

Conservation Agriculture in the 21st Century: A Paradigm of Sustainable Agriculture¹

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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, including in the various temperate environments. 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 that 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

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

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 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.

So far there has been no serious policy and institutional attempt in Europe to systematically mainstream CA as a paradigm of sustainable agriculture. European Union is burdened with a costly Common Agricultural Policy (CAP) that is environmentally and economically unsuited for the 21st century. There is thus an unprecedented opportunity for Europe to incorporate CA-based paradigm for sustainable agriculture at the heart of the next CAP upon which to build a low carbon foot print agricultural economy and reduce the heavy financial and environmental cost of agriculture to farmers and society. This will also offer better value for money in terms of improving environmental services and addressing global challenges of climate change and rising food, energy and production costs.

Key words: Conservation Agriculture, Europe, 21st century paradigm, no-tillage, mulch cover, crop rotation, soil health, sustainability, adoption, policy support, institutional support, Common Agricultural Policy

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).

This is also true for Europe where, in addition to land and water scarcity in its Mediterranean region, agricultural land use is beset with several environmental constraints and threats, particularly land degradation from wind and water erosion, loss of organic matter and soil structure, soil compaction and poor rainfall infiltration, that cause floods (DEFRA, 2009; Kassam, 2009). For example, the report of the government-appointed Policy Commission on the Future of Farming and Food in the UK, under the Chairmanship of Sir Donald Curry, concluded in 2002 that (DEFRA, 2002):

“Farming and food industry is on an unsustainable course in economic terms. We believe it is also unsustainable environmentally – without substantial change... in the last 50 years...Soil organic content has declined and phosphorus levels in top soils have increased. Agriculture is now the number one polluter of water in the country. Land use changes have contributed to increased danger of extreme flood events, affecting thousands of homes. Beyond any doubt the main cause of this decay has been the rise of modern, often more intensive, farming techniques. ... things are still getting worse...in soil compaction and erosion, in the loss of certain species. A lot of the environmental damage in the countryside over the last 50 years has to be laid at the door of modern farming techniques. Much damage by farmers is not willful but arises out of ignorance. We believe a major advice effort will be needed... to help farming meet its new challenges. It will be very important that advice should also cover environmental issues.”

The degradation of agricultural soils in Europe as well as in most agricultural soils in the rest of 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 trap the snow from winter precipitation, 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 to produce large yields. 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.

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 in Europe (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, which have some similarities in their climatic conditions with northern Europe, 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).

This paper is a compilation of evidence of CA successes from a range of national and international sources including those that the co-authors have published earlier. The paper aims to serve as a context setting information source for discussion at the Congress. The paper presents some of the: (a) concepts and principles that underpin CA ecologically and operationally; (b) worldwide experience of benefits that can and are being harnessed through CA systems; (c) current status of adoption and spread of CA globally; and (d) relevance of CA to farming in Europe and globally in the 21st century.

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. 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 by 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, 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 CO₂ to the atmosphere, 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 CO₂ 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 CO₂ and loss to the atmosphere. Expanded across a wide area, CA has the potential to slow/reverse the rate of emissions of CO₂ 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 CO₂ (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 N₂O (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 N₂O 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 N₂O 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 N₂O after N leaching or runoff, or following gaseous losses and consecutive deposition of N₂O 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 N₂O 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 N₂O emissions and the overall balance of GHG emissions (expressed on a carbon dioxide (CO₂-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 industrialised countries

USA: No-till agriculture in the modern sense originated in the USA in the 1950s, and from then up until 2007 the USA had the largest area under no-till worldwide. Currently, USA accounts for some 25.5% of all no-till crop area. Conventional agriculture with tillage remains in the majority even if CA is a valid option for farmers, as compared with southern Latin America where no-till has become the majority agricultural system with 60% of the crop area. According to CTIC (2005), only 10-12% of the total area under no-till in the USA is being permanently not tilled. This occasional tillage prevents the system from reaching its optimum balance, as the soil is disturbed from time to time. Research has shown that it takes more than 20 years of continuous no-till to reap the full benefits of CA. Farmers that practice rotational tillage (plough their soils occasionally) will not experience the full benefits of the system (Derpsch, 2005).

Canada has fourth largest area under no-till with some 13.5 M ha (25.9% of crop area), although the no-till technology is used over much larger area, 46.1% of crop area (Derpsch & Friedrich, 2009b). The regions with highest percentage of adoption of no-tillage are Saskatchewan (60.1%), Alberta (47.8%), Ontario (31.2%), Manitoba (21.3%) and British Columbia (19.0%). Canada has had a similar development as the United States, with heavy erosion problems in the 1930's and the subsequent focus on conservation tillage. However, after the year 2000 more importance was given to a systems approach, not only focusing on reduced or zero tillage and chemical fallows, but including factors like soil organic cover and crop rotations. As a consequence between 1999 and 2004 the amount of wheat grown in Canada went down by 6.4 % while the oil crops increased by 48.7 % and pulses by 452.7 %. At the same time the use of fallow went down by 58.7 % (Yuxia & Chi, 2007). These developments are parallel to the recent increase in the application of Conservation Agriculture in Canada since the year 2000 (Goddard *et al.*, 2008).

