3. *Area under CA by continent*

Continent	Area (hectare)	Percent of total
South America	55,630.000	47.6
North America	39,981.000	34.1
Australia & New Zealand	17,162.000	14.7
Asia	2,630.000	2.2
Europe	1,150.000	1.0
Africa	368.000	0.3
World total	**116,921,000**	**100**

Except in a few countries (USA, Canada, Australia, Brazil, Argentina, Paraguay, Uruguay), however, CA has not been "mainstreamed" in agricultural development programmes or backed by suitable policies and institutional support. Consequently, the total area under CA is still very small (about 8%) relative to areas farmed using tillage. Nonetheless, the rate of increase globally since 1990 has been at the rate of some 6 M ha per annum, mainly in North and South America and in Australia and New Zealand. However, area under CA is on the increase in all parts of Asia, and we expect large areas of agricultural land to switch to CA in the coming decade as is already occurring in Kazakhstan, India and China.

Although much of the CA development to date has been associated with rainfed arable crops, farmers can apply the same principles to increase the sustainability of irrigated systems, including those in semi-arid areas. CA systems can also be tailored for orchard and vine crops with the direct sowing of field crops, cover crops and pastures beneath or between rows, giving permanent cover and improved soil aeration and biodiversity. The common constraint, given by farmers, to practising this latter type of inter-cropping is competition for soil water between trees and crops. However, careful selection of deep rooting tree species and shallow rooting annuals resolves this. Functional CA systems do not replace but should be integrated with current good land husbandry practices.

Conservation Agriculture in Africa

In the **North African** region, much of the CA work done in various countries has shown that yields and factor productivities can be improved with no-till systems. Extensive research and development work has been conducted in several countries in the region since the early 1980s such as in Morocco (Mrabet, 2007, 2008a, 2008b, 2008c); and more recently in Tunisia (M'Hedhbi *et al*., 2003, Ben-Hammouda *et al*., 2007).

Key lessons from international experiences about CA and considerations for its implementation in the Mediterranean region have been summarised by Centero-Martinez *et al.* (2007), Lahmar & Triomphe (2007), and Pala *et al.* (2007). They all endorse the potential benefits that can be harnessed by farmers in the semi-arid

Mediterranean environments in that region while highlighting the need for longer-term research including on weed management, crop nutrition and economics of CA systems. In addition, it is clear that without farmer engagement and appropriate enabling policy and institutional support to achieve effective farmer engagement and a process for testing CA practices and learning how to integrate them into production system, rapid uptake of CA is not likely to occur.

According to Centero-Martinez *et al.* (2007), the main reasons for adoption of CA are: (1) better farm economy (reduction of costs in machinery and fuel and time-saving in the operations that permit the development of other agricultural and non-agricultural complementary activities); (2) flexible technical possibilities for sowing, fertiliser application and weed control; (3) yield increases and greater yield stability; (4) soil protection against water and wind erosion; (5) greater nutrient-efficiency; and (6) better water economy in dryland areas. Also, no-till and cover crops are used between rows of perennial crops such as olives, nuts and grapes. CA can be used for winter crops, and for traditional rotations with legumes, sunflower and canola, and in field crops under irrigation where CA can help optimize irrigation system management to conserve water, energy and soil quality and to increase fertiliser use efficiency.

Work by ICARDA and CIMMYT has shown benefits of CA especially in terms of increase in crop yields, soil organic matter, water use efficiency and net revenue. CA also shows the importance of utilising fallow period for cropping and of crop diversification, with legumes and cover crops providing improved productivity, soil quality, N-fertilizer use efficiency and water use efficiency. CA is perceived as a powerful tool of land management in dry areas according to Lahmar & Triomphe (2007). It allows farmers to improve their productivity and profitability especially in dry areas while conserving and even improving the natural resource base and the environment. However, CA adaptation in drylands faces critical challenges linked to water scarcity and drought hazard, low biomass production and acute competition between conflicting uses including soil cover, animal fodder, cooking/heating fuel, raw material for habitat etc. Poverty and vulnerability of many smallholders that rely more on livestock than on grain production are other key factors.

In the **Sub-Saharan Africa**, innovative participatory approaches are being used to develop supply-chains for producing CA equipment targeted at small holders. Similarly, participatory learning approaches such as those based on the principles of farmer field schools (FFS) are being encouraged to strengthen farmers' understanding of the principles underlying CA and how these can be adapted to local situations. The corresponding programmes recognize the need to adapt systems to the very varied agro-ecosystems of the regions, to the extreme shortage of land faced by many farmers and to the competing demands for crop residues for livestock and fuel – problems that are particularly pronounced amongst small-scale farmers in Africa in the semi-arid tropical and Mediterranean regions.

