Adoption of Conservation Agriculture and the Role of Policy and Institutional Support[1*]

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Content

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Abstract

Conservation Agriculture (CA) 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.

CA represents a fundamental change in production system thinking. It has a number counterintuitive and hitherto unrecognised or underemphasised 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.

The paper presents an overview of the adoption of CA world-wide and discusses some of the major benefits of CA. This is followed by an elaboration of the conditions and steps that are necessary for the adoption of CA, and the role of policy and institutional support.

Key Words: Conservation Agriculture, No-Till, Technology Adoption, Policy Support, Institutional Support, Soil Health, Soil Carbon, Eurasia

1. INTRODUCTION

Conservation Agriculture (CA) is, to those who know it, the best bet for a sustainable and productive agriculture. People refer to CA as a win-win agricultural production system and it is successfully applied on some 100 million hectares of arable land in so many different agro-ecosystems and cropping systems that the reason and justification for soil tillage should become weaker and weaker. Already in the 1940s Edward Faulkner in his revolutionary "Ploughman's Folly" stated that 'no *one has ever advanced a scientific reason for ploughing'*. Wherever CA has been adopted it has proven its benefits. The cases where CA did not perform as expected can usually be related to mistakes or shortcuts in the management of the system, but not to any inherent failures in the system.

Yet the question arises: if CA is so good, why is it not spreading like wildfire? The simple answer is that the answer is not that simple. 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. Indeed, the scaling up of CA practices to achieve national impact requires a dynamic complement of enabling policies and institutional support to producers and supply chain service providers to operate in a complementary manner towards a common goal of transforming the prevailing tillage-based production systems to CA-based systems as a basis for sustainable production intensification.

This explains, why in all cases where CA has been or is currently in a process of successful adoption, this process follows an S-curve with a slow to very slow start, leading then into exponential growth, and slowing down towards a plateau level, which is most likely above 90% adoption. Since so far only about 6-7 % of the world cropland is farmed under CA (although more is farmed with no-till only), it can be postulated that in most countries CA is introduced as an "unknown" new concept and that neither the knowledge nor the other elements of an enabling environment for the adoption of CA in the country exist. This is the common, on-the-ground situation which embodies most of the constraints to adoption of CA.

Only in very few occasions, as was the case with the southern parts of Brazil in the 1970s where problems with conventional tillage-based farming practices become so severe that spontaneous change to no-till system and its widespread adoption and evolution towards CA occurred despite the above mentioned constraints. In this particular case, it was the uncontrollable water erosion combined with extremely poor profit margins for farmers. Similarly, it was severe wind erosion in the mid-west USA and the Canadian Prairies that led to the adoption of CA in USA and Canada. Obviously the reasons to change from one cropping system to another vary according to location, but in most cases erosion problems, climatic problems (drought) and unfavourable profit margins are the most important motivations for farmers to adopt CA. These problems are now widespread in the Eurasia region that has soil and climatic conditions similar to those in the mid-west USA and the Canadian Prairies.

As the adoption of CA advances, the constraints decline, explaining the exponential uptake after some years. The duration of this slow early adoption before it turns into the exponential growth can be influenced mainly through enabling policies and institutional support for services and related regulations.

The paper presents an overview of the adoption of CA world-wide and discusses some of the major benefits of CA. This is followed by an elaboration of the conditions and steps that are necessary for the adoption of CA, and the role of policy and institutional support in fostering the development of a dynamic agriculture sector based on CA.

2. ADOPTION OF CONSERVATION AGRICULTURE

CA and other similar systems for intensive farming that lead to the progressive build-up of soil organic matter have been successfully tested and applied by farmers in many parts of the world over the past 40 years. Though these systems vary in the technologies applied across countries, climates, soils and crop types, their common features are that they enable farmers to create conditions favourable to biotic activity in the soil through the simultaneous application of the following three practices:

(a) Maintaining, to the extent that local conditions allow, a year-round organic matter cover over the soil provided by the current crop, including specially introduced cover crops and intercrops and/or the mulch provided by retained residues from the previous crop;

(b) Minimising soil disturbance by tillage, eliminating tillage altogether once the soil has been brought to good condition; and

(c) Diversifying crop rotations, sequences and associations, adapted to local socio-economic and environmental conditions, which contribute to maintaining biodiversity above and in the soil, and help avoid build-up of pest populations within the spectrum of soil inhabitants.

These three practices when applied together are referred to as CA in which the practices interact synergistically such that the 'whole is larger than the sum of its parts'.

2.1 Global Area and Regional Distribution

Although much of the CA development to date has been associated with rainfed arable crops, farmers can apply the same principles to increase the sustainability of irrigated systems, including those in semi-arid areas. CA systems can also be tailored for orchard and vine crops with the direct sowing of field crops, cover crops and pastures beneath or between rows, giving permanent cover and improved soil aeration and biodiversity[2]. Functional CA systems do not replace but should be integrated with current good land husbandry practices.

Because of the benefits that CA systems generate in terms of yield, sustainability of land use, incomes, timeliness of cropping practices, ease of farming and eco-system services, the area under CA systems has been growing exponentially, largely as a result of the initiative of farmers and their organizations (Figure 1). It is estimated that, worldwide, there are now around 100 million hectares of arable crops which are grown each year without tillage in CA systems (Table 1). Except in a few countries, however, these approaches to sustainable farming have not been "mainstreamed" in agricultural development programmes or backed by suitable policies and institutional support, and the total area under CA is still very small (about 6-7%) relative to areas farmed using tillage.

[2] The common constraint, given by farmers, to practising this latter type of inter-cropping is competition for soil water between trees and crops. However, careful selection of deep rooting tree species and shallow rooting annuals resolves this.

2.2 Area with CA in Developed Countries

No-till agriculture in the modern sense originated in the USA in the 1950s, and from this time until 2007 the USA has always had the biggest area under no-till in the world. In 2008 Brazil nearly overtook the USA. But it is interesting to note that, in the USA, no-till accounts for only 22.6% of all cropland areas. Conventional agriculture with tillage remains majority even if CA is a valid option for farmers, as compared with the Southern Cone of Latin America where no-till becomes the majority agricultural system with 60% of the surface.