The main co-benefits from CA have been documented by Baig & Gamache, 2009. There is excellent technical research being done on crop diversification and on integrated weed management (Blackshaw *et al.*, 2007). Alberta has also initiated a voluntary carbon off-set trading scheme that encourages industry under a 'cap and trade' regulation to purchase carbon off-sets from farmer associations whose members are practicing a production system based on the government-approved no-till protocol to sequesters additional soil carbon and reduce greenhouse gas emissions (Haugen-Kozyra & Goddard, 2009). The key lesson here is that there is no need for governments to wait for an international or global treaty before a country or a province within a country can initiate good CA practices that can not only offer all the economic and environmental benefits but also mitigate climate change and be paid for this environmental service by domestic industry sector. Alberta government and research community have worked closely with farmers and industry to develop a set of working protocols. The policy and institutional support to the farmers and industry has created an enabling environment for a win-win situation to operate. Currently, industry is paying for carbon off-sets at \$10 to 15 per tonne of carbon and this figure may rise towards \$25 per tonne in the future (Tom Goddard 2010, personal communication with Amir Kassam on 22 July 2010).

In **Australia** CA has been widely and quickly embraced by farmers, making it the country with fifth largest area of 17.0 M ha. It has improved weed control, time of sowing, given drought tolerance and has enabled dry regions to use water most efficiently (Crabtree, 2004; Flower *et al.*, 2008; Llewellyn *et al.*, 2009). The adoption of no-till by farmers in Australia varies from 24% in northern New South Wales to 42% in South Australia and 86% in Western Australia. Overall adoption of no-till in Queensland is approximately 50% with some areas as high as 75%. Conservation Agriculture methods have led to large increases in profitability, sustainability and positive environmental impact in the Australian cropping belt. Also the use of cover crops is getting popular among no-till farmers. Because of the water, time and fuel savings with no-till system as well as the other advantages, cropland under no-tillage is expected to continue to grow. Another complementary technology used in Australia on no-tillage farms is controlled traffic farming to avoid soil compaction

New Zealand has about 162,000 ha under CA, which corresponds to about 25% of all cropland area including pasture, forage crops and arable crops. New Zealand is

amongst the first in the world to use and develop the no-till technology. In the beginning in the seventies, pasture renovation without tillage was tried and practiced successfully. Later, also annual crops were seeded with the no-till. However, the majority of the increase in CA area has occurred since 2000.

Europe: CA is not widely spread in Europe (Basch *et al.*, 2008; Lahmar, 2009): no-till systems do not exceed 2% of the agricultural cropland. Since 1999 ECAF (European Conservation Agriculture Federation) has been promoting CA in Europe, and adoption is visible in Spain, Finland, France, Germany and Ukraine, with some farmers at ‘proof of concept’ stage in the UK, Ireland, Portugal, Switzerland, and Italy. More information on the state of play in countries in Europe is given in the next section.

Experience of adoption of CA in Europe (including Russia)

Europe is considered to be a developing continent in terms of the adoption of Conservation Agriculture. Only Africa has a smaller area under Conservation Agriculture than Europe. According to Basch (2005), “European and national administrations are still not fully convinced that the concept of Conservation Agriculture is the most promising one to meet the requirements of an environmentally friendly farming, capable to meet the needs of the farmers to lower production costs and increase farm income, and to meet the consumer demands for enough and affordable quality food with a minimum impact on natural, non-renewable resources. The reliance of Conservation Agriculture on the use of herbicides and the alleged increased input of herbicides and other chemicals for disease and pest control are the main constraints for the full acceptance of Conservation Agriculture as sustainable crop production concept”. However, the situation has begun to change in recent years not through the Common Agriculture Policy (CAP), but through individual countries taking their own initiative to introduce and promote CA. Increase awareness of farmers, politicians and society as a whole that soils are a non-renewable resource is leading to gradual changes in the overall approach to soil conservation (Basch *et al.*, 2008).

The key lesson that can be drawn from the EU experience is that in absence of policy and institutional support to the farmers, the transformation of agriculture in Europe from its currently unsustainable state towards CA is not likely to occur rapidly. This is because under the current CAP provision, the single farm payment is not linked to any cropping system or soil management protocol or to any scheme that offers payment for environmental services. Thus, farmers have no real incentive to change, and as long as the corporate sector remains unresponsive in terms of producing CA equipment and machinery and the research community dominated by corporate interests and reductive science, change for the better in Europe does not look hopeful.

A description of the status of adoption in Europe is presented below based on Derpsch & Friedrich (2009a, 2009b) and Derpsch *et al.* (2010).

Spain: No-tillage research in Spain started in 1982. On the clay soils of southern Spain no-tillage was found to be advantageous in terms of energy consumption and moisture conservation, as compared to both, conventional or minimum tillage techniques (Giráldez & González, 1994).

