Conservation agriculture: Concepts, worldwide experience, and lessons for success of CA-based systems in the semi-arid Mediterranean environments

Kassam A., Friedrich T.

in

Bouzerzour H. (ed.), Irekti H. (ed.), Vadon B. (ed.).
4. Rencontres Méditerranéennes du Semis Direct

Zaragoza : CIHEAM / ATU-PAM / INRAA / ITGC / FERT
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 96

2011
pages 11-51

Conservation Agriculture: Concepts, worldwide experience, and lessons for success of CA-based systems in the semi-arid Mediterranean environments

A. Kassam and T. Friedrich

*Plant Production and Protection Division, Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, 00153 Rome (Italy)
e-mail: amirkassam786@googlemail

Abstract. Conservation Agriculture (CA), comprising minimum mechanical soil disturbance and direct seeding, organic mulch cover, and crop diversification, is now practiced on more than 115 million ha in all continents and all ecologies, including the semi-arid Mediterranean environments. There is worldwide scientific evidence from research and empirical evidence from farmer practice to show that there are large productivity, economic, social and environmental benefits that can be harnessed through the adoption of CA practices in all semi-arid Mediterranean environments, including those in the CWANA region. However, CA is not being mainstreamed in any serious sense in the countries of the Mediterranean basin and of Central Asia region. CA represents a fundamental change in production system thinking and is counterintuitive, novel and knowledge intensive. Experience across many countries has shown that the adoption and spread of CA requires a change in commitment and behaviour of all concerned stakeholders. While adoption of CA under the given climatic conditions of the Mediterranean region might be more challenging, it is at the same time more urgent than in other climatic zones. 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 economic, social and environmental benefits CA 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. The CWANA region, its people and institutions, both public and private sector, 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 Mediterranean region will become part of the solution of addressing regional and global challenges including resource degradation, land and water scarcity and climate change.

Keywords. Conservation Agriculture – Semi-arid Mediterranean environments – No-till – Mulch cover – Crop rotation – Soil health – Sustainability – Adoption – Policy support – Institutional support.

Agriculture de Conservation : Concepts, expérience mondiale et succès des systèmes à base d'AC en milieux semi-arides méditerranéens

Résumé. *L'agriculture de conservation (AC), réduisant au minimum la perturbation mécanique du sol et intégrant le semis direct, le paillis organique, et la diversification des cultures, est désormais pratiquée sur plus de 115 millions d'hectares dans tous les continents et toutes les écologies, y compris les milieux semi-arides méditerranéens. De par le monde, des résultats de la recherche scientifique et des pratiques des agriculteurs montrent l'existence d'une importante productivité, des avantages économiques, sociaux et environnementaux qui peuvent être exploitées grâce à l'adoption de pratiques de l'AC dans les milieux semi-arides méditerranéens, y compris ceux de la région CWANA. Toutefois, l'AC n'est pas intégrée comme pratique agricole entière dans les pays du bassin méditerranéen et de l'Asie occidentale. L'AC présente un changement fondamental dans la pensée du système de production, elle est nouvelle, contre-intuitive et intensive en savoir. L'expérience de nombreux pays a montré que l'adoption et la diffusion de l'AC exigent un changement dans l'engagement et le comportement de tous les acteurs concernés. Bien que l'adoption de l'AC dans les conditions climatiques de la région méditerranéenne puisse être plus difficile, elle est en même temps plus urgente que sous d'autres climats. Pour les agriculteurs, l'expérimentation, l'apprentissage et l'adoption sont une nécessité préalable. Pour les décideurs politiques et les institutions leaders, la reconversion des systèmes basés sur le travail du sol en systèmes basés sur* *l'AC exige qu'ils comprennent bien les grands avantages économiques, sociaux et environnementaux qu'offre l'AC aux producteurs et à la société. En outre, la reconversion nécessite une politique et un appui institutionnel durables qui apportent les incitations et les services nécessaires aux agriculteurs pour adopter les pratiques de l'AC et les améliorer au fil du temps. La région CWANA, ses peuples et ses institutions, publiques et privées, ont tout à gagner en adoptant l'AC en tant que base pour l'intensification agricole et la gestion durables des écosystèmes. Le plus grand impact, qui peut résulter de l'adoption de l'AC, est que le développement de l'agriculture dans la région méditerranéenne contribuera à relever les défis régionaux et mondiaux relatifs à la dégradation des ressources, de la terre, aux pénuries d'eau et aux changements climatiques et à leur trouver des solutions.*

Mots-clés. *Agriculture de Conservation – Milieux méditerranéens semi-arides - Non labour – Couvert végétal – Rotations – Hygiène du sol – Durabilité – Adoption – Politique de soutien – Soutien institutionnel.*

I – Introduction

The challenge of agricultural sustainability has become more intense in recent years with the sharp rise in the cost of food and energy, 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 the semi-arid Mediterranean environments in the countries of the Mediterranean basin in Europe, North Africa and West Asia and in Central Asia and the Caucuses, where, in addition to land and water scarcity, agricultural land use is beset with several environmental constraints and threats. These arise from a negative annual water balance, short and variable rainy season, land degradation from wind and water erosion, loss of organic matter and soil structure as well as from soil salinity, and extreme temperatures in the continental parts (Kassam, 1981, 1988, 1992). The semi-arid Mediterranean environments are defined here as those geographical regions with subtropical and temperate thermal climates in the countries of the Mediterranean basin in North Africa, Europe, West and Central Asia and the Caucuses (the CWANA region) that have their annual precipitation dominantly during the "winter" period. The precipitation is received as rain or snow during autumn, winter and spring period from October to May and can range from some 200 to 600 mm annually, corresponding to a reference average length of frost-free crop growing season of 90-150 days, with high precipitation variability within and between seasons (Kassam, 1988). Some 88% of arable land in the region falls within this category (Oram and de Haan, 1995). The semi-arid Mediterranean environments located near the sea have relatively mild winter temperatures and hot summers (maritime Mediterranean environments); those located away from the sea within a larger land mass have severely cold winter temperatures and hot dry summers (continental Mediterranean environments). Thus, in the Mediterranean basin proper, there is a variety of climatic regimes owing to the complex configuration of seas and mountainous peninsulas in the 3,000 km incursion into Central Asia and the Caucuses. At higher altitudes and latitudes inland, the severity of winter temperatures is exaggerated but with moderate temperatures during the dry summer period. The semi-arid Mediterranean-type environments are often referred to as the "dry areas" or "dry lands", and sometimes collectively represent the hyper-arid, arid, semi-arid and sub-humid moisture regimes in the Mediterranean region with rainfall from less than 200 to more than 600 mm. Globally, they occur in the subtropics and temperate climates on every continent, in addition to the countries of the Mediterranean basin proper, in south western South Africa, south and south western Australia, central and southern Chile, west central Argentina, north west Mexico, the Pacific Northwest in North America including Washington and Oregon, and the south west USA including California. The semi-arid temperate Mediterranean-type environments correspond to the temperate grasslands or steppes or prairies or pampas or savannas shrub lands.

The CWANA region was once the breadbasket of civilizations and food production from the region sustained the most powerful empires of the ancient world, such as the Romans. Yet, already during those ancient times tillage-based agriculture led to soil degradation resulting in the reduced human carrying capacity of the land (Montgomery, 2007). The degradation of agricultural soils in the semi-arid environments of the countries in the Mediterranean basin, 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. Thus, most agricultural soils in the semi-arid environments of the Mediterranean basin have low organic matter with poor soil aggregate structure, and there is little effort made by farmers to develop organic soil cover from crop residues, stubbles and green mulches to feed the soil microorganisms, or to maximize rainfall infiltration, or to trap the snow from winter precipitation, or to protect the soil from water and wind erosion. The agricultural soils which are most vulnerable to tillage-stimulated rapid loss of soil organic matter are those of coarse texture Regosols and Xerosols and where the clay fraction is dominated by low-activity clays. Such soils are widely distributed in the semi-arid environments of the Mediterranean basin particularly in the lower elevations of the WANA region. Agricultural soils in the region are also dominated by calcareous soils with high clay content that are alkaline and low in organic matter such as Yermosols (Kassam, 1981, 1988; Stewart *et al.*, 2007).

Other agricultural soils that cover significant area are Cambisols and Luvisols which have fairly high productive capacity if treated properly. In the semi-arid environments of Central Asia where the temperature environment is strongly continental, Chernozem loamy soils with relatively high organic matter content are common. These soils are also very vulnerable to tillage that leads to loss in carbon, as well as to severe wind and water erosion when left unprotected without any organic soil cover during fallow periods. Thus, dust storms are still common in the region. In the mountainous areas of the semi-arid Mediterranean environments, agricultural soils are even more vulnerable to tillage because of the nature of the terrain. Overall, the negative water balance in the semi-arid Mediterranean environments can lead to salinity problems, particularly under intensive tillage conditions and low soil organic matter content (Nurbekov, 2008; FAO, 2009).

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 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 are demanded and sought to meet future needs. The severe degradation of the resource base and environment and the negative externalities associated with mainstream tillage-based agricultural practices is occurring in all parts of the world. In the industrialised nations such practices rely on increasingly 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 national institutions, international organizations and donor agencies towards the adoption and spread of similar harmful practices. 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 – the biological processes and ecosystem management paradigm. This alternative paradigm has been shown to work in many parts of the world, and is biologically and ecologically as well as economically more effective and efficient in producing the required outputs of goods such as edible and non-edible biological products and water resources while at the same time taking care of the 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 the new "biological and ecosystems" paradigm for sustainable agricultural intensification that can include arable and perennial crops, pastures as well as trees and livestock. 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 the alternative "biological and ecosystems" paradigm that can make a significant contribution to sustainable production intensification (including agricultural land restoration) and 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 sustainability 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 not in the scientific community but 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 a re-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 explicit given policy, legal and institutional level recognition to CA as a preferred agricultural production system for sustainable rural resource management and development. However, over the past 40 years, empirical 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 and Friedrich, 2008; 2009a; Kassam *et al.*, 2009; FAO, 2008, 2010). This is also true for the semi-arid environments in the Mediterranean basin and the nations in Central Asia and the Caucuses (Stewart *et al.*, 2007; Goddard *et al.*, 2008; ECAF,

2010) as well as for all other parts of the world that have subtropical or temperate Mediterranean-type environments including south western Australia, south western South Africa, south and central Argentina, central Chile, north west Mexico, and the Pacific Northwest USA and California (Derpsch and Friedrich, 2008, 2009a; Friedrich *et al.*, 2009a; Kassam *et al.*, 2009). Also, the Canadian Prairies, which have some similarities in their climatic conditions with the continental semi-arid Mediterranean-type environments in Central Asia and the Caucuses, have adopted CA practices at provincial scale in the provinces of Alberta, Saskatchewan and Manitoba that have led to significant economic and environmental benefits (Baig and Gamache, 2009).

This paper is a collation of information from a range of national and international sources including those which the co-authors themselves have earlier been involved in compiling. The paper therefore is expected to serve as an information source for discussion. The paper presents: (i) the concepts and principles that underpin CA ecologically and operationally; (ii) worldwide experience of benefits that can and are being harnessed through CA systems; (iii) the current status of adoption and spread of CA globally and in the Mediterranean-type environments, including in the Central Asia, West Asia and North Africa (CWANA) region; and (iv) some of the lessons for success of CA in the semi-arid Mediterranean environment in the CWANA region, and ways to accelerate its adoption and spread.

II – 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. They translate into three practical principles that can be applied through contextualised crop-soil-water-nutrient 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: (i) plants never, or for the shortest time possible, suffer water stress that would limit the expression of their potential growth; and (ii) 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 the 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).

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):

(i) 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.

(ii) Carbon, plant nutrients and water are recycled.

(iii) 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 and Zeiss, 2000; Lavelle and Spain, 2001; Coleman *et al*., 2004; Uphoff *et al.*, 2006) to:

(i) 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.

(ii) 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.

(iii) 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.

(iv) 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.

(v) 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.

(vi) 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.

(vii) Increase the burrowing activities of mesoorganisms such as earthworms, and of roots (leaving tubes after they have died and been decomposed).

1. Principle components of optimum Conservation Agriculture

The three principle components of optimum CA are:

(i) Minimizing soil disturbance by mechanical tillage and thus seeding 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;

(ii) 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;

(iii) Diversifying crop rotations, sequences and associations, adapted to local environmental conditions, and including appropriate nitrogen fixing legumes; such rotations 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 CO_2 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). Tillage has long been used by farmers to loosen soil, make a seedbed and control weeds. But not all 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.

III – 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 which does not lend itself to easy scrutiny by a research community often driven by short-term reductionist thinking and approaches.

1. CA as a fundamental change in the agricultural production system

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 conventional tillage agriculture (Hobbs, 2007; Shaxson *et al*., 2008; Friedrich *et al.*, 2009a; Kassam *et al*., 2009). Ideally it 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 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 which is already in good condition, and it can regenerate that in poor condition (Doran and 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 and 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 and Owenya, 2007; Gan *et al.*, 2008). 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 land holders.

2. Higher stable yields and incomes from CA

As an effect of CA, the productive potential of soil rises because of improved interactions between the four factors of productivity: (i) physical: better characteristics of porosity for root growth, movement of water and root-respiration gases; (ii) chemical: raise d CEC gives better capture, release of inherent and applied nutrients: greater control/release of nutrients; (iii) biological: more organisms, organic matter and its transformation products; and (iv) hydrological: more water available. The combination of the above features to raise productive potential makes the soil a better 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% 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 and Friedrich, 2009a).