Another interesting point about adopters in the USA is that only about 10 - 12% of the total area under no-till is being permanently not tilled (CTIC, 2005). This occasional tillage prevents the system from reaching its optimum balance, as the soil is disturbed from time to time. Research has shown that it takes more than 20 years of continuous no-till to reap the full benefits of CA. Farmers that practice rotational tillage, i.e., plough or till their soils occasionally, will never experience the full benefits of the system (Derpsch, 2005).

Canada shows the fourth biggest area under no-till with 12.5 million ha.

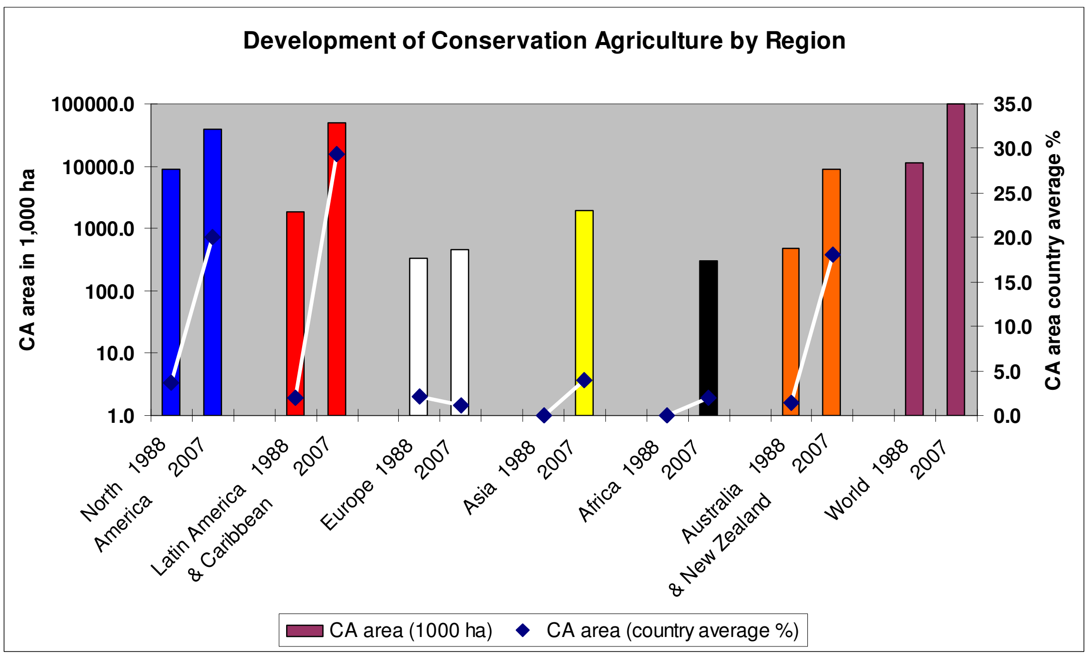


Figure 1: Development of Conservation Agriculture over the last 20 years by world region in total area (ha) and as average percentage across the adopting countries of the respective region (from FAO, 2008)

CA exists in Europe but it is not really widely spread, as the land surface under no-till systems does not exceed 2% of the agricultural land. Since 1999 ECAF (European Conservation Agriculture federation) is promoting CA in Europe. The adoption is slow but visible in Spain, France, Switzerland and Finland, with some few farmers proving the concept to work also in Germany, UK and Italy.

In Australia CA has been widely and quickly embraced by farmers. It has improved weed control, time of sowing, given drought tolerance and has enabled dry regions to use water most efficiently (Crabtree, 2004). But inappropriate seeding machines, which move the mulch too much, and sheep that graze crop residues, are leading to an insufficient soil cover. So efforts have to be made to improve the practices and so the sustainability of no-till systems.

2.3 Area with CA in Developing Countries

Amongst developing countries, Brazil has the longest experience in CA and since 1972 many useful "lessons learned" originate from there and from neighbouring Argentina and Paraguay. Their experiences have contributed to a better understanding of the long-term biophysical and environmental effects of CA application. They have also set important precedents for the engagement of farmers as principal actors in the development and adaptation of new technologies. Farmers in many other countries in Asia and Africa have also gained valuable but more recent experience on how to adapt the principles of CA to their own conditions.

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

Apart from enabling their land to be cropped more intensively without risk of degradation, CA attracted Brazilian farmers because it increased crop yields (at least 10-25%), greatly reduced surface runoff and soil erosion, and cut tractor use, resulting in big savings in fuel and production costs. Such benefits explain why today, South American farmers practice zero tillage CA on a continuous basis, year after year, on about 47 million hectares.

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

For their part, Asian and African countries have begun to take up CA practices only in the last 10-15 years, but have already acquired many useful lessons with respect to adapting the principles of CA to a vast diversity of conditions and constraints. Among the most encouraging experiences has been the CA work developed in dry environments such as Tunisia and Kazakhstan where highly innovative adaptations have been made to the very demanding low winter temperatures and low and unpredictable rainfall. In DPR Korea, the introduction of CA has made it possible to grow two successive crops (rice maize or soya as summer crop, winter wheat or spring barley as winter crop) within the same year, through direct drilling of the second crop into the stubble of the first. The feasibility of growing potatoes under zero tillage has also been demonstrated in Korea.

Innovative participatory approaches are being used in Africa to develop supply-chains for producing CA equipment targeted at small holders. Similarly, participatory learning approaches such as those based on the principles of FFS are being encouraged to strengthen farmers' understanding of the principles underlying CA and how these can be adapted to local situations.

The corresponding programmes recognize the need to adapt systems to the very varied agro-ecosystems of the regions, to the extreme shortage of land faced by many farmers and to the competing demands for crop residues for livestock and fuel – problems that are particularly pronounced amongst small-scale farmers in arid and Mediterranean regions.

CA is spreading in many areas of Africa and particularly in eastern and southern Africa, where it is promoted by FAO and the African Conservation Tillage Network. Building on indigenous and scientific knowledge and innovative equipment design from Latin America, farmers in at least 14 countries are now practicing CA (in Kenya, Uganda, Tanzania, Zambia, Swaziland, Sudan, Madagascar, South Africa, Zimbabwe, Mozambique, Ghana, Burkina Faso, Morocco and Tunisia). In Zambia alone, between 70 000 and 100 000 smallholder farmers are practicing CA (Rumley and Ong, 2007).