Spain is the leading country in terms of no-till adoption in Europe. According to AEAC/SV (Spanish Conservation Agriculture Association – Suelos Vivos), no-tillage of annual crops is practiced on 650,000 ha in Spain. Main crops under no-tillage are wheat, barley and much less maize and sunflowers. Besides annual crops grown in the no-tillage system in Spain many olive plantations and fruit orchards have turned to no-till systems. AEAC/SV reports 893,000 ha of no-tillage being practiced in perennial trees in most cases in combination with cover crops and livestock (generally sheep). Main tree crops in no-tillage system in combination with cover crops are olives and much less apple, orange and almond plantations. The extent of no-tillage practices in tree crops is not included in the global estimates in Table 2. In total it is reported that CA is applied on about 10% of arable land in Spain, and farmers practicing CA are receiving extra payment (from local, national and EU sources of funds) over and above the CAP-based single farm payment.

France: Long-term experiments with different minimum tillage techniques (including no-tillage) were started by INRA and ITCF in 1970, mainly with cereals (Boisgontier *et al.*, 1994). The authors concluded, that a comprehensive range of technical and economic data are now available in France in relation to where minimum tillage can be developed and how it can be implemented. France is among the more advanced countries in Europe in terms of adoption of CA/No-till farming. APAD (The French No-till Farmers Association) estimates that no-tillage is practiced on about 200,000 ha in this country, corresponding to just over 10% of arable land in France. Some farmers have developed superior no-till systems with green manure cover crops and crop rotation that are working very well. The 2008 IAD (Institute de l' Agriculture Durable) International Conference on Sustainable Agriculture under the High Patronage of Mr. Nicolas Sarkozy and the launching of the IAD Charter for Sustainable Agriculture are expected to show results in terms of greater acceptance of CA practices at all levels and especially at the political level, which is also needed across the whole EU in order to increase farmer acceptance. This notwithstanding, CIRAD has been researching on and promoting CA internationally for many years under the term 'Direct Seeded Mulch-Based Cropping System' (DMC) (Seguy *et al.*, 2006a, 2006b; Seguy *et al.*, 2008).

Finland: The adoption of no-tillage technologies was very fast in Finland. According to FINCA (Finnish Conservation Agriculture Association) in less than ten years no-tillage grew from some hundred hectares to 200,000 ha in 2008. In this way Finland managed to advance to one of Europe's leading no-till countries. The reason for this rapid adoption was that those farmers who believed in the no-till system and made it work communicated their experiences to their peers. The extension service and research organizations as well as agribusiness took interest in this development only later. FINCA has played a major role in spreading no-tillage in Finland. One manufacturer of no-till seeders in Finland took interest in no-tillage very early and claims to have sold almost a thousand no-till seeding machines until 2007, having about 50% of the market share in the country. About ten no-till seeder manufacturers from around the world have been able to place their no-till machines in the Finnish market and four of them are made in Finland. Another interesting fact about no-tillage in Finland is that no-tillage is practiced successfully from the far South of the country up to the Arctic Circle in the North (66° N).

Ukraine is a country where estimates on the adoption of no-tillage vary greatly depending on the source of information. Estimates vary from less than 30,000 ha to more than a million ha. Official government statistics on no-tillage state an adoption of 250,000 ha. Unfortunately, no-tillage systems as understood by the authors of this paper (see definition above), has not progressed as much as some people might wish. According to Agrosoyuz (a large cooperative farm in Dnipropetrovsk), there are about 1.1 million ha of Direct Seeding technology being practiced in Ukraine. Direct Seeding here is a technique where a specially designed machine seeds directly after the harvest of the previous crop into undisturbed soil. This type of machine, which is very widely used in Ukraine, does a virtually complete disturbance of the soil surface in the whole width of the seeding machine because it uses wide tines and often duckfoot openers. For this reason this form of seeding cannot be termed no-tillage and can only be classified as reduced tillage or mulch tillage. AgroSoyuz has organized several no-till conferences in Dnipropetrovsk inviting many renowned international speakers and since then understanding has been growing that only low disturbance systems bring additional benefits, justifying the focussing on no-tillage. As there seems to be a substantial amount of low disturbance no-tillage being practiced in Ukraine the authors of this paper, after carefully balancing information, estimated the area under no-tillage provisionally to be at 100,000 ha.

Switzerland: This country has made remarkable progress in terms of research, development and adoption of no-tillage practices. Research performed in Switzerland over more than ten years has shown equal or better yields under no-tillage in a variety of crop rotations. No-till tends to be more and more accepted in Switzerland. This is because conventional tillage (and also reduced tillage practices as chisel ploughing) exposes the soil to erosion under the topography prevailing in this country. According to Swiss No-till (no-tillage) is applied on about 12,500 ha in Switzerland and this corresponds to about 3.5% of arable land in this country. The Swiss No-till website offers very useful information on no-tillage in French and German. The No-Till ABC offers straight answers from practitioners to frequently asked questions by farmers.