Table 1. Relationship between components of CA and desired soil conditions

To achieve	CA components			
	Mulch cover: Crop residues, cover crops, green manures	**No till:** Minimal or no soil disturbance	**Legumes:** Crops fixing N supplying plant nutrients	**Rotation:** 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 fluctuation at soil surface	√			
Provide regular supply of OM as substrate for soil organisms	√			
Increase, maintain N 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 action 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				√
Rebuilt damaged soil conditions and dynamics	√	√	√	√

FAO (2001a) have indicated 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 reduced proportion of the area needing tillage (e.g., planting basins or zai/tassa/likoti), 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 and Whitten, 2000; Evers and 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 (Black Shaw *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 who have adopted CA have been striking (Landers, 2007). 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:

(i) Less soil erosion, improvements in soil structure and an increase in organic matter content, crop yields and cropping intensities.

(ii) Reduced time between harvesting and sowing crops, allowing more crops to be grown over a 12-month period.

(iii) 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.

(iv) 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).

3. 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 which achieves this also implies the presence of larger pores which contribute to through-flow of incident rainwater down to the groundwater (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).

4. Reduced greenhouse gas emissions

No-till farming also reduces the unnecessarily rapid oxidation of soil organic matter to CO_2 which 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 and Post, 2002; Blanco-Canqui and Lal, 2008; CTIC/FAO, 2008; Baig and Gamache, 2009). Making use of crop residues and the direct rhizospheric exudation of carbon into the soil represents the retention of much of the atmospheric C captured by the plants and retained above the ground. Some becomes transformed to soil organic matter of which part is resistant to quick breakdown (though still with useful attributes in soil), and represents net C-accumulation in soil, eventually leading to C-sequestration. Tillage, however, results in rapid oxidation to CO_2 and loss to the atmosphere. Expanded across a wide area, CA has the potential to slow/reverse the rate of emissions of CO_2 and other greenhouse gases by agriculture. Studies in southern Brazil show an increase in carbon in the soil under CA. According to Testa *et al*. (1992), soil carbon content increased by 47 per cent in the maize-lablab system, and by 116 per cent in the maize-castor bean system, compared to the fallow-maize cropping system which was taken as a reference. Although exceptions have been reported, generally there is an increase in soil carbon content under CA systems, as shown by the analysis of global coverage by West and 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 9 years. Under tillage agriculture and with monoculture systems the carbon liberation into the atmosphere was about 1.8 t/ha per year of CO (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 NO (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 and Bckman, 1994). The rate of production and emission of NO 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 NO formation as an intermediate in the reaction sequence of both processes which leaks from microbial cells into the atmosphere (Firestone and Davidson, 1989). In addition, mineral N inputs may lead to indirect formation of NO after N leaching or runoff, or following gaseous losses and consecutive deposition of NO 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 NO emissions (e.g., Parkin and Kaspar, 2006; Baig and 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 NO emissions and the overall balance of GHG emissions (expressed on a carbon dioxide (CO-C) equivalent basis).

5. 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 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 a re 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 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 and 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 (Bodde *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 agro biodiversity 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 which 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 allelo chemicals. The same crop mixtures, sequences and rotations provide above- ground mixed habitats for insects, mammals and birds.

IV – Worldwide experience of adoption and spread of CA

In the last 10 years the no-tillage technology has expanded at an average rate of 6 million ha per year from 45 million ha in 1999 (Derpsch, 2001) and 73 million ha in 2003 (Benites *et al.*, 2003) to 116 million ha in 2008/2009 (Table 2) showing the increased interest of farmers in this technology (Derpsch and Friedrich, 2009b). In addition to the data listed in Table 2 for field crops, there is a significant and increasing amount of CA applied to perennial crops, such as olive, vineyards and fruit orchards. Cover crops in orchards in Spain account for an additional 832,000 ha, with 347,449 ha even under no till. The practice of not tilling the soil in orchards and growing a soil cover crop instead is also spreading in Italy, Greece and the Middle East. 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.

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 of the technology being practiced by farmers, and Table 3 shows the area under no-till and the percent of adoption by continent. It is estimated that at present CA is practiced on about 116 million hectares worldwide. As Table 3 shows 46.8% of the technology is practiced in South America, 37.8% in the United States and Canada, 11.5% in Australia and New Zealand and 3.7% 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 (including in the countries of the Mediterranean basin) showing positive results for no-tillage, this technology has experienced only small rates of adoption.

Table 2. Extent of adoption of CA Worldwide (countries with > 100,000 ha)

Country	No-till area (ha)	Country	No-till area (ha)
USA*	26,500,000	Spain*	650,000
Brazil	25,502,000	South Africa*	368,000
Argentina*	19,719,000	Venezuela	300,000
Canada	13,481,000*	France*	200,000
Australia*	17,000,000	Finland	200,000
Paraguay	2,400,000	Chile*	180,000
China	1,330,000	New Zealand	162,000
Kazakhstan*	1,200,000	Colombia	102,000
Bolivia	706,000	Ukraine*	100,000
Uruguay	655,100	Russia	?
Total			**115,755,100**

Source: FAO AQUASTAT 2009.
*Includes CA in semi-arid Mediterranean-type environments .

Table 3. Area (ha) under CA by continent

Continent	Area	Percent of total
South America	49,579,000	46.8
North America	40,074,000	37.8
Australia and New Zealand	17,162,000	11.5
Asia	2,530,000	2.3
Europe	1,150,000	1.1
Africa	368,000	0.3
World total	**115,863,000**	**100%**

V – Worldwide experience of adoption of CA in the semi-arid Mediterranean-type environments

Outside the Mediterranean basin, there are several countries with subtropical or temperate semi-arid Mediterranean-type environments that have shown successful adoption of CA. These include the USA, Canada, Chile, Argentina, South Africa and Australia. In the Mediterranean basin, several countries have been successful in establishing CA but their extents are relatively modest. These include Spain, Portugal, France and Italy in Europe; Morocco and Tunisia in North Africa. Only in Kazakhstan in Central Asia has the extent exceeded one million hectares. Applied and adaptive research work on CA has also produced promising results in several countries in West Asia such as Syria, Lebanon, Jordan and Turkey, and in Central Asia and the Caucuses such as Uzbekistan and Ukraine. A brief description of the status of adoption is presented below based on Derpsch and Friedrich (2009a, 2009b).

1. Mediterranean-type environments in North and South America

A. United States

The USA began no-till farming as a response to the soil degradation and dust storms in the mid-west of USA in the 1930's as a result of the intensive tillage-based farming that was practiced there. United States has been among the few countries that has conducted regular surveys on the area under no-tillage and other forms of Conservation Tillage. The data is published at the CTIC homepage (http://www.conservationinformation.org). In 2007, in the CTIC homepage, no-tillage appears with 65.48 million acres which is equivalent to 26,493,000 ha, corresponding to 25.5% of total cropland area. Although the percentage of adoption has increased, the numbers still reveal that the majority of farmers in this country are still using conventional intensive or reduced tillage practices. Despite the fact that the growth of the area under no-tillage farming in the US has not been dramatic, a continuous and steady growth could be observed in the last decade. The adoption of CA in the Pacific Northwest, which includes semi-arid temperate Mediterranean-type environments, shows that without no-till farming it would be very risky to produce crops in the very dry areas. All the benefits mentioned in section 3 have been reported for no-till systems in this area (e.g., Williams *et al.*, 2009) but it appears that only some 10-15% of winter wheat and 20% of the spring wheat are under no-till systems. In Washington and Oregon, the lowest rainfall amount for wheat production with no-till is 150-200 mm received as snow and rain. This amount is exceptionally low to produce a crop but with good CA practices, yields of 1.5 to 1.8 t/ha have been reported. The key contribution of CA in this dry area is that it reduces risks of failure due to climatic variability and extends the limits of arable cropping into very low rainfall area. Also, no-till farming has allowed the cultivation of very steep slopes which would not have been possible under tillage-based system. There is little no-till farming being practiced in the Mediterranean environments of the south western USA.

B. Canada

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 and Chi, 2007). These developments are parallel to the recent increase in the application of CA in Canada since the year 2000 (Goddard *et al.*, 2008). Canada is actively promoting CA adoption in other countries, such as in China and Ukraine. 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%). According to the Soil Conservation Council of Canada, no-tillage is now practiced on 13.48 million ha in Canada and on average the technology is used on 46.1% of the cropped area (Derpsch and Friedrich, 2009b). Since 2000, there has been an average increase of 780,000 ha per year of no-till adoption in Canada. According to Derpsch and Friedrich (2009b) the majority of the conventionally tilled land is in the hands of the older and/or smaller farmers who will likely not change their practices. Thus the change in adoption will take place when the land changes hands. The majority of no-tillage in Canada is performed with air seeders that are equipped with hoe-type openers. The main benefits from CA in section 3 have been reported for the temperate continental environments of the Canadian Prairies (Baig and Gamache, 2009) which have some climatic similarities with the continental Mediterranean-types environment in Central Asia, particularly the receipt of winter precipitation as snow which no-till farmers must trap through stubble mulching to maximize effective precipitation. 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 soil management protocol. The protocol is based on minimum mechanical soil disturbance that sequesters additional soil carbon (Haugen-Kozyra and Goddard, 2009). The key lesson is that there is no need for governments to wait for some international treaty before a country can initiate good CA practices that cannot only offer all the benefits elaborated in section 3 but also mitigate climate change and be paid for this environmental service by domestic industry sector. Alberta government and research community have worked closely to develop a set of working protocols and policy and institutional support to the farmers and industry that has created an enabling environment for a win-win situation to operate. Currently, industry is paying for carbon off-sets at $15 per ha and this figure may rise to $25 per ha in the near future (Tom Goddard 2009, personal communication).

C. Chile

No-till pioneer Carlos Crovetto started no-tillage in 1978 and has been practicing it continuously for 31 years until now in the region of Concepción in Southern Chile, which has a semi-arid (sub-tropical and temperate) Mediterranean-type environment (Derpsch and Friedrich, 2009b). On land with 15 to 18% slope he has virtually eliminated erosion by doing away with tillage and leaving crop residues on the soil surface. Already in 1997, "after 19 years of continuous no-tillage, Carlos Crovetto had added one inch of topsoil, boosted the soil organic matter content from 1.7 to 10.6% in the first 5 cm of soil, improved the bulk density from 1.7 to 1.4 g/cm^3 increased the soil water-holding capacity by more than 100%, increased the phosphate content from 7 to 100 ppm and potash from 200 to 360 ppm in the top 5 cm of soil, improved the soil's cation exchange capacity from 11 to 26 milli-equivalents per 100 g of soil and raised the soil's pH level from 6 to 7" (No-till Farmer, 1997). According to Carlos Crovetto (Derpsch and Friedrich, 2009b), also author of several books about no-tillage, there are about 180,000 ha of no-tillage being practiced in Chile, which is about 30% of the cropped area in rainfed farming systems. Unfortunately there is a relatively large proportion of no-till farmers that has not yet understood the importance of organic soil cover in this system and burn their cereal residues regularly putting the sustainability of the system at risk. Official research institutions have taken little interest in this technology and have not been willing to study the long term detrimental effect of burning on soil health and yield. The lesson here is that without policy and institutional support, it is difficult for CA to be mainstreamed in a country.

D. Argentina

First research and farm experiences with no-till started in Argentina in the early 1970's. Several farmers began experimenting with no-till system and then gave up because of the lack of adequate herbicides and machinery which together with 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 1986 of AAPRESID, the Argentinean Association of No-till Farmers based in Rosario. Since 1992 AAPRESID is organizing no-till conferences in August of every year (with simultaneous translation into English) which have been visited by more than 1,000 farmers at the beginning and nowadays exceed 2,000 farmers. Since the founding of AAPRESID, Argentina also experienced an exponential growth in no-till farming (Derpsch and Friedrich, 2009b) including in the semi-arid Mediterranean-type environments of central Argentina. The advent of the no-tillage technology caused a paradigm shift in Argentina as the idea that tillage was necessary to grow crops was finally abandoned. In Argentina the concept of "arable" soils has been discarded after discovering that soils that cannot be ploughed can be direct seeded. According to AAPRESID (2008) in 2006 there were 19.7 million ha of no-tillage being practiced in this country (http://www.a apresid.org.ar). With almost 20 million ha under no-tillage, Argentina is among the most successful countries in terms of no-till adoption. The first group of farmers started practicing no-till farming in 1977/78 after exchanging ideas with Carlos Crovetto, one of the most renowned no-till experts from Chile, as well as with Dr. Shirely Phillips and Dr. Grant Thomas from the US. At the beginning, growth in adoption 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 has increased year by year thanks to the intensive activities of AAPRESID so that in 2006 about 69% of all cropland in Argentina was under no-tillage farming. The main advantages of the no-till system according to AAPRESID (2008) is that it is not only possible to produce and intensify without degrading the soil but that soil physical, chemical and biological properties can even be improved. The rapid growth of no-till in Argentina was possible because no-till seeding equipment manufacturers have responded to the increasing demand in machines. 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 like to practice 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. In the semi-arid Mediterranean environment in central Argentina, CA is practiced on nearly 20 million hectare representing about 70% of the arable land. The adoption of CA in this environment has boosted production by either increasing the number of crops grown per year or by expanding cropping into low rainfall areas which under conventional tillage would not have safely produced a crop (Derpsch and Friedrich 2009b; AAPRESID 2010).