In the specific context of Africa (where the majority of farmers are resource-poor and rely on less than 1 ha, and there is food insecurity, degradation of soil fertility, drought and irregular rains, shortage of human power for agricultural labour) CA systems are very relevant for addressing the old as well as new challenges of climate change, high energy costs, environmental degradation, no sustainable intensification paradigm other than the standardized tillage-based "green revolution" types relying on the inefficient use of purchased inputs of agro-chemicals. In Africa CA should respond to growing food demand by increasing food production while reducing negative effects on the environment and energy costs, and develop locally adapted technologies that are consistent with CA principles. (Kueneman *et al.*, 2007)

While large numbers of small-scale farmers – in Paraguay, China and various African countries – have taken up CA, experience indicates that adoption tends to be at a much slower pace than amongst larger-scale farmers. With food security among their major objectives, many small-scale farmers are hesitant to invest scarce labour, land, seed and fertilizer in cover crops that do not result in something to eat or to sell. They also suffer from restricted access to relevant knowledge as well as to inputs or credit. As a result, there is an increasing recognition of the need to encourage farmers to move towards full adoption of CA at their own pace, testing out promising approaches initially on small areas of their farms and progressively expanding as their confidence in the results develops.

The largest areas under CA nowadays are in the major grain exporting countries (USA, Brazil, Argentina, Canada, Australia). CA is being taken up rapidly in a number of Asian countries (DPR Korea, China, Kazakhstan). In Central Asia, a fast development of CA can be observed in the last 5 years in Kazakhstan and the neighbouring Russian areas. Kazakhstan now has 3.5 million ha under reduced tillage, and of this 1.2 million ha are "real" CA with permanent no-till and rotation. China has equally a dynamic development of CA. It started 10 years ago with research, then the adoption increased during the last few years and the technology had been extended to rice production system. Now about 1.3 million ha are under CA in China. In India and the Indo-Gangetic plains, in the wheat-rice cropping system, there is large adoption of no-till wheat with more than 4 million ha, but only marginal adoption of permanent no-till systems and full CA.

Table 1: Conservation Agriculture adoption by country over the last 20 years in ha and in percent of total arable land (source: FAO AQUASTAT 2008 and FAO, 2008)

Conservation Agriculture area in 1,000 [ha]	1988-1991	1993-1996	1998-2001	2003-2007
Argentina	500.0	3,950.1	15,000.8	19,719.4
CA area (%)	1.8	13.9	51.5	66.8
Australia	400.0			9,000.0
CA area (%)	0.8			18.1
Bolivia				550.0
CA area (%)				16.9
Brazil	1,350.0	8,847.0	18,744.5	25,501.7
CA area (%)	2.3	13.5	28.2	38.3
Canada	1,951.2	4,591.8	8,823.5	13,480.8
CA area (%)	3.8	8.8	16.9	25.9
Chile				120.0
CA area (%)				5.2
China				100.0
CA area (%)				0.1
Colombia				102.0
CA area (%)				2.8
France	50.0			150.0
CA area (%)	0.3			0.8
Kazakhstan				1,790.6
CA area (%)				8.0
Mexico				22.8
CA area (%)				0.1
New Zealand	75.0			
CA area (%)	2.0			
Paraguay		200.0	1,200.0	2,094.0
CA area (%)		7.4	33.4	48.7
South Africa				300.0
CA area (%)				1.9
Spain				300.0
CA area (%)				1.6
United Kingdom	275.0			
CA area (%)	3.9			
United States of America	6,839.2	17,361.0	21,124.6	25,252.4
CA area (%)	3.7	9.6	11.8	14.3
Uruguay			753.5	1,082.3
CA area (%)			53.4	76.7
Venezuela (Bolivarian Republic of)				300.0
CA area (%)				8.7
World total	11,440.3	34,949.9	65,646.9	**99,866.0**

2.4 Global Distribution of CA Across Climate Zones

CA is practiced in all climate zones of the world where annual and perennial crops can be grown, from the tropics and subtropics to the temperate regions. Functional examples exist in the tropics and sub-tropics (summer rainfall) in the moist (sub-humid) and dry savanna and the humid forest environments in Latin America (e.g., Brazil, Colombia, Venezuela, Argentina, Bolivia, Chile, Mexico, Paraguay, Uruguay), Africa (e.g., Kenya, Tanzania, Zimbabwe, Zambia, Swaziland, South Africa, Madagascar, Zambia, Ghana), Asia (e.g., India, Pakistan, China), northern Australia and USA. In the African tropical Sahel zone, CA is practiced in the form '*zai*' pits which involve concentrating available nutrients and moisture supply around and close to the plants or trees.

In the subtropics, CA is practiced in the winter rainfall areas with Mediterranean-type environments in Latin America (e.g., Chile, Argentina), in Africa (Tunisia, Morocco), Asia (Syria, Kazakhstan), and in California, USA. In the temperate regions, CA is practiced in Latin America (e.g., Chile, Argentina), Asia (e.g., DPR Korea, China), North America (USA, Canada) and Europe (e.g., Spain, France).

2.5 Distribution of CA Across Farm Types

CA concept and principles are applicable to any size farm (large land holdings, commercial farmers, medium scale farmers, small scale farmers) subject to availability of equipment. In Latin America, Africa and Asia, it has been shown to work in large, medium and small farms. However, the area of CA comprises mainly of large farms which, under labour shortage situations, can capture the economies of scale with the use of CA machinery and equipment.

In 2002, it was estimated that of the total area under CA, only a small proportion (about 450,000 ha) was practiced on small farmers by around 200,000 farmers. This is because only few countries (e.g., Brazil) have seriously invested in research and developed technologies to suit small farmers. Brazil is also among the few countries that manufacture equipment for small farmers (one or two-row seeding machines, sprayers, knife rollers, fertiliser and lime spreaders for animal traction, hand jab planters etc).

However, in 2005, according to FEBRAPDP, the Federation of No-Till Farmers of Brazil, there were about 500,000 to 600,000 ha of no-till being adopted by small farmers with animal traction. This corresponds to some 100,000 small farmers using no-till practice in Brazil. Also, in Paraguay the number of small farmers adopting CA practices has grown rapidly recently. It was estimated that in 2005, some 12,000 farmers were using no-till on about 30,000 ha. Another region with a large number of small farmers who have adopted no-till technology is the Indo-Gangetic Plains. Here a few hundred thousand small farmers are using the technology on an estimated 2 million ha.