Germany: Investigations into no-tillage technologies in Germany started in 1966. Intensive and long-term research has concluded that no-tillage is a viable cultivation system. According to Teebrügge and Böhrensen (1997), no-tillage is a very profitable cultivation system compared to conventional tillage because of the lower machinery costs and lower operating costs. No-tillage decreases the purchase costs, the tractor power requirement, the fuel consumption, the amount of required labour as well as the variable and fixed costs. Since the same crop yields can be achieved by no-tillage compared to plough tillage, on average the profit will be greater with no-tillage systems.

Despite these facts and opportunities, adoption of no-till farming in Germany is still very low. Well informed scientists, farmers and experts with a thorough understanding of no-till farming as practiced in most parts of the world do not coincide so that probably still today there are no more than about 5,000 ha of this technology being practiced by farmers in Germany. At the same time one can recognize that there are outstanding farmers practicing no-tillage in this country like for instance Thomas Sander who farms in Oberwinkel, Saxony and receives many

visitors every year. The quality of his no-tillage operation with crop rotations and cover crops has earned his farm the Environmental Award of the State of Saxony 2006. With increased fertilizer and fuel prices, erosion problems in some regions and regular droughts in others, interest in no-tillage farming is growing steadily and adoption is increasing. Some farmers like Alfons Bunk from Rottenburg, Suabia have been using continuous no-till for more than 10 years successfully.

Portugal and Italy, despite showing significant signs of soil degradation and erosion already since antique times (Montgomery 2007), have still fairly low levels of CA adoption. According to ECAF (2010), Portugal has some 80,000 ha under CA/No-Till system similar to some 80,000 under CA in Italy where CA is referred to as *Agricultura Blue* (Pisante, 2007). However, especially in Italy there is significant and growing adoption of CA concepts such as no-tillage and cover crops in fruit and olive orchards and regional governments in Italy do subsidize farmers for applying reduced tillage.

Russia: In Russia no-tillage is often referred under the umbrella term “Resource Saving Technology”. Despite all the efforts made to get at least some information on the area under no-tillage in Russia it has not been possible to obtain realistic numbers for this country. We need to recognize that in this huge country it is difficult at the moment to get reliable data on the area under no-till. On the other hand those people that have closer contact with Russia will know that several machine manufacturers have exported no-till machines to Russia in significant numbers. In Russia, the National Foundation for development of Conservation Agriculture (NFDCA) has been promoting CA, and NFDCA is a member of the European Conservation Agriculture Federation (ECAF). For this reason we believe there is considerable area under no-till farming in Russia. We hope to be able to obtain reliable estimates on the area under no-tillage in Russia in the near future.

Compared to other world regions CA development in Europe has been particularly slow, with some few exceptions, such as for example Finland and Spain. There is a number of reasons for this slow adoption in Europe, some of which are the moderate climate which does not cause too many catastrophes urging for action, agricultural policies in the European union including direct payments to farmers and subsidies for certain commodities, which take the pressure off the farmers for extreme cost savings and discourage the adoption of diversified crop rotations. In addition to this, there are interest groups opposed to the introduction of CA, which results for example in difficulties for a European farmer to buy a good quality no-till direct seeder with low soil disturbance and high residue handling capacity. Most of the European farmers practicing CA have directly imported CA equipment or have had contact to small import agents. However, the environmental pressure in EU is also increasing and the next European Common Agricultural Policy (CAP) currently under formulation is most likely to turn more favourable towards CA.

Conservation Agriculture in developing countries

Brazil has the longest experience in CA, and now has 25.5 M ha under various forms of CA. Since its first appearance in 1972, many useful lessons have originated from Brazil and from neighbouring Argentina and Paraguay, which now have respectively 25.8 M ha and 2.4 M ha of CA. They have also set important precedents

for the engagement of farmers as principal actors in the development and adaptation of new technologies and practices in including the integration of pasture, trees and livestock.

The first set of no-tillage experiments in Brazil were started in April 1971 at the IPEAME Research Institute (later EMBRAPA), in Londrina, Paraná, by Rolf Derpsch, one of the co-authors of this paper. The following year, Herbert Bartz, the first farmer to try the technology in Latin America, was already introducing the system on his farm. From there it took Brazil almost 20 years to reach the first million ha of no-tillage being applied by farmers, but after this milestone the practice has experienced an exponential growth.

Brazil took the initiative when herbicides (paraquat and diquat) and direct-drilling equipment became available in the US, and the realisation that conventional ploughing was leading to a severe environmental and economic crisis for farmers in southern Brazil. Progressive and wealthy farmers led the way, some travelling to the USA to learn about soil conservation and management systems there and to purchase direct-drilling equipment. Common interest groups were then formed amongst large-scale farmers and subsequently amongst small-scale farmers. The spread of CA in Brazil is mainly the result of farmer innovation together with problem-solving support from input supply companies, state and federal research and extension organizations, universities, as well as long-term funding commitments from international donors such as the World Bank and GTZ. However the momentum for innovation and adoption is still with farmers and their organizations.