2. Mediterranean environments in Europe

Europe is considered to be a developing continent in terms of the adoption of Conservation Agriculture (Basch, 2005). Only Africa has a smaller area under Conservation Agriculture/no-till than Europe. According to Basch (2005), "European and national administrations are still not fully convinced that the concept of CA 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 CA 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 CA 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, 2008), and some countries in the Mediterranean Europe have begun to make progress such as Spain, France, Portugal and Italy. 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 is dominated by corporate interests, change for the better in the Mediterranean Europe does not look hopeful.

A. 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 (Girládez and 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 live stock (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.

B. 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 which 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 following launching of the IAD Charter for Sustainable Agriculture is expected to show results in terms of greater acceptance of CA/No-till practices at all levels and especially at the political level. A greater acceptance of CA/No-till at political level is needed in the EU in order to increase farmer acceptance. This not withstanding, 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 and 2006b; Seguy *et al.*, 2008).

C. Portugal and Italy

Despite showing significant signs of soil degradation and erosion already since antique times (Montgomery 2007), these countries 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.

3. Mediterranean-type environments in Australia

According to WANTFA (Western Australia No-till Farmers Association), no-tillage is now practiced on about 17 million ha in this country (Derpsch and Friedrich, 2009b). Overall large increases in no-till adoption have been experienced since 2003 with high levels of growers using no-till to establish crops in 2008. Reduced soil disturbance through no-till and conservation farming methods have led to large increases in profitability, sustainability and environmental impact in the Australian cropping belt (Llewellyn *et al.*, 2009). The proportion of growers using at least some no-till is now peaking at levels around 90% in many regions. In regions with relatively low adoption 5 years ago, there have been very rapid increases in adoption, particularly in the period 2003-2006 (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. During 2008 the percent of the area under no-tillage is expected to grow to 88% in Western Australia and to 70% in South Australia (Flower *et al.*, 2008), and these regions constitute the semi-arid Mediterranean-type environments in Australia. Because of the water, time and fuel savings with this technology, as well as the other advantages of the system, no-tillage is expected to continue growing in this country, especially in those States with lower rates of adoption. In northern New South Wales the area under no-tillage is expected to increase from 24% in the year 2000 to 36% in 2010. Overall adoption of no-till in Queensland was approximately 50% with some areas as high as 75% (Flower *et al.*, 2008). In Australia most farmers use air seeders equipped with narrow knife point openers, although some farmers use disc openers which in the last years seem to gain popularity. Also the use of cover crops is getting popular among no-till farmers. Combining cropping with livestock (generally sheep) is a common practice throughout the country. This often leads to insufficient crop residues left on the soil surface at seeding but more recently the importance of soil cover is increasingly recognized in Australian no-till. Another complementary technology used in Australia on no-tillage farms is controlled traffic farming to avoid soil compaction (Friedrich *et al.*, 2009c). According to Fowler *et al.* (2008), the success of CA in Australia generally has been due to the public-private partnership in which the corporate sector organizations in collaboration with the National Landcare Programme of the Government Department of Agriculture have funded and supported CA through a network of closely associated conservation-minded farmer groups, under the designation Conservation Agriculture Alliance of Australia and New Zealand (CAAANZ) with their collaborating organizations. Such collaboration between farmer groups, research, extension, and industry organizations is vital to accelerate and sustain the spread of high quality CA. This appears to be a generic lesson that is consistent with similar lessons else where in the semi-arid Mediterranean-type environments such as in Argentina, Canada, Spain and Kazakhstan (see below).

4. Mediterranean-types environments in Asia

A. Kazakhstan

This country has experienced big changes in land tenure and farming systems in the last decades. No-till adoption has been promoted for some time by CIMMYT and FAO which introduced no-tillage systems in a CA project from 2002 to 2004. CA has had an explosive development in recent years as a result of farmers' interest, facilitating government policies and an active input supply sector. No-till adoption started from 2004 onwards in the north Provinces (North-Kazakhstan, Kostanai and Akmola) where the highest adoption rates have been registered (Derpsch and Friedrich, 2009b). A survey in this country showed a total area of adoption in Kazakhstan of 600,000 ha in 2007 and 1.3 million ha in 2008. With this Kazakhstan places itself under the ten countries with the biggest area under no-tillage in the world. The total area not using the plough anymore has even increased more. The official reports by the Ministry of Agriculture count about twice the area reported in this paper, including also technologies with high soil disturbance. However, 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 (Gan *et al.*, 2008; Suleimenov *et al.*, 2006).

B. Turkey

Only recently this country engaged in no-till techniques (generally referred to as direct seeding or conservation tillage) mainly at the experiment level by universities and research institutes. Results have been positive for no-tillage compared to minimum and conventional tillage systems in terms of time and energy consumption. Yields of no-tillage have been comparable to other tillage and seeding practices. But research results have not yet reached the farmers. The main reasons for this are, according to Derpsch and Friedrich, (2009b): (i) there is not enough information available in this field; (ii) there is lack of know how on how to do no-tillage; (iii) some farmers tried no-till but abandoned because of reduced yields; (iv) there is no government support for Conservation Agriculture technologies; (v) crop rotation is almost impossible due to low income of the farmers; (vi) small sizes of farms (average 6.1 ha) make it difficult to buy a specialized machine; and (vii) no-tillage machines are not available in the market to try. These problems are common to many developing countries including those in the CWANA region and have to be solved first before any attempt should be made to diffuse no-tillage technologies widely. Turkey could benefit from the results of no-tillage technologies being applied by GTZ projects under similar conditions in Syria and Lebanon.

C. Lebanon, Syria and Jordan

In the three countries there is an increased awareness about the benefits of CA at government level, mainly resulting from pilot and research projects and regional meetings on CA. Yet, so far the development has not gone beyond the pilot demonstration stage.

5. Mediterranean-type environments in Africa

For the last decade no-tillage has been in a state of intensive promotion in Africa, including countries in North Africa with semi-arid Mediterranean environments, as well as in South Africa that has Mediterranean-type environments in its Western Cape Province. Reported levels are still low, even where some massive large scale adoption is taking place. Adoption in Africa in general is in the early stages of building capacities and setting up structures for up scaling (FAO, 2008).

A. North Africa

No-tillage systems have been promoted particularly in Morocco and Tunisia. In Morocco 4,000 ha of no-tillage have been reported, despite long-term research on no-till farming having been initiated in the early eighties (Mrabet, 2008). This state of affair of limited adoption despite three decades of no-till research has been due to lack of concerted policy support and multi-stake holder network of scientists, manufacturers, industry, innovative farmers and opinion developers working together to promote CA (Mrabet, 2008). In Tunisia the promotion and development was farmer centered and the area under no-tillage increased from 27 ha on 10 farms in 1999 to nearly 6,000 ha on 78 farms in 2007 (Baccouri, 2008). One limiting factor for further spread of CA is the availability of lower cost CA equipment compared to the actually available machines, suitable also for smaller farmers, which would facilitate the access to the technology for more farmers and lead to a faster uptake of CA in the country.

B. South Africa

This country has experienced only a modest growth in the area under no-tillage since 2005 when it was 300,000 ha (Derpsch, 2005). According to Derpsch and Friedrich (2009b), the area has grown to a bout 368,000 ha since then. Although research and practical results have identified that CA techniques can be applied with beneficial outcomes, this obviously has not been communicated in an appropriate form to farmers and technicians. South Africa needs to make bigger efforts to promote and spread no-tillage systems to overcome erosion problems and limited rainfall in many regions. Derpsch and Friedrich (2009b) believe that this country, including its Western Cape Province with semi-arid Mediterranean-type environments, presents excellent conditions for applying no-tillage technologies, e.g., adequate infrastructure, the presence of no-till clubs and government programs to promote CA adoption, which needs to be better exploited.

VI – Lessons for success of CA-based systems in the semi-arid Mediterranean environments

There has been a good deal of scientific and operational research that has been done in most of the countries with semi-arid Mediterranean environments in the CWANA region as well as in the Mediterranean Europe (Stewart *et al.*, 2007; Goddard *et al.*, 2008; Lahmar, 2008). By and large, the international work shows that CA does work in the Mediterranean-type environments including those in the countries of the Mediterranean basin and in the CWANA region, and that the key benefits from CA, as elaborated in section 3, can indeed be harnessed by small and large farmers alike. The following sections deal with lessons on: (i) productions systems for CA; (ii) necessary steps for introduction and adoption of CA; and (iii) the role of policy and institutional support for scaling-up.

1. Production systems in the semi-arid Mediterranean environments, and opportunities for CA

Broadly, production systems in the semi-arid Mediterranean environments comprise the rainfed cereal-based systems with irrigated production during the summer period. The cereal crop is either spring or winter wheat or barley. This is generally followed by a fallow period, or where water is available, by irrigated crops particularly vegetables. Generally, livestock is an integral component of the farming system and so are tree crops such as olives. In the higher elevation areas of the maritime Mediterranean environments winter cereals give way to spring cereals, followed by irrigated crops in the summer period where water is available. This is also the case in the continental semi-arid Mediterranean environments in Central Asia and the Caucuses where spring cereal is often followed by a fallow period. In the mountainous areas rainfed arable cropping is practiced with cultivation of fodder crops as livestock is an important component of the systems.

The semi-arid environments adjoin the more arid environments where the main production systems are based on barley-sheep system supplemented by natural pastures and shrubs. These arid environments are integrated with the semi-arid environments which are a source of fodder and crop residues, and there is close area-wide integration between crops and livestock through the pastoral and agro-pastoral systems that are constantly in search for livestock feed. In recent years, market integration has permitted the production of livestock such as poultry and stall fed animals across the sub-humid, semi-arid and arid environments based on purchased feed as well as any locally produced feed. To improve the supply of livestock feed, there have been attempts to improve species composition of pastures and pasture nutrition and grazing management, and to introduce shrubs such as *Atriplex* and cactus, particularly in the arid areas.

A. CA-based rainfed systems

In general, much of the CA work that has been 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, 2008a, 2008b, 2008c, 2008d); and more recently in Tunisia (M'Hedhbi *et al* ., 2003, Ben-Hammouda *et al* ., 2007), in Syria, Lebanon and Jordan (Belloum, 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 Cantero-Martínez *et al.* (2007), Lahmar and 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 Cantero-Martínez *et al.* (2007), the main reasons for adoption of CA are: (i) 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); (ii) flexible technical possibilities for sowing, fertilizer application and weed control; (iii) yield increases and greater yield stability; (iv) soil protection against water and wind erosion; (v) greater nutrient-efficiency; and (vi) 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 fertilizer use efficiency. CA is perceived as a powerful tool of land management in dry areas according to Lahmar and 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. 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 utilizing 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.

Given that the semi-arid Mediterranean environments generally have a limited growing season, the time taken to develop the organic soil cover can take several seasons. However, what is important to keep in mind is that without the organic soil cover, the full benefits of no-till cannot be obtained (Derpsch, 2008b). As explained in section 3, with CA the whole ecosystem is part of production management in order to optimise resource use and productivity as well as enhance a range of ecosystem services. Organic matter in and on the surface of the soil not only drives the food webs of soil microorganisms and arthropods including beneficial predators, it is also essential for sustaining soil aggregate structure, for maintaining the chemical integrity of the soil, to facilitate weed control, to protect the soil surface from erosion and to maintain high rainfall infiltration capacity. With stubble mulching and green manure cover crops, including legumes and deep rooted crops, biomass therefore plays multiple functional role that maintains a biologically healthy and productive soil in addition to serving as a source of livestock feed and bioenergy etc.

B. CA-based irrigated systems

CA has not been introduced into irrigated agriculture to any significant degree in the semi-arid Mediterranean environments. However, the principles and practices involved with CA systems apply to both rainfed systems and irrigated systems. In the case of irrigated rice, systems of production that avoid or minimize soil disturbance can work well with CA. This is beginning to occur in Egypt where wheat-rice-cotton-legume rotations are widespread. Surface irrigation systems require special attention to residue management, but as all other irrigation systems they likewise benefit from water savings under CA. In recent years, supplementary micro irrigation has become popular for cereal crops to harness savings in crop water requirements which can be reduced further under CA systems. Vegetable and fruit production under irrigation after rainfed cereal is common in the semi-arid Mediterranean environments including the mountainous areas in Central Asia, and such systems can benefit from the adoption of CA practices. In Central Asia, particularly in Uzbekistan and Kyrgyzstan, wheat and cotton are dominant irrigated crops produced under tillage-based system. Thus, such systems can benefit from CA as has been shown in other parts of the world, including South Asia. In particular, CA on permanent raise beds with furrow irrigation, as opposed to flood irrigation has produced positive results. Also, there is a need to test and apply micro irrigation technology to CA systems.

C. Integration of trees and livestock into CA systems

Most of the work on CA in the semi-arid Mediterranean environments has focused on arable crops in rainfed systems. There is little work so far on the explicit integration of trees and livestock into CA systems. However, cereal-based CA systems invariably have small ruminants as part of the farming system, and tree crops such as olives are often an integral part of the farming system. In general, it is essential to ensure that where livestock is an integral component of the farming system, there is enough *in situ* biomass being produced within the cropping system to support its multiple functions including protecting and feeding the soil as well as serving as livestock feed. Where there is a so called conflict for biomass between livestock and soil, it means that the production system is not generating enough biomass, or the stocking rate is beyond the lands carrying capacity for sustainable production systems being practiced. In the semi-arid Mediterranean environments, there are several sources of biomass such as crop residues, fodder crops including sown and natural pastures of annual and perennial grasses, annual and perennial forage legumes, leguminous ad non-leguminous cover crops, and trees and perennial shrubs such as cactus and *Atriplex*, *Acacia, Artemesia, Opuntia* and *Salsola*. In general, crop residues tend to be consumed by livestock, and there is no allocation of residues to feed and cover the soil. Also, stubble will need to be used under CA systems to protect the soil and trap the snow. The situation in the semi-arid Mediterranean environments must change in the future to accommodate greater production and retention of biomass within the system, and ensuring sustainable stocking rates. The development of poultry in the Mediterranean region is generating large amount of biomass in the form of poultry litter. There is a potential to utilise biodigested manure as a source of organic matter and nutrients to feed the soil. Integration of trees and shrubs into CA systems is a compatible practice since no-till favours the establishment and good growth performance of trees and shrubs that can add biomass and resilience to the production system as well as many other advantages related to ecosystem services and livelihood. The highly desirable compatibility and complementarity that exists between agroforesty systems and CA systems is elaborated in Sims *et al.* (2009).