It is estimated that CA will grow at a much slower pace in smallholder farming systems than in mechanized medium and large scale systems. The most important reasons for this are too little research and development, inadequate extension efforts, and funding shortages allocated for this target group worldwide. Another important reason is the logistics of how to reach a greater number of small farmers in remote areas, with shrinking budgets for extension services. While mass media strategies can work well with well-educated medium and large farmers, individual assistance over a period of time is necessary when working with small-scale subsistence farmers. Lately, experiential learning and extension systems based on the FFS approach are showing promising results particularly in Africa.

4. ACHIEVABLE BENEFITS FROM CA

CA represents a fundamental change in the agricultural production system. There are many benefits that are offered by CA when practiced correctly. The fundamental change and the benefits are described in the following sections.

3.1 CA as a Fundamental Change in the Agricultural Production System

Conservation agriculture is a means of reproducing plants and water recurrently and sustainably from landscapes and the soils which cover them. It does this by favouring improvements in the condition of soils as rooting environments. CA is not a single technology, but one or more of a range of technologies that are based on one or more of the three main *c*onservation agriculture principles described at the beginning of Section 2. CA functions best when all three key features are adequately combined together in the field. It is significantly different from conventional tillage agriculture in that, ideally (Shaxson *et al.*, 2008):

- It avoids tillage once already-damaged soil has been brought to good physical condition prior to initiating the CA system.
- It 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.
- It specifically uses sequences of different crops and cover-crops in multi-year rotations;
- It relies on nitrogen-fixing legumes to provide a significant proportion of that plant nutrient - which is needed for biomass production of crops and cover-crops.

CA also relies on liberating other plant nutrients through biological transformations of organic matter. This can be augmented as necessary by suitable artificial fertilizers in cases of specific nutrient deficiencies; but organic matter also provides micronutrients that may not be available ‘from the bag’.

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.

The above mentioned multiple effects of CA when fully applied together are illustrated in Table 2 (Friedrich *et al*., 2009). By 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. 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-stabilised yields accompanied by lowered costs of production. Furthermore, CA is a major opportunity that can be explored and exploited for achieving many of the objectives of the International Conventions on combating desertification, loss of biodiversity, and climate change (Benites *et al*., 2002).

Table 2: Effects of CA components fully applied together (Friedrich *et al.,* 2009)

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

Interdependence of the macroscopic benefits from CA and the microscopic features of the soil it has improved:

It is important to recognise 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.

"Widespread adoption of CA has been demonstrated to be capable of producing "large and demonstrable savings in machinery and energy use, and in carbon emissions, a rise in soil organic matter content and biotic activity, less erosion, increased crop-water availability and thus resilience to drought, improved recharge of aquifers and reduced impact of the apparently increased volatility in weather associated with climate change. It will cut production costs, lead to more reliable harvests and reduce risks especially for small landholders. … " (FAO, 2008).

CA as the fundamental basis of soil system 'sustainability':
The key feature of a sustainable soil ecosystem is the repetitive biotic actions on organic matter in suitably-porous soil. This occurs under CA's conditions of management which continually maintain the organisms' living conditions, including soil aeration. This means that under CA, soils become *potentially self-sustainable*. Activities which damage this capacity for self-sustainability by, for example tillage and/or compaction, therefore prejudice future profitability, environmental integrity and ongoing productive capacity.

3.2 Higher Productive Capacity of Soils in CA Systems

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

No-till, or a reduced proportion of the area needing tillage (e.g., planting basins, or 'zai/tassa'), requires less input of energy per unit area, per unit output, and lower depreciation-rates of equipment than formerly. It involves lower production costs, thereby increasing the profit margin, at the same time as lessening emissions from burning of tractor-fuel.

3.3 Higher Stable Yields and Incomes from CA

The combination of features which raises productive potential makes the soil a better environment than before for the development and functioning of crop-plants' roots. Improvements in the soil's porosity has two major positive effects: (a) a greater proportion of the incident rainfall enters to the soil; (b) 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 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 applied 'from the bag'. 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.

"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". (FAO, 2001b)

Better soil protection by mulch cover minimises 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.

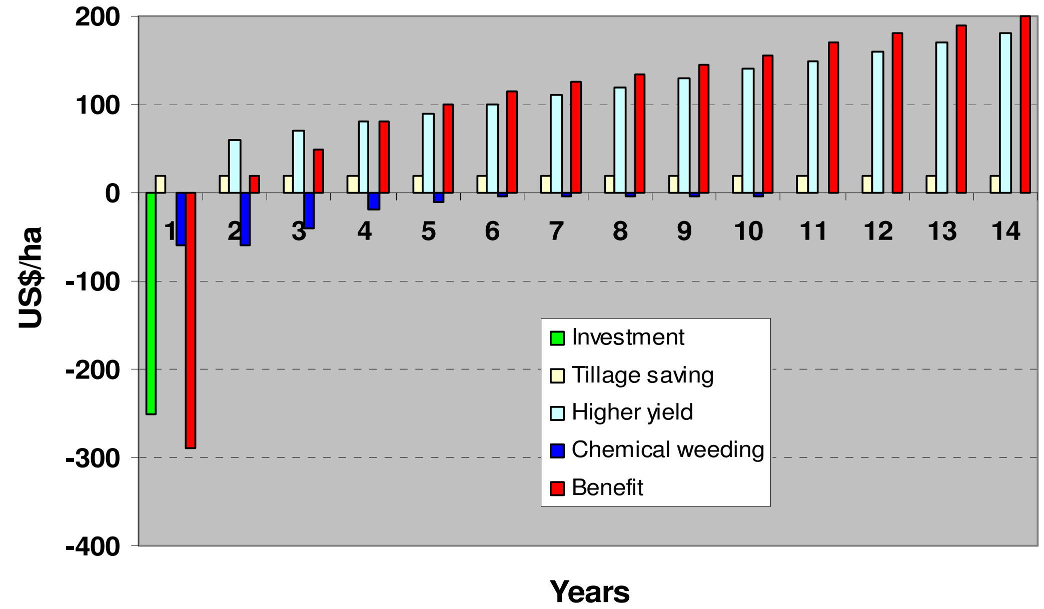
Systems are less vulnerable to pests, diseases, drought effects because better soil conditions include also greater biotic diversity of potential predators on pests and diseases, while crop rotations break pest build-ups. Here, much of the cost of avoiding or controlling significant attacks is diminished because of it being undertaken by natural predators.