Apart from enabling their land to be cropped more intensively without risk of degradation, CA attracted Brazilian farmers because it increased crop yields (at least 10-25%), greatly reduced surface runoff and soil erosion, and cut tractor use, resulting in big savings in fuel and production costs. Such benefits explain why today, Latin American farmers practice CA on a continuous basis on more than 55 M ha.

Argentina: Already in the early 1970's Argentina began its first research and farm trials with no-till. Several farmers started with the system and then gave up because of the lack of adequate herbicides and machinery that, together with lack of know how, constituted the main constraint for early adopters. A milestone in the development and spread of no-till in Argentina was the foundation in 1989 of AAPRESID, the Argentinean Association of No-till Farmers, based in Rosario. Since 1992 AAPRESID has been organizing no-till conferences in August of every year (simultaneous translation into English), which have been attended by more than 1,000 farmers at the beginning and nowadays exceed 2000 farmers. Since the founding of AAPRESID, Argentina also experienced an exponential growth of the no-till farming.

Argentina experienced a paradigm shift with the advent of the no-tillage practice and finally discarding the idea that tillage was necessary to grow crops. In Argentina the concept of "arable" soils has been abandoned after recognizing that soils that cannot be ploughed can be directly seeded. According to AAPRESID (2010) in 2007/08 there were 25.8 million ha of no-tillage being practiced in Argentina (<http://www.aapresid.org.ar>), making it one of the most successful countries in terms of no-till adoption. The first group of farmers started using no-till in 1977/78 after exchanging ideas with Carlos Crovetto, one of the most renowned no-till experts from

Chile, as well as with Shirely Phillips and Grant Thomas from the US. At the beginning growth was slow because of lack of experience, knowledge on how to do it, machines and limitations on the availability of herbicides. It took 15 years until 1992/93 when about one million ha under no-tillage were reached. Since then adoption increased year by year as a result of the intensive activities of AAPRESID so that in 2008/09 about 79% of all cropland in Argentina was under no-tillage system. The main advantages of the system according to AAPRESID (2010), is that it is possible to produce without degrading the soil and that soil physical, chemical and biological properties are improved.

One of the main factors that made the rapid growth of no-tillage possible in Argentina was the fact that machine manufacturers quickly responded to the increasing demand in no-till seeders. Among the many big and small no-till seeders manufacturers in Argentina there are at least 15 that are in conditions to export their equipment. No-tillage in Argentina is almost exclusively performed with disc seeders.

Similar to other countries in South America, farmers in Argentina prefer to do permanent no-tillage once they have started with the system. More than 70% of all no-tillage practiced in Argentina is permanently not tilled. At the beginning cover crops were not an issue for no-till farmers in this country because it was believed that these crops would take too much moisture out of the soil. This has changed in recent years when research could show, that water use efficiency can be enhanced when using appropriate cover crops. A milestone in no-tillage in Argentina was reached on 7 May 2010 when G. Cabrini with the help of AAPRESID became the first farmer to certify his no-till production system. The certification protocol is based on principles and criteria developed from international initiatives that focus on sustainability.

Paraguay has experienced a continuous and steady growth of CA adoption, almost all of it over the past ten years. Tillage practices have disappeared almost completely. In tractor mechanized farming systems, about 90% (of the total 2.4 M ha in 2008) of all crop area is under CA (Derpsch & Friedrich, 2009b). Similarly, in small farmer production systems with animal traction or manual systems, no-till practices have increased to about 30,000 ha covering 22,000 small farmers. The increased interest in small farmer CA systems has been a result of government support that provides grants for buying no-till equipment.

In **Bolivia** CA practices increased in the last ten years especially in the lowlands in the east of the country where the main crop is soybeans whose area has increased from around 240,000 ha in the year 2000 to 706,000 ha in the year 2007 (Derpsch & Friedrich, 2009b). The occurrence of wind erosion in conventional tillage systems has been one of the major driving forces for adoption. Also, farmers value the increased water use efficiency with no-till system in this low and erratic rainfall region.

Uruguay About 82% of cropland, that is 655,000 ha was under no-till systems in the 2006/07 growing season according to the Uruguayan No-till Farmers Association (AUSID). This is a great progress compared to the 2000/01 season when only 119,000 ha of no-tillage were reported, corresponding to 32% adoption. Some 65% of arable crops are seeded on rented land for which contracts are renewed every year, and this hinders the planning of medium term crop rotation and investment strategies. In Uruguay the integration of crops with livestock is very popular and CA systems fit

well into the requirements for crop-livestock production systems. Pastures are grown for several years until they show signs of ‘degradation’. Crops are then grown for several years according to the needs of the farmers and the market situation.