2. Necessary steps for the introduction and adoption of CA

Conservation Agriculture in its different local adaptations is practiced for more than 3 decades and has reached nearly every part of the world. Wherever it has been adopted it has proven the benefits usually claimed in its favour. Therefore the question arises: if CA is so good, why is it not spreading like wildfire? Equal to many other good and proven agricultural production practices, the adoption of CA needs a primer before it can start moving on its own (Derpsch, 2008b; Friedrich and Kassam, 2009; Friedrich *et al.*, 2009a, 2009b; Kassam *et al.*, 2009). CA represents a fundamental change in production system thinking. It has a number counterintuitive and hitherto unrecognised or under emphasized elements that promote soil health and productive capacity, and ecosystem services. The practice of CA therefore requires a deeper understanding of its ecological underpinnings in order to manipulate and manage its various parts for sustainable production intensification in which the aim is to optimise resource use and protect or enhance ecosystem processes in space and time over the longer-term. These are some of the features that are responsible for the practice of CA to be branded as being "knowledge intensive".

A number of constraints lie between the theory and a full scale adoption. These constraints come in different categories, such as intellectual and knowledge, social, financial, technical, infrastructural and last but not least policy and institutional. Experience across many countries has shown that the 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 economic, social and environmental benefits CA 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.

As was indicted at the beginning, CA is knowledge intensive and a complex system to learn. It cannot be reduced to a simple standard technology and especially for pioneers and early adopters there are many hurdles in the way before the full benefits of CA can be reaped. Above all, those involved in promoting CA must properly understand the principles that underpin CA and formulate practices that fit the local farming situation. The introduction and adoption of CA into existing agricultural situations must be seen as a longer-term process of change based on experiential learning. The following sections elaborate on what are some of the necessary steps for the introduction of CA and transformation of tillage system, as also described in Friedrich *et al.* (2009a, 200b).

A. The importance of involving the farmers

CA principles can be applied in many forms of agricultural practice. Because CA comprises several principle-based technologies rather than a single, prescriptive approach, farmers can choose the tools they judge to be most appropriate for them. Assisting farmers to improve the husbandry of land with CA must start with a thorough understanding of the present situation, of which the farmers themselves have the most detailed knowledge (FAO, 2001a). Therefore from the outset *they* must be the deciders of what is to happen. Farmers must be the principal point of focus, rather than the focus being on the land on its own, as they make the ongoing decisions about how the land will be used and managed. In spite of the fact that projects and field teams may tend to focus on technical issues within CA such as tillage, cover crops, weed control and implements at the field scale, sufficient attention needs also to be given to non-technical issues, such as rural finance, marketing and value-chain development, organizational or policy issues.

Though the principles of CA remain the same in all situations, how they can be best applied depends on how individual farm families make decisions. This depends on how each farm family responds to specific combinations of: (i) environmental conditions; (ii) farmers' resource-availability; (iii) type of production and farming system; (iv) market opportunities and transport availability; and (v) policy and institutional support. Farmers can be ingenious in problem-solving, and if they pick up information about CA from friends and other acquaintances, they may well innovate and adapt the method to their own conditions. Because of its flexibility and multiple options, CA is a system that can trigger the innovative creativity of farmers.

B. Importance of Farmers' Organizations

Farmers tend to believe their trusted peers more than their formal advisers when discussing the advantages and disadvantages of a new technique, approach, or tool. Making it easy for them to interchange ideas and experiences will help strengthen their own linkages and reinforce recommendations. Interested farmers may have already coalesced into informal groups with common interests. Such groups can form the basis for Farmer Field Schools (FFS), with guidance from well-trained advisory staff, for purpose s of regular experimenting and "learning by doing". Farmer groups, which may also form themselves into Associations, Federations, and/or Co-operatives, derive confidence from mutual support and exchange, from training together, from working together to reach goals such as joint actions towards environmental improvements. On the one hand, small informal groups of farmers may evolve and develop into co-operatives and larger bodies. On the other hand, if such bodies already exist, they may embrace the CA ethic and actions, and draw in new members. Such groups and organizations also develop bargaining power with buyers and sellers, traders, transport agencies, and others: and this benefits all the members of the group. If sufficiently well-organized, they may be able effectively to pressure government for necessary reforms to aid the CA cause. The development of such groups can then become a powerful means of encouraging others to join, and benefit from the movement towards getting CA established among increasing numbers of farmers and across ever-larger areas of land.

C. Role of scientists and extension/advisory agents

Appropriate roles for scientists in support of CA are: (i) to respond to unsolved technical problems, (e.g., cover crops for different situations); (ii) explore new potentials and possibilities based on what is already known and observed; (iii) clarify basic soil conditions, the significance of organic-matter's effects and related interactions with respect to soil productivity and its changes over time under different treatments; and (iv) 'blue-sky' exploratory research with possible relevance to CA. These lines may be at odds with the conception that fancy new techniques are the main route to solving old problems. Advisory staff may need to be trained as facilitators of knowledge-expansion and information-exchange, of problem-solving, as travel-a gents for study visits and interchanges, and of linkages between farmers and their groups with service-providers, and with government. They can bring in knowledge from outside, act as 'Yellow Pages' sources of information, as guides to introduction of helpers. There is always a need for good linkages and feed-back loops to be developed and maintained, in both directions, between researchers, advisory/facilitating staff, and farmers, so that all sides can remain well-informed about needs of the farmers, results of research, and of possibilities to be explored.

D. The need for relevant research

There is generally little participatory, farmer-centered research and development. Despite requests for solutions to specific problems raised by farmers and/or field staff (e.g., for refinements for better adaptation of CA principles to local conditions), there may be unwillingness to alter emphases in research and/or advisory programmes to address them. Key aspects still requiring greater attention under different ecological and socio-economic situations include: (i) weed control and integrated weed management in CA systems; (ii) integration of integrated pest (including weeds) management with CA; (iii) economically viable crop rotations and diversification of production with CA; (iv) plant nutrition and nutrient management under CA conditions with respect not only to grain or economic yields alone but also generation of plant biomass usable to raise organic-matter levels in the soil to maintain soil health and access to a balanced supply of nutrients; (v) development of effective CA in the semi-arid to arid zones in the tropics, sub-tropics and temperate climates in view of their characteristic environmental limiting factors; and (vi) the integration of livestock and mixed cropping into CA on small and medium holdings.

Research is sometimes undertaken and reported without regard to the need for results to complement each other in the actual field situations in which they are applied: e.g., "…best developments in weed-control research were not being incorporated into the [soil] fertility research, and the best results from the crop rotation research were not being incorporated into the tillage -systems research program" (Gan *et al.*, 2008).

E. Building up a nucleus of knowledge and learning system in the farming, extension and scientist community

The Latin American experience with CA has shown (FAO, 2001b) that by providing institutional and financial support, government has played a crucial role in creating incentives for adoption. The studies also point to the importance of credit availability for the purchase of new no-till machinery. Smallholders have been a special target as they lack the capacity to raise funds and retrain on their own. The World Bank reiterated these observations in its review of a project in Brazil promoting sustainable agriculture, modern forms of land management, and soil and water conservation. It considered rural extension to be a pivotal element in the project. In addition, monetary incentives were highly successful in motivating group formation among farmers, leading to an increase in cooperation and social capital. It recognized rapid paybacks and government financial incentives and support as key influences on adoption. Elsewhere, CA plus the FFS approach to assisting and informing small and larger farmers creates a form of insert into national and regional development which can underlie and enrich "watershed management" as a concept for sustainable improvement of landscapes and livelihoods.

Sustainable forms of agriculture must be maintained in all ecosystems many of which are vulnerable under ever-changing economic conditions, and therefore must be constantly monitored by the farmers themselves, supported by appropriate technical and policy changes. Most importantly, a nucleus of practical knowledge and learning system should be built up in the farming, extension and research community and this knowledge and learning system should always be put out and demonstrated to stakeholders as evidence of relevance and feasibility, and used for hands-on training students, researchers, extension agents and farmers as well as sensitizing institution leaders and decision-makers.

Demonstration areas: Once initial "benchmark" demonstrations of CA have been established among interested farmers themselves, it will become important to catch the interest of other potential supporters. For this reason it will be desirable to work with innovative farmers who are prepared to describe and share their experiences with a wider range of people, beyond the farming community. Such demonstrations would need to be clearly visible (e.g., alongside public roads) and easy of access to people from e.g., commercial organisations, different branches of Government, potential financiers who might assist broader expansion, and others.

Staff training: Key to success of FFS and other guidance of farmers in CA is that those advising farmers and other should be fully conversant with the ethos, changed mind-set, agro-ecologic and socio-economic principles, and modes of application of CA. It will be appropriate to set up dedicated training courses for this purpose at the outset, to generate a commonality of understanding among the trainees. On this they can base understanding of what they encounter among farmers and in the field, and provide consistent information. The training institution should maintain close links with the fieldwork and experiences to gain feedback and make appropriate adjustments to the programme for the refining of future courses.

Field days and study-visits: As already noted, much relevant experience is passed from farmer to farmer in conversation, on the basis of their own experiences and appraisals of recommendations and trials. Field days enable many farmers to get together to see new things and exchange views. Specifically-arranged study visits to unfamiliar areas within their own country, and/or different countries and among farmers in very different circumstances, can be powerful means of engendering new ideas and observing and discussing novel techniques. On return home, these may become the focus of further innovation and experimentation by the farmers.

Participatory and interdisciplinary learning process: For the development of CA in the field, intercommunication between farmers, researchers and advisers about progress and problems needs to develop active feedback loops, with information, requests, responses and results passing between all the parties involved. In this way a nucleus of information in common can be developed within and between the farming, advisory and scientist communities. A participatory and interdisciplinary process should be the basis for the analysis of socio-economic and agro-ecological factors which determine problems at farming system level and the methodology to identify technical solutions, which can be managed by farmers. This has certain implications for policy-makers. On the one hand, an assumption that CA will spread on its own in some desirable fashion is not appropriate. On the other hand, a uniform policy prescription to fit many locations is not realistic either, whether it consists of direct interventions or more indirect incentives stemming from research and development, or some mix of both. Designing successful policies to promote CA is likely to start with a thorough understanding of farm-level conditions. This understanding needs to include management objectives, attitudes to risk, willingness to make trade-offs between stewardship and profits. The next step is the careful design of location-sensitive programmes that draw on a range of policy tools. Flexibility is likely to be a key element in policy design to promote CA. A type of research which is seldom undertaken, but which can pay dividends for in good interactions between farmers and those who would advise them is that of "Operational Research". It is aimed at investigating, in the field, and with farmers, how improved practices (whether defined by researchers and/or by farmers) actually have their effects in the field, and how farmers perceive and manage them. Farmers and researchers become partners in such investigations, to the mutual benefit of both. Other criteria of success than profit alone, many of which may be suggested by farm-families themselves, become part of the "stock-in-trade" of such collaborative teams.

F. Financing and enabling the initial stages

An effective sequence of initial interventions for promoting the transformation towards CA systems could be as follows:

(i) Identify what are the limiting factors to farmers making improvements to their livelihoods (which may not always primarily be financial) to catch their attention. Falling soil productivity may well be at the base of the cited problem.

(ii) Identification of factors limiting crop yields (beyond just "fertilizer") and what could be done to alleviate these.

(iii) Identify one or more farmers already undertaking CA and demonstrating it’s agronomic, financial and/or livelihood benefits, and set up study visits.

(iv) Or: set up demonstration for researchers and advisory staff (extensionists) and farmers’ groups leaders, to catch their interest.

(v) Initiate "learning by doing" e.g., through FFS network or other participatory forms of investigation and learning. Gain insight into what farmers know already and how they would tackle the apparent problems in the light of new knowledge introduced.

(vi) Determine what are optimum means of achieving CA’s benefits for different situations of farm size, resource-endowments, through on-station and on-farm research and benchmark demonstration, observation, FFS etc and Field Days on farms already attempting CA. Record-keeping, analysis and feedback loops, Operational Research, are all important

(vii) Importing suitable samples of equipment (e.g., jab planters, direct seeders, knife rollers, walking tractors, etc.) to be able to demonstrate their use at the beginning.

(viii) Interact with any already-established farmers’ groups, e.g., co-ops, to gain interest and support.

It must be assumed that, as a minimum, a sufficient budget is available to cover, among others, costs of staff salaries and training-costs, travel costs, transport, equipment purchase, publications, and permission is given for field staff to work on CA.