As a result, the financial benefits for farmers in Latin America who have adopted CA have been striking. 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 ten years. He found that by the tenth year net farm income had risen from the CA farms from under US$10,000 to over US$30,000, while on conventional farms net farm income fell and even turned negative. Medium and large-scale farmers have experienced:

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

Such effects are cumulative over space/area, and accumulate over time from degraded condition to improved stabilised condition, with yields and income rising over time, as in this example of large-scale wheat production under CA in Kazakhstan. Figure 2 shows the development of wheat yields and financial benefits after changing from conventional tillage to no-till agriculture on mechanised farms in northern Kazakhstan. The internal rate of return to investment (IRR) is equal to 28% (Fileccia, 2008). Thus, farmers should turn away from the struggle to reach the highest yield. Instead they should struggle for the highest economic yield. Figure 2 indicates that CA can achieve that goal even under the current conditions prevailing in Eurasia.

Figure 2 - Financial Benefits of Conservation Agriculture in Wheat Production in Northern Kazakhstan (IRR = 28%)



Further, in Paraguay, yields under conventional tillage declined 5-15 percent over a period of ten years, while yields from zero-tillage [CA] systems increased 5-15 percent. Over the same period, fertilizer and herbicide inputs dropped by an average of 30-50 percent in the CA systems. In Brazil, over a 17-year period, maize and soybean yields increased by 86 and 56 percent respectively, while fertilizer inputs for these crops fell by 30 and 50 percent, 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).

3.4 Climate Change Adaptation and Less Vulnerability

Less vulnerability to effects of drought, less erosion, lower soil temperatures, represents a managed adaptation to climate-change's effects of, for example, more intense rainstorms, increased daily ranges of temperatures, and more severe periods of drought.

Good mulch cover provides 'buffering' of temperatures at soil surface which otherwise are capable of harming plant tissue at the soil/atmosphere interface, thus minimising 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 soil's infiltration-capacity.

In the continental Eurasia region where a significant portion of annual precipitation is in the form of snow fall in the winter, CA provides a way of trapping the snow evenly in the filed which may otherwise blow away, and also permitting snow to melt evenly into the soil, thus maximising effective precipitation. In the semi-arid areas of continental Eurasia, one-third or more of the precipitation is not effectively used in tillage systems, forcing farmers to leave land fallow to 'conserve' soil moisture. On the other hand, in CA system, more soil moisture can be conserved than leaving the land as fallow, thus allowing for the introduction of additional crops including cover crops into the system.

3.5 Reduced Greenhouse Gas Emissions

No-till farming also, and most importantly, reduces the unnecessarily-rapid oxidation of organic matter to CO_2 which is induced by tillage. Together with addition of mulch as a result of saving crop residues *in situ*, 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.

Making use of crop residues represents retention of much of the atmospheric C captured by the plants. Some becomes transformed to soil organic matter of which part is resistant to quick breakdown, (though still with useful attributes in soil), and represents net C-accumulation in soil, eventually leading to C-sequestration. Tillage however results in rapid oxidation to CO2 and loss to the atmosphere. Expanded across a wide area, CA has potential to slow/reverse rate of emissions of CO2 and other 'greenhouse' gases by agriculture.

With CA, reduced use of tractors and other powered farm equipment results in lesser emissions of exhaust gases.

Studies in southern Brazil show an increase in carbon in the soil under conservation agriculture. The different cover-crops show significant effects on the organic carbon level for two depths (0-5cm and 5-15cm). The means of all cover crops presented greater values for soil organic carbon than fallow at both depths (Calegari and Alexander, 1998). During the initial years until the establishment of the cropping system the increase in total organic carbon content was restricted to only the surface layers of the soil (0-2.5 cm) (Testa *et al*., 1992). With time, this effect reached deeper soil layers (2-5 – 7.5 cm). Castro Filho *et al.* (1998) found a 29 percent increase of soil organic carbon in no-tillage compared to conventional tillage in the surface 0-10 cm of the soil, irrespective of cropping system.

According to Testa *et al.* (1992), soil carbon content increased by 47 percent in the maize-lablab system, and by 116 percent in the maize-castor bean system, compared to the fallow-maize cropping system which was taken as a reference. In systems where nitrogen was applied as a fertilizer, the carbon contents increased even more. Baker *et al.* (1996) found that crop rotation systems in CA accumulated about 11 t/ha of carbon in the topsoil (0-17.5 cm) after nine years. Under tillage agriculture and with monoculture systems the carbon liberation into the atmosphere was about 1.8 t/ha per year of CO_2 (FAO, 2001a).

CA systems can also help reduce the emissions for other relevant green house 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, or from severely compacted soils. CA improves the internal drainage of soils and the aeration and avoids anaerobic areas in the soil profile, provided soil compactions through heavy machinery traffic are avoided and the irrigation water management is adequate. Technical solutions are available for both.

3.6 Better Ecosystem Functioning and Services

Societies everywhere benefit from a multitude of resources and processes that are supplied by nature. Collectively they are known as ecosystem services because there is a demand for these natural assets and processes by human beings for their survival and well-being. These ecosystem services include products such as clean drinking water, edible and non-edible biological products, and processes that decompose and transform organic matter. Five categories of services are recognised -- *provisioning* such as the production of food and water; *regulating*, such as the control of climate and disease; *supporting*, such as nutrient cycles and crop pollination; *cultural*, such as spiritual and recreational benefits; and *preserving*, which includes guarding against uncertainty through the maintenance of biodiversity.

Greater quantities of cleaner water and increased biological nitrogen fixation:
CA's benefits from ecosystem services derive from improved soil conditions – air-space, water, nutrition – in the soil volume explored by plants' roots. The improvement in the porosity of the soil is effected by the actions of the soil biota – such as microscopic bacteria, fungi, small insects, worms etc. - which are present in greater abundance the soil under CA. The mulch on the surface protects against the compacting and erosive effects of heavy rain, damps-down wide temperature fluctuations, and provides energy and nutrients to the organisms below the soil surface.