Venezuela, Chile, Colombia and Mexico each have modest amounts of their land under no-till systems, ranging from some 23,000 ha in Mexico and 102,000 ha in Colombia to 180,000 ha in Chile and 300,000 ha in Venezuela (Derpsch & Friedrich, 2009b).

The main crops grown under CA in Latin America include soybean, maize, wheat, sunflower, canola as well as cassava, potato and a number of horticultural and cover crops. CA practices are also being applied to perennial crops and to tree crops. Soil cover is achieved by growing cash crops and cover crops either in association or sequentially. Main cover crops include oats, oilseed-radish, rye, lupine, vetch, *Mucuna* (velvet bean), *Dolichos* and pigeon pea. In some cases, especially amongst small-scale farmers herbicide use is reduced by direct-drilling of the seed into a cover crop that has been flattened with a knife roller. Specialized no-till equipment has been developed in Brazil and the Americas, including tractor-mounted, animal drawn and hand tools (including jab planters). These are being exported to Africa and Asia and being adapted there for local use and manufacture.

Asian and African countries have seen uptake of CA in the past 10-15 years. In Central Asia, a fast development of CA can be observed in the last 5 years in **Kazakhstan** which now has 3.5 M ha under reduced tillage, mostly in the northern drier provinces, and of this 1.3 M ha (5.7% of crop area) are “real” CA with permanent no-till and rotation that puts Kazakhstan amongst the top ten countries in the world with the largest crop area under CA systems. No-till adoption has been promoted for some time by CIMMYT and FAO who introduced no-tillage systems in a Conservation Agriculture project from 2002 to 2004. No-till adoption started from 2004 onwards in the north Provinces (North-Kazakhstan, Kostanai and Akmola) where the highest adoption rates have been registered. CA has had an explosive development in recent years as a result of farmers’ interest, accumulated research knowledge, facilitating government policies and an active input supply sector (Derpsch & Friedrich 2009b). Extra incentive is offered to no-till farmers by government which has also supported long-term research work to provide solutions to farmers on issues such as the need to maximise effective winter snowfall through stubble trapping; to increase the generation of biomass through cover crops replacing bare or chemical fallows; to diversify cropping systems; and to improve integrated weed management (Suleimenov & Thomas, 2006; Suleimenov & Akshelov, 2006).

China too has equally a dynamic development of CA. It began 10 years ago with research, then the adoption increased during the last few years and the technology had been extended to rice production system. Now more than 1.3 M ha are under CA in China and 3,000 ha in **DPR Korea** where the introduction of CA has made it possible to grow two successive crops (rice, maize or soya as summer crop, winter wheat or spring barley as winter crop) within the same year, through direct drilling of the second crop into the stubble of the first. The feasibility of growing potatoes under zero tillage has also been demonstrated in DPR Korea (FAO, 2007).

In the **Indo-Gangetic Plains** across India, Pakistan, Nepal and Bangladesh, in the wheat-rice cropping system, there is large adoption of no-till wheat with some 5 M ha, but only marginal adoption of permanent no-till systems and full CA (Hobbs *et al.*, 2008). This is because virtually all rice is grown under some form of intensive tillage system. In India, the adoption of no-till practices by farmers has occurred mainly in the wheat-rice double cropping system and has been adopted primarily for the wheat crop. The main reason for this is the fact that tillage takes too much time resulting in delayed seeding and yield loss of the wheat crop after rice (Hobbs and Gupta, 2003; Hobbs *et al.*, 2008). The Rice–Wheat Consortium for the Indo-Gangetic Plains, an initiative of CGIAR, led by IRRI and CIMMYT, and involves several National Agricultural Research Centres, has been promoting no-till practice and it is mainly their efforts that have resulted in the massive uptake of no-till wheat in the region (Erenstein *et al.*, 2008). The uptake of the technology was rapid in the north-western states which are relatively better endowed with respect to irrigation, mechanization and where the size of holdings is relatively large (3 to 4 ha) compared to the eastern region which is less equipped and mechanized and where the average land holding is small (1 ha) (Derpsch & Friedrich, 2009a, 2009b).

In the **CWANA** (Central and West Asia and North Africa) 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 WANA 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), in Syria, Lebanon and Jordan (Belloume, 2007; Bashour, 2007; Pala *et al.*, 2007; Ghosheh, 2007) and in Turkey (Avci *et al.*, 2007). Similarly in Central Asia, work on CA practices for Eurasia has been reported by Gan *et al.* (2008), for Kazakhstan by Suleimenov (2009) and Fileccia (2009), and for Uzbekistan by Nurbekov (2008) and FAO (2009). ICARDA and CIMMYT have also been active in CA research in the CWANA region (Pala *et al.*, 2007; Karabayev, 2008; Suleimenov, 2009; Nurbekov, 2009).

Key lessons from international experiences about CA and considerations for its implementation in the Mediterranean region have been summarised by Centro-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 the CWANA 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 Centro-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.