Risks attend any changeover from one way of making a livelihood to another. All farmers, large or small, with and without resources, will be subject to such risks, though in different ways and to different degrees, and will make their own decisions on how best to minimise or avoid them. In recommending that governments give fullest support, at all levels, to CA, it is assumed that this will also include whatever may be necessary to reduce and ameliorate any extra risks to farmers arising from the process of change during the transition period – until the new system of CA has become safely and appropriately established. Such assistance to farmers could be appropriately in the form of sharing costs of any additional start-up credit, of purchase of suitable equipment, of extra insurance premiums (for perceived greater risks attending an unfamiliar set of procedures), etc.

Having made a commitment, it is also important for a government to make a policy that will ensure that sufficient and appropriate support to farmers' efforts be provided and maintained, to share costs and risks taken by small farmers during the period of changeover from tillage agriculture to that of CA. This period might be up to say five years in each instance of uptake, covering the time from initial awareness-raising to farmers and their groupings having developed full confidence in their capacity to manage their own development and attainments. Because uptake would not all occur at the same time, such assistance would necessarily be on a "rolling" basis. A corollary of the above is that arrangements should be made in advance of the timetabled cessation of a donors' financing to maintain continuity of support to farmers at the required, or a planned and diminishing, level of staffing, transport, finance.

As mentioned above, the period of changeover from tillage agriculture to a reduced/ minimal/ no-tillage form of production needs to have provision made for responding to needs that can be anticipated. This is likely to include differing degrees of cost-sharing for inputs, equipment, travel etc., for fixed durations from uptake, as a form of minimising the increased risks which could arise during the alterations in crop-production methods and management. The need for credit can be foreseen, and suitable arrangements made, whether with a banking system, or maybe "merry-go-round" loans made out of a group's own regular savings. Foreseeable needs may also include that of ensuring the availability of CA-specific equipment for farmers' use from government or commercially operated equipment pools until such time as farmers have been able to evaluate, and perhaps improve such equipment and decide to purchase their own items. Lack of availability of such equipment at critic al times for the farmers who need them has been found to be a strong disincentive to making further progress with CA because of loss of timeliness or precision then prejudices expectations of yield. Sufficient finance should be available in budgets for study tours, field days and other opportunities for farmers to meet each other and discuss CA matters of mutual interest. This has been found to be a potent way of stimulating exchange of information and innovations.

G. Mobilize input supply sector to service this new developing market

With keen farmers grouping together into Associations (see above), potential suppliers of inputs and technical advice will become aware of potential commercial opportunities, and can be encouraged to join, and provide supplies to the team of people spearheaded by the farmers themselves. Usually some "kick start" is necessary to break the deadlock of farmers not adopting because of lack of available technologies and the commercial sector not offering these technologies for lack of market demand. Policies facilitating procurement with credit lines, promoting technologies with technical extension programmes and introducing supportive tax and tariff policies are important for building up the long term commercial development of suitable input supplies for CA. Arrangements for marketing the crops and for selling farm inputs require attention at the time of beginning the CA revolution in a country where these may not work adequately well. Markets may exist already, but they may be inaccessible or be attractive to farmers because of poor roads, high transport costs, "rigged" pricing, etc. This has implications for improving the bringing-together of suppliers and purchasers to work as a team together with government field staff and others in responding to farmers' needs and requirements.

H. Sensitise policy-makers and institutional leaders

Both the field demonstrations and technical discussions generated by the growing spread of CA methods and successes, as told by farmers and others, will also make government department heads, policy-makers, institutional leaders and others aware of benefits, and of the desirability of backing the initiatives. It is important that policy makers come to a full understanding of the implication of the CA system. This makes it easier for them to justify supportive policies, which in the end are beneficial not only for the farming community but for everyone and hence for the policy makers and their reputation. On the other hand it is important for policy makers to think in long term developments and in integrated approaches, even across sectors and ministries. Import taxes on equipment or certain mechanization policies can counteract for example policies for sustainable agriculture if not coordinated well. As Pieri *et al.* (2002) put it: "The rules to be designed need to be based on real-life experiences demonstrating the positive environmental and socio-economic impact of Conservation Agriculture, which can be confirmed by testimonies of farmers and extensionists, as thus being measurable and visible results". "For the transition to more sustainable agricultural and other land use systems to occur, governments must facilitate the process with an appropriate range and mix of policy instruments and measures… It makes sense to take a planning horizon of five to ten years, within which to consider the likely impact of various policy measures". "It is…important for decision-makers to understand that the supportive environment created by favourable institutional and policy conditions will accelerate the process of change towards sustainable economic and social development with measurable effects. These favourable conditions are also critical to scale-up success NT [=CA] pilot projects".

VII – The role of policy and institutional support

Adoption of CA can take place spontaneously, but it usually takes a very long time until it reaches significant levels. Adequate policies can shorten the adoption process considerably, mainly by removing the constraints mentioned previously. This can be through information and training campaigns, suitable legislations and regulatory frameworks, research and development, incentive and credit programmes. However, in most cases policy makers are also not aware about CA and many of the actually existing policies work against the adoption of CA (Friedrich *et al.*, 2009b, 2009c). Typical examples are commodity related subsidies, which reduce the incentives of farmers to apply diversified crop rotations, mandatory prescription for soil tillage by law, or the lack of coordination between different sectors in the government. There are cases where countries have legislation in place which supports CA as part of the programme for sustainable agriculture. If those countries, within the same Ministry of Agriculture, have then also a programme to modernize and mechanize agriculture, it usually happens that the first items introduced under such a mechanization programme are tractors with ploughs or disk harrows. This does not only give the wrong signal, but it works directly against the introduction and promotion of CA, while at the same time an opportunity is missed to introduce the tractors with no-till seeders instead of the plough, helping in this way to overcome this technology constraint.

Countries, with their own agricultural machinery manufacturing sector, also often apply high import taxes on agricultural machinery to protect their own industry. This industry often has no suitable equipment for CA available in the short term, but due to the high import taxes the importation of equipment from abroad is made impossible to the farmers who wish to adopt CA. In other cases the import tax for raw material might be so high that the local manufacturing of CA equipment becomes unfeasible. In all those cases regulations have to be revised even beyond the influence of the Ministry of Agriculture, which often proves very difficult. Policymakers and legislators must be made aware of CA and its ramifications to avoid such contradictory policies.

Where farmers do not only farm their own land, but rent land from others, there are additional problems with the introduction of CA: the building up of soil organic matter under CA is an investment into soil fertility and carbon stocks, which so far is not recognized by policy makers, but increasingly acknowledged by other farmers. Farmers who still plough know that by ploughing up these lands the mineralization of the organic matter acts as a source of plant nutrients, allowing them to "mine" these lands with reduced fertilizer costs. This allows them to pay higher rent for CA land than the CA farmer is able to do. Such cases can be observed in "developing" African countries as well as in "developed" European ones. To avoid this some policy instruments are required to hold the land owner responsible for maintaining the soil fertility and the carbon stock in the soil, which in absence of agricultural carbon markets is difficult to achieve. According to Friedrich *et al.*, (2009a, 2009b), the following role of policy and institutional support is important in accelerating the uptake and spread of CA.

1. Need for political emphasis on CA

In general it has been observed that issues like soil health and soil productivity, unless they result in catastrophic dimensions of erosion, do not inspire or attract policy makers. They might take note about concerns of soil degradation but the n move over to the next agenda item. Those who are content to maintain the *status quo* of tillage agriculture, and seeing no reason to change it, would be unlikely to be public champions for promoting CA as its environmentally-preferable successor. Particularly sectors which are gaining from tillage-based agriculture and might lose out under CA are even likely to militate against a wider adoption of CA. This is the case with the tractor industry and most likely in the long term with the agrochemical industry, both sectors with potentially considerable political influence. Without a government's high-level political commitment to favouring spread of CA, it will suffer from insufficient back-up of positive support to the pioneer farmers who begin the changeover, such that increases in interest could falter or fail, for which some of the reasons are outlined above. Further, successes and failures in agriculture depend on the decisions and actions of individual farmers and how they manage the soil resource base on their farms. It is in this context that off-farm laws, policies, decisions, advice, market-prices and other forces are responded to or ignored. It is also the context in which changes in such forces aiming to favour the uptake of CA will be considered, ignored again, or be responded to and acted upon. This means that farmers need to take a leading role in the process of introducing and implementing CA on a large scale. But to take up this role they need a supportive policy environment.

2. Enabling Policies

CA has the potential to have an appreciable and widespread effect on large-scale farming as well as on the lives of large numbers of small farmers. For this to happen, however, it is important that national governments make a firm commitment to sustained promotion of the development of CA and that they continue to support its implementation. This commitment – in the form of enabling rather than prescriptive policies – would both remove existing obstacles and limiting factors, but also encourages and facilitates the adoption process, so as to bring CA into the main stream of agricultural activity. A facilitating policy environment can be an important determinant of whether CA is adopted or not. In cases where policy has been weak or ineffective, much of the successful diffusion of CA has occurred because of support from the private sector, farmers groups or other non-governmental organisations. In some countries, existing policies have both encouraged and discouraged CA at the same time. In spite of this, successes can be seen in the green decoupling programmes in Europe, and in farmland stewardship programmes such as Australia's Landcare. While CA can certainly spread in a limited fashion without policy support, it cannot be assumed that it does not need a supportive policy environment. However, it is unrealistic to assume that it is possible to devise a "one size fits all" policy in support of CA: whether this comprises direct interventions, indirect incentives via research and development activities, or a mix of the two. Since the principles of CA are based on an understanding of farm-level conditions, management objectives, attitudes to risk and trade-offs between stewardship and profits, policies in support of CA need to be formulated on a similar appreciation. The main implication of this is that most policies to support CA must be enabling and flexible, rather than unitary and prescriptive. Allowing the de sign of location-sensitive programmes which draw on a range of policy tools will ensure that policies are designed which both accommodate and promote the location-specific nature of CA. However, one area where a more uniform policy may be appropriate is in the development of social capital, to promote the precursor conditions for collective action – such as the development of group extension approaches (FAO, 2001a). Within this flexible policy framing, however, there are four other issues policymakers need to consider (Friedrich *et al.*, 2009a):

A. Policy coherence

CA is compatible with existing approaches to promoting agricultural and environmental sustainability, such as watershed management. However, it is not simply a case of meshing CA principles with policies encouraging a traditional approach to agricultural production. Any policies designed to promote CA will need to be examined for their coherence with (for example) existing laws on water use, health, the use of pesticides and other chemicals, and the burning of crop residues. A first step in creating legal rules for the protection of natural resources may be to establish a national framework whose provisions have a stimulating and motivating character and whose responsibilities are shared between the land users and the executing organizations. However, the interdisciplinary nature of CA principles means that CA policies may well cut across traditional Departmental boundaries. This means that there is a clear need to co-ordinate the adoption of a CA approach across departments to reduce the likelihood of conflicting policies being implemented. Agriculture-related incentives or subsidies must be examined to ensure that they do not jeopardize farmers' ability to adopt CA practices. Ultimately, skill levels and reward systems in the public sector may need to be adjusted so that government staff provide conservation-effective advice to all farmers, all of the time. This could be accomplished by decentralizing a CA programme to a regional capacity within the existing governmental organisation, avoiding the need to create a new entity to execute new laws or regulations. Non-government agencies, such as international donors and NGOs, should be encouraged to adopt the same stances, so as to mesh effectively with the national priority of CA.

B. Policies to actively encourage knowledge sharing

If farmers are to take the leading role in implementing CA, there will be a need for policies which encourage knowledge-sharing a t all levels. Farmers, advisors and even policymakers will need to share knowledge about how CA works, who it works for, where it works (or where it doesn't work), why it works, and how well specific practices and policies can be transferred between communities, regions and countries. This could be accomplished by developing appropriate local, national and regional CA networks and task forces to facilitate capacity building and active mutual learning. Part of the mission of these networks and task forces would be to build a good shared awareness of positive opportunities and constraints for CA within existing and transitional policy environments.

C. Basing "macro" policies on "micro" understanding

National policy needs to be framed in the full understanding of how micro-level issues – technical, socio-cultural, economic and environmental – are significant to the broad macro-scale features of agriculture and the environment as a whole. At the farm level, micro-level changes (such as raising the OM content of the soil) give rise to macro-level effects such as increased yields and profits. In a similar way, the aggregative effects of farm-level CA activities can be seen at a landscape level in terms of groundwater recharge, and improved water quality. This has significant implications for the framing of programmes of research, of pre-service and in-service training of technical staff, and for advisory mechanisms to farmers and their groupings. This relates as much to policy formulation as it does to the provision of technical advice. For example, a community comprising a group of small farmers may decide to develop their own local bye-laws – as for instance to regulate open grazing of post-harvest residues. Any national policy which promotes the formation of farmer groups must be supportive of these sorts of local initiatives within the national legal framework.

D. Policies relating to farm-level risk management

Adopting CA may, in the short term, involve costs and risks to which farmers, especially small-scale farmers in resource-poor settings, are averse. For example, late-starting farmers in dry areas may feel that the time taken to first prepare the soil adequately for CA might delay planting to such an extent that they risk losing the entire potential crop. If they need to hire oxen and equipment from other farmers, the added financial risk may seem too great for them to begin to make the transition to CA in that particular year. If CA is to be a national priority, governments need to recognise the public goods value of the environmental benefits generated by widespread adoption of CA practices. This means that appropriate policies and incentives need to be put in place to share costs and risks. The potential benefits arising from widespread implementation of CA are so high that it is cost-effective to provide tapered support to farmers during their change-over period. If CA becomes a national priority, then it needs a commitment from governments in the form of policies and (if necessary) legislation which make a formal undertaking to mitigate the risks associated with the transition phase. Whether CA is adopted by large or small-scale farmers, wider society gains in a number of ways, such as:

(i) Reduced erosion and runoff, resulting in less downstream sedimentation and flood-damage to infrastructure.