CA is now beginning to spread to Sub-Saharan Africa region, particularly in eastern and southern Africa, where it is being promoted by FAO, CIRAD, the African Conservation Tillage Network, ICRAF, CIMMYT, ICRISAT, IITA (Haggblade & Tembo, 2003; Kaumbutho & Kienzle, 2007; Shetto & Owenya, 2007; Nyende *et al.*, 2007; Baudron *et al.*, 2007; Boshen *et al.*, 2007; SARD, 2007; Erenstein *et al.*, 2008).

Building on indigenous and scientific knowledge and equipment design from Latin America, farmers in at least 14 African countries are now using CA (in Kenya, Uganda, Tanzania, Sudan, Swaziland, Lesotho, Malawi, Madagascar, Mozambique, South Africa, Zambia, Zimbabwe, Ghana and Burkina Faso). CA has also been incorporated into the regional agricultural policies by NEPAD (New Partnership for Africa's Development), and more recently FARA (Forum for Agricultural Research in Africa) and AGRA (Alliance for a Green Revolution in Africa) are becoming interested in CA through their work on natural resources management and soil health. In the specific context of Africa (where the majority of farmers are resource-poor and rely on less than 1 ha, CA systems are relevant for addressing the old as well as new challenges of climate change, high energy costs, environmental degradation, and labour shortages. So far the area in ha is still small, since most of the promotion is among small farmers, but there is a steadily growing movement involving already far more than 100,000 small-scale farmers in the region. A network coordinated by FAO with qualified informants in different countries of Africa has gathered initial information about the application of no-tillage in some countries with following preliminary results: Ghana 30,000 ha; Kenya 15,000 ha; Morocco 4,000 ha; Mozambique 9,000 ha; Sudan 10,000 ha; Tanzania 6,000 ha; Tunisia 6,000 ha; Zambia 40,000 ha; Zimbabwe 7.500 ha. In Africa CA is expected to increase food production while reducing negative effects on the environment and energy costs, and result in the development of locally-adapted technologies consistent with CA principles (FAO 2008).

While large numbers of small-scale farmers (in Paraguay, China and various African countries) have adopted CA practices, experience indicates that spread tends to be at a slower pace than amongst larger-scale farmers. With food security among their major objectives, many small-scale farmers are hesitant to invest scarce labour, land, seed and fertilizer in cover crops that do not result in something to eat or to sell. They also suffer from restricted access to relevant knowledge as well as to inputs or credit. As a result, there is an increasing recognition of the need to encourage farmers to move towards full adoption of CA at their own pace, testing out promising approaches initially on small areas of their farms and progressively expanding as their confidence in the results develops. The global evidence of CA adoption presented in this paper and elsewhere (Fowler & Rockstrom 2000; Haggblade & Tembo, 2003; FAO 2008) suggests that CA elements can work for small farmers in sub-Saharan Africa.

Concluding Comments

The global research and development community in general as well as most of the farmers worldwide are at a crossroad, and must decide on the question: which way forward with agriculture in the 21st century? We have purposely provided the historical and current details regarding the adoption and spread of CA at the country level in all continents covering all agro-ecologies for large and small farmers as constituting a strong set of evidence to suggest that the future mainstream agricultural production systems (including those with pasture, trees and livestock) will not be based on the so called the 'modern' tillage-based and agro-chemically driven high carbon foot print agricultural production systems – the dominant paradigm of the 20th century.

The empirical evidence provided by the farming communities as presented in this paper tells us that farmer-led transformation of agricultural production systems based on Conservation Agriculture is already occurring and gathering momentum globally as a new paradigm for the 21st century. Further, the evidence tells us that where the transformation process has the support of the private corporate sector as well as public sector policy and institutional support, the rate of change can be rapid. Furthermore, the evidence also tells us that much of the current production system science and education as well as the policy and institutional support systems for the modern tillage-based agricultural practices are not suitable to support the transformation towards Conservation Agriculture as a mainstream new paradigm for the 21st century.

"The age-old practice of turning the soil before planting a new crop is a leading cause of farmland degradation. Tillage is a root cause of agricultural land degradation - one of the most serious environmental problems world wide – which poses a threat to food production and rural livelihoods" (Huggins & Reynolds, 2008). Combined with the lack of importance accorded to the role of soil microorganisms and soil biological processes in mainstream production system paradigm during the past century, globally we currently have most of our agricultural lands performing under suboptimal and degrading conditions. As long as and where ever the tillage-based paradigm continues to hold sway, it will also inhibit the development of agricultural production systems and associated policy instruments that can enhance environmental services from agricultural land use, address global challenges of climate change, and cope with the rise in food, energy and production costs.