The Role of CA in Farming in Europe

As seen above, CA is being widely practiced outside Europe, including in areas with similar agro-climatic conditions, particularly in North America (Baig & Gamache, 2009). There is now a growing conviction amongst many agricultural development experts, and increasingly by research scientists, that CA has an important role in transforming agriculture everywhere towards a more sustainable and efficient system (Goddard *et al.*, 2008; FAO, 2008).

For Europe, there are now strong reasons why CA should be at the heart of an alternate farming paradigm upon which to build future sustainable food and land use system. One major development goal of the next CAP should be the replacement of the current tillage-based unsustainable farming paradigm by CA-based paradigm for sustainable agriculture. CA-based land use systems including pasture, trees and livestock can serve as a major production system pillar upon which to build national and regional policy and institutional support for the management of affordable national food security and payment for environmental services to farmers.

However, currently CA is not being popularised in the EU generally, and is not being seriously researched. The lack of knowledge on CA systems and their management, and the absence of dynamic and effective innovation systems and lack of policy support, makes it difficult and socio-economically risky for European farmers to give up ploughing which is a farming practice rooted in their cultural traditions. In Finland, and Spain the adoption of CA is being encouraged and subsidised in order to reverse land degradation, reduce production costs, optimise resource use while mitigating climate change and enhancing ecosystem services. In other European countries the adoption process seems mainly farmer driven motivated by the reduction in the cost of machinery, fuel and labour. Land degradation and climate change concerns or environmental services do not appear to be the main

drivers in the European farmers' decision to shift to CA or not. This adoption trend may grow in the future in response to increasing energy and input costs, and the realisation by governments, research institutions and farmers that CA does offer a paradigm for sustainable agriculture and a strong agro-ecological foundation upon which to build policy and institutional support for higher quality farming and payments for a range of environmental services.

EU policy on sustainable agriculture and sustainable production intensification

CA as a different paradigm to underpin “sustainable production intensification” recognizes the need for a productive and remunerative agriculture that at the same time conserves the natural resource base and environment, and positively contributes to harnessing the environmental services. Sustainable crop production intensification must not only reduce the impact of climate change on crop production but also mitigate the factors that cause climate change by reducing emissions and by contributing to carbon sequestration in soils. It should enhance biodiversity in crop production systems above and below the ground, to improve ecosystem services for better productivity and healthier environment. CA delivers on all of these goals. It saves on energy use in farming and thus reduces emissions. And, it enhances biological activity in the soils, resulting in long-term yield increase. In fact CA represents a practical concept to achieve and sustain improved soil health and better soil-crop-nutrient-water management in agricultural landscapes leading to ecologically and economically sustainable agriculture.

European agricultural development policy can and should have a clear approach to sustainable farming which is not possible with tillage-based agriculture; hence all development activities dealing with crop production intensification in EU states should be assessed for their compatibility with CA principles. Environmental management custodian schemes in Europe do not promote the principles and practices of CA. This is because CA practices do not attract special rewards in the single farm payments to European farmers. On the contrary, commodity related subsidies or payment for set-aside land work against the adoption of CA. Thus environmental costs arising from intensive agriculture in Europe continue to be externalised and shifted to the society at large. Consequently, the degradation of soil, biodiversity and environment continues largely unabated.

EU governments must make a firm and sustained commitment to encourage and support CA, expressed in policies which are consistent and mutually reinforcing across the spectrum of government responsibilities and sufficiently flexible to accommodate variability in local characteristics. Facilitation should include tapered financial and logistical support for the number of years needed for farmers to make the changeover and become familiar with the functioning of CA. Formal recognition should be given to the public goods value of environmental benefits generated by adoption of CA. The research and education system should be permeated with understanding of well-managed CA as an optimum expression of sustainable productive agriculture.

The EU proposed Soil Framework Directive, resulting from the Soil Thematic Strategy, for example, would have facilitated national policies in support of CA and

enhancing the role of soil under CA as a repository of carbon. Unfortunately it was not adopted because five EU members opposed it. However, the new EU Water Framework Directive includes permissible levels for pollutants in water such as nitrates, phosphates or pesticides, but only under permanent no-till systems (i.e., CA) can the erosion and leaching of agrochemicals into surface and subsurface water bodies be reduced to a level compatible with the new directive.

Within EU there is an increasing concern about the sustainability of farming and organizations promoting CA in Europe, such as ECAF (European Conservation Agriculture Federation), have begun to raise awareness of CA at the practical as well as policy level. CA principles, knowledge, skills and practices as well as the associated learning and dissemination processes are of a 'public goods' nature and are effective in reducing purchased exogenous input requirements while enhancing the natural endogenous biotic and ecological productivity enhancing processes. EU member governments and European Commission will have to take responsibility of promoting the transformation of current production systems towards CA systems through the EU's CAP mechanisms which have been generally effective in managing agricultural change over the past several decades.