(ii) Better recharge of groundwater, more regular stream flow throughout the year, and better replenishment of wells and boreholes.

(iii) Cleaner civic water supplies with reduced costs of treatment for urban/domestic use.

(iv) Increased stability of food supplies due to greater resilience of crops in the face of climatic drought.

(v) Better nutrition and health among rural populations, with less call on health services.

A first step would be to classify, and where possible quantify, the benefits to society that can result from adopting CA. Information on these benefits of CA could be used to create public awareness and lobby for policy reforms that would adequately reward adopters, protect farmers against the additional short-term risks of making the transition to CA, and reward successful adopters for their effective stewardship of land and water resources.

3. Importance of policy support for rapid up-scaling

The capacity of CA specifically to address the improvement of sustainability – through its biological components – should spur innovative thinking and action at government levels in the search to revitalise agriculture on all degraded lands of any degree, where increasing expenditures are required just to maintain yields at a level average. While farmers would adopt CA due to its benefits, there are certain hurdles which keep farmers from doing this step or which slow down the adoption process considerably. Government policies play an important role for the adoption process. Uncoordinated policies between government sectors, for example making access to new equipment impossible or expensive, or crop-related subsidies work against the adoption of CA, while supportive policies can accelerate the adoption process dramatically. A good example for this is Kazakhstan.

CA has been promoted in Kazakhstan for some time by CIMMYT and FAO which introduced Conservation Agriculture through a project from 2002 to 2004. CA has had an explosive development in recent years as a result of farmers taking keen interest, enabling and facilitating government policies, and an active input supply sector. While the total CA area in the country in 2004 was be low 1000 ha, it grew until 2007 to 600,000 ha and in 2008 to 1.3 million ha, placing Kazakhstan in only 4 years among the top ten CA adopting countries in the world. Be sides a general policy support for CA, which encouraged public and private extension services to take up this message, the government provided initial subsidies for locally produced herbicides to decrease the initial costs and credit lines for purchasing no-till seeding equipment to overcome problem of capital availability for investment. Further, the country was open for importation of no-till seeding equipment, despite having one of the main seed drill manufacturing facilities from the Soviet times.

4. Government institutional restrictions

Even in the face of looming problems posed by complexities of climate change effects and its interactions with increasing demands for production from the land, a number of governments are not yet fully enthused by the possibilities of CA. The global and national urgencies are such that it is not appropriate just to let the adoption of CA takes its own course, even though Brazilian experience shows that this can occur – though more slowly than it would have done if there had been stronger and subject-specific backing. The effectiveness of such backup will depend on coherence of purpose and approach between the different agencies of government involved in encouraging the spread of CA. Institutions (e.g., Government departments) are normally arranged in ways conformable with, and dedicated to, only maintaining the current ways of doing things, inappropriate though that might be. Ways of tackling certain problems –e.g., soil erosion– are usually based on time-honoured convention more than they could be on active observation, feedback, and adjustment by the agency with responsibility for technical matters of land use and conservation.

There are sometimes rivalries between, or clashing objectives of, different Ministries, Departments, or agencies within Government, which do not have adequate inter-communication (e.g., as between Agriculture and Local Government regarding the improvement of inappropriate byelaws; or between Agriculture as Veterinary Departments as to which has main responsibility for animal husbandry). Often there is found to be inadequate "horizontal" coherence between related Departmental policies –e.g., between those on environment *vs* agriculture *vs* water supplies *vs* human health. There may be found inadequate "vertical" coherence between decision-making at HQ and necessities at regional/local levels. This may be so especially in matters of keeping field staff (at the interface with farmers) up-to-date with information and motivation (e.g., study-trips outside their areas to see different situations and provide opportunities to discuss with others). An example is a tendency to make apparently arbitrary decisions about postings of field staff from one place to another, without due consideration of the need for consistency and continuity of linkages with farmers.

E. Institutional capacity

CA is not a static set of technologies, but a dynamic system that differs from place to place and from year to year, depending on the prevailing bio-physical and socio-economic conditions facing individual farmers. The institutions that are set up to promote and support CA need to be similarly dynamic so that they can respond to farmers' varied and changing needs. As well as policymaking departments, these institutions include the research and development programmes on which much of the technical knowledge of CA is based. Whatever technological combinations are used by farmers, RandD activities must help to assure that good husbandry of crops, land and livestock (Shaxson, 2006) can occur simultaneously for the system to function well. Both the technical and social sciences must be combined with the views and opinions of stakeholders to develop technologies and systems that can be adapted to varied conditions facing farm families adopting CA as a way of farming. This means that the diverse providers of information –and their investors– need to be involved in broad programmes to develop the science and technology for CA. Such institutions include international agencies, multi-donor programmes, NGOs, national government staff, academic institutions, commercial organisations and agribusiness. Each brings a different expertise and understanding to the table. However, unless these are tied together within a common framework of understanding of the principles and benefits of CA, their potential synergy cannot be felt. One way forward would be to develop common indicator sets to assess progress towards the environmental, economic and social benefits of CA. This would help promote CA as the sustainable alternative to tillage-based agriculture techniques, and to build a common basis for understanding the potential of CA for both large and small-scale farming communities.

F. Accessibility and affordability of required inputs

There are costs involved in making the transition from tillage-based agriculture to CA. The farming patterns which preceded a farmer's decision to switch production techniques may not have produced enough saved resources to allow him or her to accept all the potential risks associated with the change-over. Nor may it be possible for him or her to make the necessary investments in unfamiliar seeds (e.g., of cover crops) or to hire new equipment such as manual, animal-drawn or larger tractorised seeders. Once CA has become established on a farm, its lowered costs and the higher and more stable yields then begin to generate sufficient resources to pay full commercial costs of these new inputs.

G. Knowledge, education and learning services

CA involves a fundamental change in the way we think about agricultural production and how it is related to environmental stewardship and nature. There are three implications of this. First, we need to think differently about how cognitive knowledge is spread to farm families, of all farm sizes, and to public at large. One necessary change will be to inculcate schoolchildren –and then right up through graduate and postgraduate education– of the need to go beyond tillage agriculture and to understand the importance of CA systems in all settings for sustaining the production of crops and water from landscapes, and for protecting the environment and biodiversity. Doing this will ensure that CA principles become the accepted norm for agriculture and environmental stewardship, whatever the scale of farming.

A second change will be to ensure that people working in specialised areas of agricultural science and policy are informed of emerging CA successes from the field and the implications and inter-relations with their specialisations. Both researchers and advisory staff need to be kept up to date with the principles of CA, its effects and results. This means having the capacity to work across the traditional science disciplines and to work closely with farming communities to understand what constitute s good land husbandry. Without compromising the quality of education in the traditional agricultural and social sciences, it would be possible to boost education and training on CA principles and benefits in universities, colleges and schools. Such training would stress the commonality of the principles of CA principles and show how they can be applied through diverse technologies and development approaches. In addition, while the greatest impact will come from applying all three principles of CA at the same time, farmers' constrained socio-economic situations and attitude to risk may mean that what is more likely to succeed is a step-wise approach which responds to their individual conditions. This means that knowledge management systems in research and extension need to be able to operate at different scales simultaneously. They need to be able to assess the landscape-scale benefits of adopting CA whilst also providing evidence of how well CA performs in the micro-environments of individual farms and farming communities. A key function of the tertiary education system in both developed and developing countries would be to research and validate the science underpinning CA techniques.

Third, an active international Community of Practice (CoP) comprising national and international stakeholders needs to emerge and operate effectively in the CWANA region so that it can acquire, evaluate, share and disseminate robust evidence about the principles, practices and impacts of CA. Raising awareness of CA in government, professional organizations and the general public will help support the diverse initiatives of research, extension, advocacy and evaluation which must be in place to advance the state of the art in CA. This international CoP might devise specific encouragements for larger-scale and more advanced CA practitioners to advise and mentor those at earlier stages of adaptation and uptake. It could also monitor the results of CA projects and programmes, at all levels, and disseminate them to the international community.

VIII – Concluding remarks

Despite the obvious productivity, economic, environmental and social advantages and benefits of CA, adoption does not happen spontaneously. There are good reasons for individual farmers not to adopt CA in her/his specific farm situation. The origin of the hurdles ranges from intellectual, social, financial, biophysical and technical, infrastructural to policy issues. 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 soaring food prices, high energy and input costs, 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 from agricultural land use, which could be linked to the introduction of sustainable farming methods such as CA. In this way 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.

CA has taken off and spreading in several Mediterranean-type environments outside the CWANA region particularly in South America and in Australia. However, in the countries of the Mediterranean basin, CA has not taken off as yet in any significant scale. Morocco and Tunisia are the only two countries in the WANA region where there are now 4,000 and 6,000 ha respectively under CA practices. This shows that its technically possible to adopt CA under these conditions and that the reason for not doing so has a different origin. This is also true in Central Asia and the Caucuses, except for Kazakhstan where there are 1.3 million ha of wheat-based system under CA. Kazakhstan serves as a good example that shows that accelerated transformation from tillage-based system to CA is possible if policy and institutional support can be provided to farmers. Similarly, in the Mediterranean Europe, Spain has begun to make significant progress with annual as well as perennial crops and soon will have over a million ha of CA, for reasons similar to those for Kazakhstan.

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) in the CWANA region 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 CWANA region 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 region. The region, its people and institutions, both public and private sector, 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 Mediterranean region will become part of the solution of addressing regional and global challenge s including resource degradation, land and water scarcity, climate change.

References

AAPRESID, 2010. Website of AAPRESID http://www.aapresid.org.ar/institucional_sd.asp

Avci M., Mevveci K., Akar T., Ozdemir B., Yururer A., Karakurt E., Surek D. and Karacam M. 2007. Turkish experience on dryland agronomy: lessons from the past and the recent experiments. In: *J. Agric, Res.,* 45(1), p. 33-42.

Baig M.N. and Gamache P.M., 2009. *The Economic, Agronomic and Environmental Impact of No-Till on the Canadian Prairies*. Alberta Reduced Tillage Linkages, Canada.

Baker C.J., Saxton K.E., Ritchie W.R., Chamen W.C.T., Reicosky D.C., Ribeiro M.F.S., Justice S.E. and Hobbs P.R., 2007. *No-Tillage Seeding in Conservation Agriculture,* 2nd edn. Rome: CABI and FAO.

Basch G., Geraghty J., Stret B. and Sturny W.G., 2008. No-tillage in Europe – state of the art: constraints and perspective. In: *No-Till Farming Systems,* Goddard T., Zoebisch M.A., Gan Y.T., Ellis W., Watson A.

and Sombatpanit S. (eds). World Association of Soil and Water Conservation, Special Publication No. 3, WASWC, Bangkok, pp. 159-168.
Bashour I., 2007. Impact of Conservation Agriculture on soil fertility in dry regions. In: *The Proceedings of the International Workshop on Conservation Agriculture for sustainable Land Management to Improve the Livelihood of People in Dry Areas,* Stewart B., Fares Asfary A., Belloum A., Steiner K. and Friedrich T. (eds.), 7-9 May 2007, ACSAD and GTZ, Damascus (Syria), pp. 111-120
Belloum A., 2007. Conservation Agriculture in the Arab region between Concept and Application. In: *The Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas,* Stewart B., Fares Asfary A. Belloum A., Steiner K. and Friedrich T. (eds), 7-9 May 2007, ACSAD and GTZ, Damascus (Syria), pp. 11-24
Ben-Hammouda M., M'Hedhbi K., Kammassi M. and Gouili H., 2007. Direct drilling: An agro-environmental approach to prevent land degradation and sustain production. In: *The Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas,* Stewart B., Fares Asfary A. Belloum A., Steiner K. and Friedrich T. (eds), 7-9 May 2007, ACSAD and GTZ, Damascus (Syria), pp. 37-48.
Benites J., Vaneph S. and Bot A., 2002. Planting concepts and harvesting good results. In: *LEISA Magazine October*, 18(3), pp. 6-9.
Bhogal A., Chambers B.J., Whitmore A.P. and Powlson D.S., 2007. *The effects of reduced tillage practices and organic material additions on the carbon content of arable soils*. Scientific Report for Defra Project SP0561. Rothamsted Research and ADAS, Harpenden, UK.
Blackshaw R.E, Harker K.N., O'Donovan J.T., Beckie H.J. and Smith E.G., 2007. Ongoing Development of Integrated Weed Management Systems on the Canadian Prairies. In: *Weed Science,* 56(1), pp.146-150.
Blanco-Canqui H. and Lal R., 2008. No-tillage and carbon sequestration: an on-farm assessment. In: *Soil Science Society of America,* 72, pp. 693-701.
Blank, D. (2008). A fresh look at life beneath the surface. In: *No-Till Farming Systems,* Goddard T., Zoebisch M., Gan Y., Ellis W., Watson A. and Sombatpanit S. (eds), World Association of Soil and Water Conservation, Special Publication No. 3, WASWC, Bangkok, pp. 73-81.
Boddey R.M., Bruno J.R.A. and Irquiaga S., 2006. Leguminous biological nitrogen fixation in sustainable tropical agroecosystems. In: *Biological Approaches to Sustainable Soil Systems*, Uphoff N., Ball A.S., Fernandes E., Herren H., Husson O., Laing M., Palm C., Pretty J., Sanchez P., Sanginga N. and Thies J. (eds). CRC Press, Taylor and Francis Group, Boca Raton: Florida, pp. 401-408.
Boisgontier D., Bartholomy P. and Lescar L., 1994. Feasibility of minimum tillage practices in France. In: *Proceedings of the EC-Workshop-I-, Giessen, 27-28 June, 1994, Experience with the applicability of no-tillage crop production in the West-European countries*, Wissenschaftlicher Fachverlag, Giessen, pp. 81-91.
Bouwman A.F., 1990. Exchange of greenhouse gases between terrestrial ecosystems and the atmosphere. In: *Soils and the Greenhouse Effect,* Bouwman A.F. (ed.), John Wiley and Sons, Chichester, UK, pp. 61-127.
Brimili W., 2008. A case of extreme particulate matter concentrations over Central Europe by dust emitted over the Southern Ukraine. In: *Atmospheric Chemistry and Physics*, 9, p. 997-1016.
Cantero-Martínez C., Gabiña D. and Arrúe J.L., 2007. Evaluation of conservation agriculture technology in Mediterranean agriculture systems. In: *The Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas* Stewart B., Fares Asfary A. Belloum A., Steiner K. and Friedrich T. (eds), 7-9 May 2007, ACSAD and GTZ, Damascus (Syria), pp. 157-164.
Coleman D.C., Crossley D.A. and Hendrix P.F., 2004. *Fundamentals of Soil Ecology*. Elsevier: NY.
CTIC/FAO, 2008. Mitigating climate change: Conservation Agriculture stores soil carbon. In: *Recommendations of the Conservation Agriculture Carbon Offset Consultation*. CTIC, West Lafayette, IN, 28-30 October. At http://www.fao.org/ag/ca.
Derpsch R., 2001. Frontiers in Conservation Tillage and Advances in Conservation Practice. In: *Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting,* Stott D.E., Mohtar R.H. and Steinhardt G.C. (eds), 24 -29 May 1999, Purdue University and the USDA-ARS National Soil Erosion Research Laboratory, pp. 248-254.
Derpsch R., 2005. The extent of Conservation Agriculture adoption worldwide: Implications and impact. *Proceedings of the 3rd World Congress on Conservation Agriculture*, 3-7 October, Nairobi (Kenya). ACT, Harare.
Derpsch R., 2008a. No-tillage and Conservation Agriculture: A Progress Report. In: *No-Till Farming Systems,* Goddard T., Zoebisch M., Gan Y., Ellis W., Watson A. and Sombatpanit S. (eds). World Association of Soil and Water Conservation, Special Publication No. 3., WASWAC, Bangkok, pp. 7-39.
Derpsch R., 2008b. Critical Steps in No-till Adoption. In: *No-Till Farming Systems.* Goddard T., Zoebisch