With increasing awareness of the need for sustainable production intensification, and of improved understanding of how to achieve it, CA is a good mainstream paradigm for a sustainable and productive agriculture in the 21st century globally. Yet the question arises: if CA is so good, why is it not spreading faster? CA is knowledge intensive and a complex system to learn and implement. It cannot be reduced to a simple standard technology thus early adopters face many hurdles before the full benefits of CA can be reaped. The scaling up of CA practices to achieve national impact requires a dynamic complement of enabling policies and institutional support to producers and supply chain service providers. Only then will it become possible for all stakeholders to transform the prevailing tillage-based production systems to CA-based systems as a basis for sustainable production intensification.

The primary restriction to CA adoption is the assumption that soil tillage is essential for agricultural production. Other restrictions include those of intellectual, social, technical, environmental and political characteristics. Key restrictions with mainstreamg CA systems relate to problems with up-scaling which is largely due to the lack of knowledge, expertise, inputs (especially equipment and machinery), adequate financial resources and infrastructure, and poor policy support (Friedrich & Kassam, 2009; Friedrich *et al.*, 2009b).

Ultimately, it must be recognised that a behavioural change in all stakeholders must be encouraged and facilitated if CA practices are to take off globally. This includes the role and competences of the key national extension, research and education institutions, the government departments, development agencies and donors that support them, as well as the private sector that has an important and often unique role to play in innovation processes and in input supply including equipment and machinery.

CA is knowledge intensive with many new aspects and those who must promote it or practice it require training. In the case of farmers, an opportunity to test, learn and adapt is necessary. For extension staff, training is necessary in alternative mechanization technologies. Similarly, in universities and research institutions, there is a need to include training and research on CA-related agronomy and cropping system management at the field and landscape level, as well on the equipment options for different sources of farm power.

Knowing the respective bottlenecks and problems allows developing strategies to overcome them. Crisis and emergency situations, which seem to become more frequent under a climate change scenario, and the political pressures for more sustainable use of natural resources and protection of the environment on the one hand and for improving and eventually reaching food security on the other provide opportunities to harness these pressures for supporting the adoption and spread of CA and for helping to overcome the existing hurdles to adoption. In this way, the increasing challenges faced around the world, from the recent sudden global crisis caused by higher food and energy prices and input costs, and increasing environmental concerns to issues of climate change facilitate the justification for policy makers to introduce supportive policies and institutional services, even including direct payments to farmers for environmental services, including carbon sequestration, from agricultural land use, which could be linked to the introduction of sustainable farming methods such as CA. Thus, the actual global challenges are providing at the same time opportunities to accelerate the adoption process of CA and to shorten the initial slow uptake phase.

The crucial role of the national and international corporate institutions and private business sector is to ensure that CA machinery and equipment, fertiliser and pesticide (against insect pests, weeds and diseases), particularly low risk herbicides, are available to the farmers through government-assisted programmes, as appropriate. It is in the interest of everyone if the farmers involved in CA adoption were part of a CA-based producer organization.

At the same time, national and international knowledge systems must increasingly align their work in research, education and extension to helping to promote CA systems and practices. Research in particular must help to solve farmer and policy constraints to CA adoption and spread. It would not be out of place to suggest that it would be considered negligent if the stakeholders (including politicians, policy makers, institutional leaders, research scientists, schools, universities and academics, extension agents, private sector) who carry the responsibility of transforming the tillage-based agriculture into CA practices do not earnestly align and support the national and regional agricultural innovation systems towards this goal. In fact every country in the world must begin to set target for change towards CA, and use all available means and processes to set the transformation in motion thereby securing significant economic, socioeconomic and environmental benefits for the farmers and for the population at large in the world. People and institutions, both public and private sector, everywhere have everything to gain from adopting CA as a basis for sustainable agricultural intensification and ecosystem management. The greater impact that can result from the adoption of CA as a matter of policy and good stewardship is that agriculture development in the future everywhere will become part of the solution of addressing national, regional and global challenges including resource degradation, land and water scarcity, climate change.

CA practices offer a new way of effectively and efficiently managing agricultural environments and the natural resource base for multifunctional services to the society. As full benefits of CA take several years to fully manifest themselves, fostering a dynamic CA sector requires an array of enabling policy and institutional support over a longer-term time horizon. This will allow farmers to take advantage of the future carbon and water markets and support for environmental services currently under discussion internationally.

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31-07-2010