When the effects, seen on a square meter of a field surface, are reproduced across enough farms in a contiguous micro-catchment within a landscape, and beyond, the ecosystem services provided – such as clean water, sequestration of carbon, avoidance of erosion and runoff - all 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 from wells, boreholes. 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, blocking bridges etc.

Legumes in CA rotations provide increased *in-situ* availability of nitrogen, as the essential plant nutrient for producing biomass, diminishing the need for large amounts of applied nitrogenous fertilizers. Also, there is increasing evidence of significant amount of 'liquid carbon' being deposited into the soil through root exudation into the rhizosphere.

Wider society gains in a number of ways from the actions of those who embrace CA, whether large or small farmers, among them:

- much-diminished erosion and runoff,
- less downstream sedimentation and flood-damage to infrastructure;
- better recharge of groundwater, more regular stream-flow throughout the year, and the drying of wells and boreholes less frequent.
- 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;
- better nutrition and health of rural populations, with less call on curative health services.

Protection and better use of agrobiodiversity
The addition of soil organic carbon also clearly represents the incremental development of the soil from the surface downwards, by contrast with its depletion under tillage agriculture.

In CA systems, the mixtures, sequences and rotations of crops encourages agro-biodiversity because each crop will attract different overlapping spectra of micro-organisms. The optimisation of the 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 allelochemicals.

Above-ground the same crop mixtures, sequences and rotations provide mixed habitats for insects, mammals, birds, without undue mechanical disturbance during the year.

Under CA, increased biodiversity from both soil organisms' proliferation as well as from the wider range of crops favours a broader range of insect pollinators.

4. THE NECESSARY CONDITIONS FOR THE INTRODUCTION AND ADOPTION OF CONSERVATION AGRICULTURE

As was indicted at the beginning of this paper, CA is knowledge intensive and a complex system to learn and adapt to local conditions. 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 (Derpsch, 2008b; Shaxson *et al.*, 2008; Friedrich and Kassam, 2009). 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 general steps for the introduction of CA and transformation of tillage system.

4.1 The Importance of Involving the Farmers

CA principles can be applied in many forms of agricultural practice. Because CA comprises several principle-based technologies working simultaneously 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, rotations 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. Changing over to a new system and ways of doing business carries a real risk of failure, and this aspect must be taken into account in the initiatives that are designed to promote CA.

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:

- Environmental conditions, such as

  - temperature regime and variations
  - expectations of rainfall and snow
  - soil types and condition, and historical trends in productivity;
- Farmers' resource-availability, including:
  - land area;
  - availability and types of finance;
  - sources of farm-energy, such as manual/animal-power/fuel-powered machinery;
  - availability of direct seeding machinery;
  - skills and knowledge
  - assessments of risks.
- Production system
  - Type of farming system (crops/livestock/mixed) and whether the system is rainfed or irrigated;
- Market opportunities and transport availability
- Support, encouragement, guidance, from
  - farmer groups;
  - formal 'extension' programmes;
  - policies, laws and regulations.

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.

4.2 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 purposes 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 organisations 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-organised, they may be able effectively to pressure national and local governments and institutions for necessary reforms and services, including research and extension, 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.

4.3 The Need for Scientists and Extension/Advisory Agents to Facilitate Problem Solving

Scientists in support of CA need to: (a) to respond to unsolved technical problems, (e.g., cover crops for different situations); (b) explore new potentials and possibilities based on what is already known and observed; (c) clarify basic soil conditions regarding the significance of organic-matter's effects and related interactions with respect to soil productivity and its changes over time under different treatments; (d) '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-agents 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.

4.4 The Need for Relevant Research

There is generally little participatory, farmer-centred 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, in no particular order, still requiring greater attention under different ecological and socio-economic situations include:

- Machinery and equipment to match the needs of CA practices under different sources and types of farm power (e.g., Baker *et al.*, 2007).
- Economically viable crop rotations and associations (including mixed cropping), and diversification of production with CA (e.g., Goddard *et al.*, 2008).
- Soil cover management with cover crops, crop residues and stubbles (e.g., Goddard *et al.*, 2008).
- Weed control and integrated weed management in CA systems (e.g., Upadhyaya and Blackshaw, 2007; Blackshaw *et al.*, 2007).
- Integration of integrated pest management (including insects, diseases and weeds) management within CA (e.g., Chaboussou, 2004).
- 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 (e.g., Derpsch 2008b; Kassam and Friedrich, 2009a and 2009b).

- Development of effective CA in the semi-arid to arid rainfed zones in the tropics, sub-tropics and temperate climates in view of their characteristic environmental limiting factors, for irrigated CA systems and for rainfed and irrigated CA systems (e.g., Goddard *et al.*, 2008).
- The integration of livestock and mixed cropping into CA, particularly on small and medium holdings, including the use and management of organic manures (e.g., Landers, 2007).
- Soil biological processes related to soil health and productive capacity under CA systems, including indicators of ecosystem health, and on-farm monitoring of changes in the various aspects of ecosystem health and functions such as soil quality, agrobiodiversity, nutrient and water balances and fluxes, C sequestration, catchment and landscape level ecosystem processes, etc (e.g., Uphoff *et al.*, 2006; Blanco-Canqui and Lal, 2008).
- Economics of the various benefits – food security, livelihoods, environmental protection, biodiversity enhancement, economic growth etc.-- derived from CA by the producers and local communities, the nation and the region, and the international community (e.g., Uri *et al.*,1999; Uri, 2000)
- Approaches and processes involved in CA innovation system dealing with experiential learning, adaptation, adoption and scaling under different agroecological and socio-economic situations, and the mechanisms for providing enabling policy and institutional support for individual and collaborative action for agricultural transformation to CA systems and practices (e.g., Derpsch, 2008b; FAO 2008; Friedrich and Kassam, 2009; Friedrich *et al.*, 2009).
- Developing and linking CA protocols for Greenhouse Gas offsets to carbon markets (e.g., Goddard *et al.*, 2009), and to certification schemes including payments for good agricultural practices and ecosystem services (e.g., Lorenzatti *et al*., 2009).