M.A., Gan Y.T., Ellis W., Watson A. and Sombatpanit S. (eds.), World Association of Soil and Water Conservation, Special Publication, No. 3. WASWC, Bangkok, pp. 479- 495.

Derpsch R. and Friedrich T., 2009a. *Global Overview of Conservation Agriculture Adoption*. Proceedings, Lead Paper, 4th World Congress on Conservation Agriculture, 4-7 February 2009, New Delhi (India), pp. 429-438.

Derpsch R. and Friedrich T., 2009b. Development and Current Status of No-till Adoption in the World; Proceedings on CD, *18th Triennial Conference of the International Soil Tillage Research Organization (ISTRO)*, 15-19 June 2009, Izmir (Turkey).

Derpsch R., Roth C.H., Sidiras N. and Kopke U., 1991. Controle da erosa o no Paraná, Brasil: Sistemas de cobertura do solo, plantio direto e preparo conservacionista do solo. GTZ, Eschborn, Germany.

Doran J.W. and Zeiss M.R., 2000. Soil health and sustainability: Managing the biotic component of soil quality. In: *Applied Soil Ecology,*15, p. 3-11.

ECAF, 2010. European Conservation Agriculture Federation website at: http://www.ecaf.org/

Erenstein O., Sayer K., Wall P., Dixon J. and Hellin J., 2008. Adapting no-tillage agriculture to the smallholder maize and wheat farmers in the tropics and sub-tropics. In: *No-Till Farming Systems.* Goddard T, Zoebisch M.A., Gan Y.T., Ellis W., Watson A. and Sombatpanit S. (eds). Special Publication No. 3, World Association of Soil and Water Conservation (WASWC), Bangkok, pp. 253-277.

Evers G. and Agostini A., 2001. *No-tillage agriculture for sustainable land management: Lessons learned from the 2000 Brazil study tour.* FAO/TCI Occasional Paper no. 12, October. Rome.

FAO, 2001a. *The Economics of Conservation Agriculture* . FAO, Rome.

FAO, 2001b. *Conservation Agriculture: Case Studies in Latin America and Africa.* Soils Bulletin No. 78. FAO, Rome.

FAO, 2008. *Proceedings of an International Technical Workshop on Investing in Sustainable Crop Intensification: The case for improving soil health.* FAO, 22-24 July 2008. Integrated Crop Management, Vol. 6. 2008. FAO, Rome.

FAO, 2009. *Conservation Agriculture in Uzbekistan.* Crop and Grassland Service Working Paper 2, FAO, Rome. 38 pp.

FAO, 2010. FAO CA website at: www.fao.org/ag/ca

Fileccia T., 2008. *Conservation agriculture and food security in Kazakhstan.* Working Paper, Plant production and Protection Division. FAO, Rome.

Firestone M.K. and Davidson E.A., 1989. Microbiological basis of NO and N_2O production and consumption in soil. In: *Exchange of Trace Gases between Terrestrial Ecosystems and the Atmosphere,* Andreae M.O. and Schimel D.S. (eds). John Wiley and Sons, Chichester, UK, pp. 7-21.

Flaig W., Nagar B., Sochtig H. and Tietjen C., 1977. *Organic Materials and Soil Productivity* . FAO Soils Bulletin no. 35. FAO, Rome.

Flower K., Crabtree B. and Butler G., 2008. No-till Cropping Systems in Australia, In: *No-Till Farming Systems,* Goddard T., Zoebisch M.A., Gan Y.T., Ellis W., Watson A. and Sombatpanit S. (eds.). Special Publication No. 3, World Association of Soil and Water Conservation, WASWAC, Bangkok. pp. 457-467.

Friedrich T. and Kassam A.H., 2009. Adoption of Conservation Agriculture Technologies: Constraints and Opportunities. Invited paper at the *IV World Congress on Conservation Agriculture*, 4-7 February 2009, New Delhi, India.

Friedrich T., Kassam A.H. and Shaxson F., 2009a. Conservation Agriculture. In: *Agriculture for Developing Countries. Science and Technology Options Assessment (STOA) Project.* European Technology Assessment Group, Karlsruhe, Germany.

Friedrich T., Kassam A.H. and Taher F., 2009b. Adoption of Conservation Agriculture and the role of policy and institutional support. Invited keynote paper presented at the *International Consultation on No-Till with Soil Cover and Crop Rotation: A Basis for Policy Support to Conservation Agriculture for Sustainable Production Intensification*, Astana-Shortandy, Kazakhstan, July 2009.

Friedrich T., Kienzle J. and Kassam A.H., 2009c. Conservation Agriculture in Developing Countries: The Role of Mechanization. Paper presented at the *Club of Bologna Meeting on Innovation for Sustainable Mechanisation*, Hanover, Germany, 2 November 2009.

Gan Y., Harker K.N., McConkey B. and Suleimanov M., 2008. Moving towards no-till practices in Northern Eurasia. In: *No-Till Farming Systems.* Goddard T., Zoebisch M.A., Gan Y.T., Ellis W., Watson A. and Sombatpanit S. (eds). World Association of Soil and Water Conservation, Special Publication No. 3, WASWC, Bangkok, pp. 179-195.

Ghosheh H., 2007. Application of sustainable agriculture principles in weed management. In: *The Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas,* Stewart B., Fares Asfary A., Belloum A., Steiner K. and Friedrich T. (eds), 7-9 May 2007, Damascus (Syria), ACSAD and GTZ, pp. 209- 218.

Giráldez J.V. and González P., 1994. No-tillage in clay soils under Mediterranean climate: Physical aspects. In: *Proceedings of the EC-Workshop on Experience with the applicability of no-tillage crop production in the West-European countries*. Wissenschaftlicher Fachverlag, 27-28 June 1994, Giessen, pp. 111-117.

Goddard T., Zoebisch M.A., Gan Y.T., Ellis W., Watson A. and Sombatpanit S., 2008. *No-Till Farming Systems*. Special Publication No. 3. World Association of Soil and Water Conservation (WASWC), Bangkok, 540 p.

Granli T. and Bckman O.C., 1994. Nitrous oxide from agriculture. In: *Norwegian Journal of Agricultural Science Supplement*, 12, pp. 1-128.

Haugen-Kozyra K. and Goddard T., 2009. Conservation agriculture protocols for green house gas offsets in a working carbon markets. Paper presented at the *IV World Congress on Conservation Agriculture*, 3-7 February 2009, New Delhi (India).

Hebblethwaite J.F., 1997. The contribution of no-till to sustainable and environmentally beneficial crop production – a global perspective. In: *Proceedings, V Congreso Nacional de AAPRESID*, 20-23 August 1997, Mar del Plata (Argentina), pp. 79-90

Hengxin L., Hongwen L., Xuemin F. and Liyu X., 2008. The current status of conservation tillage in China. In: *No-Till Farming Systems*. Goddard T., Zoebisch M.A., Gan Y.T., Ellis W., Watson A. and Sombatpanit S. (eds.). World Association of Soil and Water Conservation, Special Publication No. 3, WASWC, Bangkok. pp. 413-428.

Hobbs P.R., 2007. Conservation agriculture: what is it and why is it important for future sustainable food production? In: *Journal of Agricultural Science,* 145, pp. 127-137.

Houghton J.T., Meira Filho L.G., Lim K., Trennton I., Mamaty I., Bonduki Y., Griggs D.J. and Callander B.A., 1997. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1–3.* Intergovernmental Panel on Climate Change. WMO/UNEP. Cambridge University Press, Cambridge, UK.

ICEPA/SC, 1999. Avaliacao do Projeto Microbacias – Relatorio de Avaliaçao Final. Instituto de Planejamento e Economía Agrícola de Santa Catarina, Brazil, September. Florianopolis, Brazil.

Jones C.E., 2007. Building soil carbon with Yearlong Green Farming. In: *Evergreen Farming September*, pp. 4-5.

Karabayev M., 2008. Improvement of soil and water management in Kazakhstan: Conservation Agriculture for wheat production and crop diversification. In: *Proceedings of an International Technical Workshop on Investing in Sustainable Crop Intensification: The case for improving soil health,* FAO, Rome, 22-24 July 2008. Integrated Crop Management, Vol. 6. 2008. FAO, Rome.

Kassam A.H., 1981. Climate, soil and land resources in North Africa and West Asia. In: *Soil water and nitrogen,* Monteith J. and Webb C. (eds), The Hague, Martinus Nijhoff/Dr. W. Junk pp. 1-29.

Kassam A.H., 1988. Some Agroclimatic Characteristics of High-elevation Areas in North Africa, West Asia and Southeast Asia. In: *Winter cereals and food legumes in mountainous areas*, Srivastava J.P.,. Saxena M.C, Varma S. and Tahir M. (eds), Aleppo, Syria, ICARDA, pp. 1-32.

Kassam A.H., 1992. *Land and water resources, land use and land potential in the WANA region*. Regional Seminar on Land and Water Resources Management in Dry Areas, Economic Development Institute of the World Bank, Arab Organization for Agricultural Development and ICARDA, 16-29 February 1992, Aleppo, Syria.

Kassam A.H., Friedrich T., Shaxson F. and Jules P., 2009. The spread of Conservation Agriculture: Justification, sustainability and uptake. In: *International Journal of Agriculture Sustainability*, 7(4), pp. 292-320.

Kliewer L., Casaccia J. and Vallejos F., 1998. Viabilidad da reducçao do uso de herbicidas e custos no controle de plantas daninhas nas culturas de trigo e soja no sistema de plantio directo, através do emprego de adubos verdes de curto periodo. Resumo de Palestras: I Seminario Nacional Sobre Manejo e Controle de Plantas Daninhas em Plantio Direto, 10-12 August 1998, RS, Editora Aldeia Norte, Passo Fundo, pp. 120-123.

Lafond G.P., Walley H., Schoenau J., May W.E., Holzafel C.B., McKell J. and Halford J., 2008. Long-term vs.short-term conservation tillage. *Proceedings of the 20th Annual Meeting and Conference of the Saaskatchewan Soil Conservation Association*, 12-13 February, Regina, Saaskatchewan, pp. 28-43.

Lahmar R., 2008. Adoption of conservation agriculture in Europe: Lessons of the KASSA project. In: *Land Use Policy*, 27(1), pp. 4-10 (doi:10.1016/j.landusepol.2008.02.001)

Lahmar R. and Triomphe B., 2007. Key lessons from international experiences about Conservation Agriculture, and considerations for its implementation in dry areas. In: *The Proceedings of the International Workshop on Conservation Agriculture for* 123- *Sustainable Land Management to Improve the Livelihood of People in Dry Areas*. ACSAD and GTZ, 7-9 May, Damascus, Syria, pp. 141.

Landers J., 2007. *Tropical Crop-Livestock Systems in Conservation Agriculture: The Brazilian Experience.* Integrated Crop Management, Vol. 5. FAO, Rome.