Farm machinery and mechanization, and precision farming

If CA is to spread in Europe, it must be understood that in the context of sustainable agricultural mechanization it is more than just a technique, such as no-tillage and direct seeding. It represents a fundamental change in the soil-crop-landscape system management and in the cropping system design and management which in turn lead to consequential changes in the required operations and mechanization solutions. This will involve a major shift in the current mix of mechanical technologies, some of which will remain but with only marginal use in future, and there will be the development of completely new set of mechanical technologies, changes in farm power requirements, and in land use suitability for sustainable intensification (Baker *et al.*, 2007).

More recently, research in Alberta, Canada, is showing that production cost savings and energy use efficiency are best achieved if precision farming technology and variable rate technology (VRT) for fertiliser application are built upon no-tillage systems. No-tillage already forms a basis for operating an agricultural carbon offset trading scheme in Alberta, as well as for reducing greenhouse gas emissions from agriculture. For example, according to the research supported by the Agricultural Research and Extension Council of Alberta (ARECA), producers throughout Alberta can reduce their fuel use and become more energy-efficient by...

- converting from conventional tillage-based practices to zero-till practices
- operating energy-efficient equipment technologies
- adopting precision farming techniques and VRT for application of fertilizers

Agriculture in Alberta, as elsewhere in the industrialized countries, is a major user of energy and conventionally tilled farms spend about 24% of their energy inputs on fuel and about 60% on fertilizer. Converting to zero-till practices alone increase energy efficiency, energy conservation and profitability. Fuel savings from converting from

conventional tillage to zero-tillage averages around 38% (across all crop rotations). During the period of 2001-2006 zero-till practices increased by 1.6 M ha and during the same time period diesel fuel consumption fell by 70.2 M liters. This led to decreased CO₂ emissions and improved soil conservation (see: www.areca.ab.ca). Since 2007, Alberta has been operating an agricultural carbon offset scheme in which the protocol that defines the production system compliance characteristics is based on no-till (Haugen-Kazyra & Goddard, 2009).

Another aspect that will have to gain increasing importance under CA is the avoidance of soil compaction, particularly in mechanized farming and in humid climates such as northern Europe. Existing mechanical technologies to reduce the danger of compaction, such as low pressure tyres and rubber tracks, tyre pressure adjustment systems and wheel track monitoring to warn the driver, will become economically more feasible for the CA farmer since the mechanical removal of soil compaction or surface tracks will not be a standard operation as is in the tillage-based farming. A safer approach to completely avoiding soil compaction in the crop zone is the controlled-traffic farming (Baker *et al.*, 2007) which is increasingly gaining popularity in Australian CA farms, but also in mechanized no-till farms in Africa and Central Asia, using satellite based guidance and eventually auto-steer options. The consequent application of controlled traffic concepts would eventually lead to completely different generations of farm machinery, from tractor through seeders to sprayers and spreaders to harvesters and transport equipment (Friedrich *et al.*, 2009).

It is perfectly feasible to meet food security needs in Europe at lower economic and environmental costs through CA systems linked to energy-efficient equipment technologies, precision farming and VRT, and controlled-traffic farming. The transformation to such systems will require effective political will and commitment backed by active support from the farming industry, including the farm machinery sector, which are currently lacking.

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.

For Europe, the current CAP, with its Single Farm Payment scheme and related instruments for environmental management, is unlikely to provide the intellectual and political momentum for such a transformation as its main purpose so far has been to increasingly manage the farming sector in Europe in a similar way to how EU member countries manage their education or the health service sectors on behalf of and for the public but without being able to address the root cause of land and environmental degradation, or the global challenges posed by climate change and rising cost of food, energy and production input.

Increasingly, the decisions regarding farming operations in Europe are driven less by market forces and more by government directives. Given that there is no effective publically funded research and extension system operating in much of Europe that can serve as the major advice effort needed to transform European farming towards CA, it is difficult to visualize the corporate sector addressing this need unilaterally. EU member governments and EU as a whole will have to realize that there are no market forces that can bring about the needed changes in the unsustainable farming practices that currently characterize European tillage-based farming (Kassam, 2009).

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 mainstream 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). As Europe is not currently generating the knowledge needed for transforming its farming sector towards CA, it must perhaps rely on: (a) the evidence and successful experience outside Europe; and (b) establish a network of publically funded on-farm operational research in which farmers can be provided with an opportunity and financial support to experiment with CA practices and adopt them to suit their socio-economic and agro-ecological conditions. Also, the engagement of the machinery sector to develop a new set of mechanical technologies for CA farming will be necessary.

EU governments must make a firm and sustained commitment to encourage and support CA, expressed in policies which are consistent and mutually reinforcing across the spectrum of government responsibilities and sufficiently flexible to accommodate variability in local characteristics. Facilitation will need to include tapered financial and logistical support for the number of years needed for farmers to make the changeover and become familiar with the functioning of CA. Formal recognition should be given to the public good value of environmental benefits generated by CA. The research and education system should be permeated with understanding of well-managed CA as an optimum expression of sustainable productive agriculture.

Ultimately, it must be recognised that a behavioural change in all stakeholders must be encouraged and facilitated if CA practices are to take off in Europe and 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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