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). Thus, there is 'integrated systems research' required to harness the fuller benefits of combining various CA practices such that the potential for synergies are better understood from research station work as well as from on-farm research work and put to use for optimising crop and system performance, and all the benefits that CA can offer.

4.5 The Need to Build 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 and continues to play a crucial role in creating incentives for adoption. The studies also point to the importance of the availability of affordable credit 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 approaches and other guidance of farmers in CA is that those advising farmers and others 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.

4.6 The Importance of Financing and Enabling the Initial Stages

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

1. 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.
2. Identification of factors limiting crop yields (beyond just 'fertilizer') and what could be done to alleviate these.
3. Identify one or more farmers already undertaking CA and demonstrating it's agronomic, financial and/or livelihood benefits, and set up study visits.
4. Or: set up demonstration for researchers and advisory staff ['extensionists'] and farmers' groups leaders, to catch their interest.
5. 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.
6. 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
7. 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.
8. 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 (b) 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 critical 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.

4.7 The Need to Mobilize Input Supply Sector to Service this New Developing Market

With keen farmers grouping together into Associations etc. (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.

4.8 The Need to 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 successful NT [=CA] pilot projects”.

5. THE ROLE OF POLICY AND INSTITUTIONAL SUPPORT TO CREATE THE SUFFFICIENT CONDITIONS FOR CHANGE

Adoption of CA can take place spontaneously, but given the need to establish the above described necessary conditions for CA introduction and adoption, it usually takes a very long time until it reaches significant levels. Thus, effective and ongoing policy and institutional support has a crucial role to play in the various processes related to the introduction and adoption of CA. *In essence, the role of policy and institutional support is to ensure that the above-described eight necessary needs are met to create the sufficient conditions for the introduction and adoption of CA and its further development on an ongoing basis so that CA practices are mainstreamed.*

Adequate policies and institutional support of various kinds can shorten the adoption process considerably, mainly by removing the constraints and needs mentioned in Section 3. 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. 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. Policy makers 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. This aspect is particularly relevant to agriculture in the continental Eurasia region where farmers are accustomed to mining the natural fertility of soils such as Chernozem through deep tillage which promotes mineralization of nutrients but also the loss of carbon.

Effective demand in the market and the supply chains beyond production are also important in ensuring that farmers receive an attractive return for their effort to produce safe and nutritious food and other agricultural products using sustainable practices. Policies and institutions that encourage and enable the certification of CA systems and their products, permit CA farmers to sell carbon off-sets to industry emitting GHG, or qualify for payments for other ecosystem services such as for improved water quality or for enhancing biodiversity would serve to transform unsustainable tillage-based systems to CA-based systems.

However, to facilitate the transformation of non-CA production systems to CA systems, the role of policy and institutional support is particularly important in the following seven areas to ensure that the all eight necessary conditions described in Section 4 are fostered and maintained in good operating order.

5.1 Putting a Political Emphasis on CA

In general it has been observed that issues like soil health and soil productive capacity, unless they result in catastrophic dimensions of erosion and cross boarder 'dust plumes', do not inspire or attract policy makers. They might take note about concerns of soil degradation but then 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 and tillage machinery 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. Most countries in the continental Eurasia have not mobilized this high-level political commitment towards CA. Kazakhstan appears to be the exception, and it is likely that other neighbouring countries may soon follow suit.

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 everywhere need to take a leading role in the process of introducing and implementing CA practices on a large scale. But to take up this role they need a supportive policy environment and the backing of some key public and private sector institutions responsible for providing financial services, production inputs including CA machinery and agrochemicals, post-harvest processing, and operational research and know how.

5.2 Formulating 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 encourage and facilitate 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 complementary relationship 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 design 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) when dealing with smallholders who are operating in poverty stricken situation with degraded resource base and poor access to markets. In the case of more developed situations involving mainly large farm holdings, producer associations can be important in attracting the needed services and policy and institutional support.

Within this flexible policy framing, however, there are five other issues policymakers need to consider:

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 jeopardise 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 decentralising 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.

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 amongst stakeholders at all levels. Behaviour of everyone concerned must change to enable CA adoption processes to establish and take roots. 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.

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.

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 whole 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. Similarly, with large farms such as those in many of the CIS members such as Kazakhstan, Ukraine and Uzbekistan, switching to CA too quickly may appear too risky in which case any likely loss in profit any risk of failure may need to be underwritten by governments. Farmers may start with 10% of their land under CA, and move forward with the rest of the land as they gain experiential knowledge on what works, why and how?

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:

- Reduced erosion and runoff, resulting in less downstream sedimentation and flood-damage to infrastructure;
- Better recharge of groundwater, more regular stream-flow throughout the year, and better replenishment 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;
- Better nutrition and health among rural populations, with less call on curative 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 can 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

5.3 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 CA 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 below 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. Besides 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 (see Figure. 2).

5.4 Removal of 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 in Europe, Asia and Africa 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.

Public 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.

5.5 Dynamic Institutional Capacity to Support CA

CA is not a static set of technologies, but a dynamic system comprising a set of best practices 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, R&D 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.

5.6 Accessibility and Affordability of Required Inputs and Equipment

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 tractorized direct 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.

According to Gan *et al.* (2008), there are special challenges to adoption of no-till systems in the continental Eurasia region. A particular challenge is the requirement for robust seeding machinery that can be operated over large areas, greater than 1,000 ha, without problems, so that seeding can be completed within the short window of optimum seeding dates. Research is required to determine optimal stubble heights (for snow trapping), row spacing, and harvest methods (straight combining or swathing). Also, under no-till systems, fertilizer placement is a critical part of machinery design and operation. This also needs to be included within research on equipment and machinery.

5.7 Providing 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 constitutes good land husbandry. Without compromising the quality of education in the traditional agricultural and social sciences, it would be possible to boost technical education and vocational 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, a new international Community of Practice (CoP) needs to emerge in the Eurasia region which can acquire, evaluate, share and disseminate robust evidence about the principles, practices and impacts of CA. Raising awareness of CA in government, professional organisations 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 for the Eurasia region 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.

6. 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 higher food and energy prices and input costs, and increasing environmental concerns to issues of climate change facilitate the justification for policy makers to introduce supportive policies and institutional services, even including direct payments to farmers for environmental services 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.