Lavelle P. and Spain A.V., 2001. *Soil Ecology* . Dordrecht. Kluwer Academic Publishers, The Netherlands.

Llewellyn R.S., D'Emden F. and Gobbett D., 2009. Adoption of no-till and conservation farming practices in

Australian grain growing regions: Current status and trends. Preliminary report for SA No-till Farmers Association and CAAANZ 26, January 2009.

Mariki W.L. and Owenya M.Z., 2007. Weed management in Conservation Agriculture for sustainable crop production. In: *The Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas*. ACSAD and GTZ, 7-9 May, Damascus, Syria, pp. 49-56.

McIntyre B.D., Herren H.R., Wakhungu J. and Watson R.T. (eds), 2008. *Agriculture at a Crossroads: Synthesis Report of the International Assessment of Agricultural Knowledge, Science, and Technology for Development (IAASTD)*. Island Press, Washington,DC.

Mazvimavi K. and Twomlow S., 2008. Conservation farming for agricultural relief and development in Zimbabwe. In: *No-Till Farming Systems.* Goddard T., Zoebisch M.A., Gan Y.T., Ellis W., Watson A. and Sombatpanit S. (eds). Special Publication No. 3. World Association of Soil and Water Conservation (WASWC), Bangkok, pp. 169-175.

MEA, 2005. *Ecosystems and Human Well-Being: Synthesis. Millennium Ecosystem Assessment.* Island Press, Washington, DC.

Metay A., Oliver R., Scopel E., Douzet J.M., Alves Moreira J.A., Maraux F., Feigl B.E. and Feller C., 2007. NO and CH emissions from soils under conventional and no-till management practices in Goiânia (Cerrados, Brazil). In: *Geoderma,* 141, pp. 78-88.

M'Hedhbi K., Chouen S. and Ben-Hammouda M., 2003. A recent Tunisian experience with direct drilling. In: *Proceedings of the II World Congress on Conservation Agriculture.* Iguassu Falls, Parana, Brazil. pp. 132-135.

Ministerio de Medio Ambiente y Medio Rural y Marino, 2006. Encuesta sobre superficies y rendimentos de cultivos (ESYRCE). http://www.mapa.es/es/estadistica/pags/encuestacultivos/resultados.htm

Montgomery D., 2007. *Dirt, the erosion of civilizations.* University California Press, Berkeley and Los Angeles, 287 pp.

Mrabet R., 2008a. Lasting benefits from no-tillage systems: Erosion control and soil carbon sequestration. In: *The Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas.* 7-9 May 2007, ACSAD and GTZ, Damascus, Syria, pp. 72-92.

Mrabet R., 2008b. Conservation Agriculture in Morocco: A Research Review. In: *The Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas.* 7-9 May 2007, ACSAD and GTZ, Damascus, Syria, pp. 183-208.

Mrabet R., 2008b. *No-Tillage Systems for Sustainable Dryland Agriculture in Morocco.* Institut National de la Recherche Agronomique (INRA). 153 pp.

Mrabet R., 2008c. No-Till Practices in Morocco. In: *No-Till Farming Systems,* Goddard T., Zoebisch M., Gan Y., Ellis W., Watson A. and Sombatpanit S. (eds). World Association of Soil and Water Conservation, Special Publication No. 3, WASWAC, Bangkok, pp. 393-412.

Mariki W.L. and Owenya M.Z., 2007. Weed management in Conservation Agriculture for sustainable crop production. In: *Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas,* ACSAD, 7-9 May 2007, Damascus (Syria), pp. 49-58.

No-till Farmer, 1997. *Stubble over the soil means No-Till forever. No-Till Farmer*, Brookfield, Wisconsin, USA, pp. 6-7.

Nurbekov A., 2008. *Manual on Conservation Agriculture Practices in Uzbekistan.* Ministry of Agriculture, FAO and ICARDA, Tashkent, Uzbekistan. 40 pp.

Oram P. and de Haan C., 1995. *Technologies for Rainfed Agriculture in Mediterranean Climates: A Review of World Bank Experience.* World Bank Technical Paper Number 300, The World Bank, Washington DC.

Pala M., Haddad A. and Piggin C., 2007. Challenges and opportunities for Conservation Cropping: ICARDA experience in dry areas. In: *The Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas,* Stewart B., Fares Asfary A. Belloum A., Steiner K. and Friedrich T. (eds), 7-9 May 2007, ACSAD and GTZ, Damascus (Syria), pp. 165-182.

Parkin T.B. and Kaspar T.C., 2006. Nitrous oxide emissions from corn-soybean systems in the mid-west. In: *Journal of Environmental Quality*, 35(4), pp. 1496-1506.

Pieri C., Evers G., Landers J., O'Connell P. and Terry E., 2002. *No-till farming for sustainable rural development.* Agriculture and Rural Development Working Paper. Washington, DC: World Bank.

Pisante M. (ed.) 2007. *Agricoltura Blu. La via italiana dell'agricoltura conservativa: Principi, tecnologie e metodi per una produzione sostenibile*. Edagricole, Bologna, Italy.

Pretty J., Noble A.D., Bossio D., Dixon J., Hine R.E., Penning de Vries F.W.T. and Morison J.I.L., 2006. Resource-conserving agriculture increases yields in developing countries. In: *Environmental Science and Technology,* 3(1), pp. 24-43.

Reicosky D.C., 2008. Carbon sequestration and environmental benefits from no-till systems. In: *No-Till Farming Systems.* Goddard T., Zoebisch M., Gan Y., Ellis W., Watson A. and Sombatpanit S. (eds). World Association of Soil and Water Conservation, Special Publication No. 3, WASWAC, Bangkok, pp. 43-58.

Rockstrom J., Kaumbutho P., Mwalley J., Nzabi A.W., Temesgen M., Mawenya L., Barron J., Mutua J. and Damgaard-Larsen S., 2009. Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. In: *Soil and Tillage Research,* 103, pp. 23-32.

Seguy L., Bouzinac S. and Husson O., 2006a. Direct seeded tropical soil systems with permanent soil cover: learning from Brazilian experience. In: *Biological Approaches to Sustainable Soil Systems,* Uphoff N., Ball A.S., Fernandes E., Herren H., Husson O., Laing M., Palm C., Pretty J., Sanchez P., Sanginga N. and Thies J. (eds). CRC Press, Taylor and Francis Group, Boca Raton, Florida, pp. 323-342.

Seguy L., Bouzinac S., Scopel E. and Ribeiro F. 2006b. New concepts for sustainable management of cultivated soils through direct seeding mulch based cropping systems: the CIRAD experience, partnership and networks. 2001–2005 Cirad's Contribution to the World Congress on Conservation Agriculture. On WWW at http://agroecologie.cirad.fr/congres/index.php?lang=enandrub=1

Seguy L., Loyer D., Richard J.-F. and Miller E., 2008. Sustainable soil management: Agro-ecology in Laos and Madagascar. In: *No-Till Farming Systems,* Goddard T., Zoebisch M.A., Gan Y.T., Ellis W., Watson A. and Sombatpanit S. (eds). World Association of Soil and Water Conservation, Special Publication No. 3, WASWC, Bangkok, pp. 207-222.

Settle W.H. and Whitten M.J., 2000. The role of small-scale farmers in strengthening links between biodiversity and sustainable agriculture. In: *XXI International Congress of Entomology*, 20-26 August, Iguazu Falls (Brazil).

Shaxson F., 2006. Re-thinking the Conservation of Carbon, Water and Soil: A Different Perspective. In: *Agronomie*, 26, pp. 1-9.

Shaxson F., Kassam A.H., Friedrich T., Boddey B. and Adekunle A., 2008. Underpinning the benefits of Conservation Agriculture: Sustaining the fundamental of soil health and function. Main document for the *Workshop on Investing in Sustainable Crop Intensification: The Case of Soil Health*, 24-27 July 2008, FAO, Rome.

Sims B., Friedrich T., Kassam A.H. and Kienzle J., 2009. Agroforestry and Conservation Agriculture: Complementary practices for sustainable agriculture. Paper presented at the *2nd World Congress on Agroforestry*, Nairobi, Kenya, August 2009.

Sorrenson W.J., 1997. *Financial and Economic Implications of No-Tillage and Crop Rotations Compared to Conventional Cropping Systems.* TCI Occasional Paper, Series No. 9. FAO, Rome.

Sorrenson W.J. and Montoya L.J., 1984. Implicaçoes econômicas da erosâo do solo e de pratcas conservacionistas no Parana, Brasil, IAPAR, Londrina. GTZ, Eschborn, Germany.

Stewart B.A., 2007. Water conservation and water use efficiency in drylands. In: *The Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas,* Stewart B., Fares Asfary A., Belloum A., Steiner K. and Friedrich T. (eds), 7-9 May 2007, Damascus (Syria). ACSAD and GTZ, pp. 57-66.

Stewart B., Fares Asfary A. Belloum A., Steiner K. and Friedrich T. (eds), 2007. *The Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas.* 7-9 May 2007, Damascus (Syria). ACSAD and GTZ, 288 pp.

Suleimenov M., 2009. From Conservation Tillage to Conservation Agriculture. In: *Proceedings of the International Consultation Conference on "No-till with soil cover and crop rotation: a basis for policy support to conservation agriculture for sustainable production intensification"*. July 8-10, 2009, Astana-Shortandy, Kazakhstan, pp. 56-68

Suleimenov M. and Thomas R., 2006. Central Asia: Ecosystems and carbon sequestration challenges. In: *Climate change and terrestrial carbon sequestration in Central Asia,* Lal R., Suleimenov M., Stewart B.A., Hansen D.O. and Doraiswamy P. (eds). Taylor and Francis Group, New York, NY, USA, Op.165-176.

Suleimenov M. and Akshalov K., 2006. Eliminating summer fallow in black soils of Northern Kazakhstan. In: *Climate change and terrestrial carbon sequestration in Central Asia,* Lal R., Suleimenov M., Stewart B.A., Hansen D.O. and Doraiswamy P. (eds). Taylor and Francis Group, New York, NY, USA. Pp.267-279.

Testa V.M., Teixeira L.A.J. and Mielniczuk J., 1992. Caracteristics quimicas de um Podzolico vermelho-escuro afteadas pro sistemas de culturas. In: *Revista Brasileira de Ciencia do Solo,* 16, pp. 107-114.

Uphoff N., Ball A.S., Fernandes E., Herren H., Husson O., Laing M., Palm C., Pretty J., Sánchez P., Sanginga N. and Thies J. (eds), 2006. *Biological Approaches to Sustainable Soil Systems.* CRC Press, Taylor and Francis Group, Boca Raton, Florida.

Yuxia L. and Chi C., 2007. Canadian Experience of Conservation Agriculture and Project Implementation in China, in APCAEM: In: *The International Seminar on Enhancing the Extension of Conservation Agriculture Techniques in Asia and the Pacific*. 24-26 October 2007, Zhengzhou, Henan (China).

WDR, 2008. *Agriculture for Development*. World Development Report. World Bank, Washington, DC.

West O.T. and Post W.M., 2002. Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. In: *Soil Science Society of America Journal, 66*, pp. 1930-1946. At http://ecoport.org/ep?SearchType=referenceandReferenceID=558810

Williams J.D., Gollany H.T., Siemens M.C., Wuest S.B. and Long D.S., 2009. Comparison of runoff, soil erosion and winter wheat yields from no-till and inversion tillage production systems in northeastern Oregon. In: *Journal of Soil and Water Conservation,* 64(1), pp. 43-52 (10.2489/jswc.64.1.43).

Wood M., 1995. *Environmental Soil Biology.* 2nd edn. Blackie A and P, Glasgow, UK.

World Bank, 2000. Implementation Completion Report (CPL-31600; SCPD-3160S) of Land Management II – Santa Catarina Project. Report No. 20482. World Bank, Washington, DC.

Conservation Agriculture (CA) increasingly dominates debates on agricultural development policy in Africa. Over the past decade lots of (donor) money has been spent on the promotion of CA to smallholder farmers and often such interventions have been hailed as a success. Yet, we think there is need to question the emergent consensus on Conservation Agriculture in development policy.Â As CA promotion is often combined with input support, the assessment of its success is difficult. Is CA uptake by resource poor farmers really caused by the benefits of the technologies promoted or are they the effect of the additional inputs provided? And how sustainable is the uptake of CA when input support is discontinued? These are pertinent questions that need to be addressed. Kassam A, Friedrich T (2010) Conservation Agriculture : Concepts, worldwide experience, and lessons for success of CA-based systems in the semi-arid Mediterranean environments. Options MÃ©diterranÃ©ennes 11â€“51Google Scholar. Knowler D, Bradshaw B (2007) Farmersâ€™ adoption of conservation agriculture: a review and synthesis of recent research.Â 1.Department of Environmental StudiesNew York UniversityNew YorkUSA. 2.The CGIAR Research Program on Water, Land and Ecosystems, CGIARColomboSri Lanka. 3.Environment and Production Technology DivisionInternational Food Policy Research InstituteWashingtonUSA. About this article. CrossMark. Conservation Agriculture. In South Africa, crop production systems based on intensive and continuous soil tillage have led to excessively high soil degradation rates. This adds to the growing problems with profitability and poverty in some of the rural areas. There is general agreement that sustainable and economically viable agriculture will be achieved through the adoption of regenerative Conservation Agriculture principles and practices.Â The CA Farmer Innovation Programme for smallholders has been implemented in the Okahlamba District Municipality (Bergville) area of KwaZulu-Natal since September 2013 as a joint initiative between Grain SA and Mahlathini Development Foundation. KwaZulu-Natal Midlands.