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

CA is now being used in all regions of the world but it has not gained much popularity in the Continental Eurasia region as a whole. A particular challenge is the requirement for affordable robust machinery that can operate over large areas without problems, so that seeding can be completed within the short window of optimal seeding dates. Research is required to determine optimal stubble heights, row spacing, and harvest methods (straight combining or swathing). Integrated weed management is another area that requires focused strategic research and on-farm operational research to minimise the use of herbicide. Similarly, research is needed on cropping systems and the rotations that can maximise profit while minimising the risks, including the risk of failure. Doing away the summer fallows and introducing legume cover crops in CA as a source of biomass and biological nitrogen needs to be tested and adopted widely.

CA practices offer a new way of effectively and efficiently managing agricultural environments and the natural resource base for multifunctional services to the society. As full benefits of CA take several years to fully manifest themselves, fostering a dynamic CA sector requires an array of enabling policy and institutional support over a longer term time horizon. Countries in the continental Eurasia region that have significant extents of Chernozem soils may find it difficult to stop mining the natural soil fertility. However, it is in their longer-term interest to switch over to CA practices with application of fertiliser that will permit the built of soil fertility while sequestering additional carbon. This will allow farmers to take advantage of the future carbon markets and support for environmental services currently under discussion by most Eurasian countries.

REFERENCES

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 Edition. CABI and FAO, Rome. 326 pp.

Benites J., Vaneph S. and Bot, A. (2002). Planting concepts and harvesting good results. *LEISA Magazine*, Oct. 2002, 18(3): 6-9.

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. Weed Science 56(1):146-150. 2008.

Blanco-Canqui, H. and Lal, R. (2008). No-tillage and carbon sequestration: An on-farm assessment. *Soil Sci. Soc. Am. J.* 72:693-701

Calegari, A. and Alexander I. (1998). The effects of tillage and cover-crops on some chemical properties of an oxisol and summer crop yields in southwestern Paraná, Brazil. *Advances in GeoEcology*, 31: 1239-1246.

Castro-Filho, C., Muzilli, O. and Podanoschi, A.L. (1998). Estabilidae dos agregados e sua relacao com o teor de carbono organico num Latossolo roxo distrofico, em funcao de sistemas de plantio, rotacoes de culturas e metodos de preparo das amostras. *Revista Brasileira de Ciencia do Solo*, 22: 527-538..

Chaboussou, F. (2004). Healthy Crops: A New Agricultural Revolution. Jon Carpenter Publishing. 244 pp.

Crabtree, B. (2004). Strong Economics of no-tillage cause widespread adoption in southern Australia. *Paper presented at the First congress on Conservation Agriculture/No-till*, Dnepropetrovsk, Ukraine, 18-23 November 2004.

CTIC (2005). *CTIC National Crop Residue Management Survey 2004.* Conservation Technology Information Centre, CTIC Partners. West Lafayette, Indiana, USA.

Derpsch, R. (2005): The extent of conservation agriculture adoption worldwide: Implications and impact. In: *The Proceedings of the 3rd World Congress on Conservation Agriculture*, Nairobi, Kenya, 3-7 October 2005; ACT, Harare.

Derpsch, R. (2008a). No-tillage and Conservation Agriculture: A Progress Report. In: *No-Till Farming Systems* (Goddard, T. et al., Eds.), pp. 7-39. WASWC Special Publication No. 3, Bangkok.

Derpsch. R. (2008b). Critical Steps in No-till Adoption. In: *No-Till Farming Systems* (Goddard, T. *et al.*, Eds.), pp. 479-495. WASWC Special Publication No. 3, Bangkok.

Doran, J.W. and Zeiss M.R. (2000). Soil health and sustainability: managing the biotic component of soil quality. *Applied Soil Ecology*, 15(1):3-11.

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

Friedrich, T.F., Kassam, A.H. and Shaxson F (2009). Conservation Agriculture. *STOA Project: Agriculture Technologies for Developing Countries.* European Technology Assessment Group. Institute for Technology Assessment and Systems Analysis, Karlsruhe, Germany.

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., Gan, Y., Ellis, W., Watson, A., Sombatpanit, S. (Eds.), pp. 179-195. Special Publication No.3, World Association of Soil and Water Conservation (WASWC), Bangkok.544 pp.

FAO (2001a). *Conservation Agriculture: Case Studies in Latin America and Africa.* Soils Bulletin No. 78. FAO, Rome. 66 pp.

FAO (2001b). *The Economics of Conservation Agriculture*. FAO, Rome. 65 pp.

FAO (2008). Investing in Sustainable Agricultural Intensification: The Role of Conservation Agriculture – A Framework for Action' FAO Rome, August 2008 (available at www.fao.org/ag/ca/).

Fileccia, T. (2008). *Conservation Agriculture and Food Security in Kazakhstan.* Working Paper (final draft), Plant production and Protection Division, FAO, Rome.

Goddard, T., Haugen-Kozyra, K. And Ridge, A. (2009). Conservation Agriculture Protocols for Greenhouse Gas Offsets in a Working Carbon Market. Invited paper at the VIIth International Conference on *Sustainable Agriculture Based on System Approach.* Dnipropetrovsk, Ukraine, 22-26 June 2009.

Goddard, T., Zoebisch, M., Gan, Y., Ellis, W., Watson, A. and Sombatpanit, S. (2008) (Eds.). *No-Till Farming Systems.* WASWC Special Publication No. 3, Bangkok, 544 pp.

Kassam A.H. and Friedrich, T. (2009a). Perspectives on Nutrient Management in Conservation Agriculture. Invited Keynote Paper at the 4th World Congress on Conservation Agriculture: *Innovations for Improving Efficiency, Equity and Environment.* 4-7 February 2009, New Delhi, ICAR.

Kassam A.H. and Friedrich, T. (2009b). Nutrient Management in Conservation Agriculture: A Biologically-Based Approach to Sustainable Production Intensification. Invited paper at the VIIth International Conference on *Sustainable Agriculture Based on System Approach.* Dnipropetrovsk, Ukraine, 22-26 June 2009.

Kueneman, E., Kassam, A.H., Legoupil, J. and Freude, B. (2007). Harnessing the agricultural productivity of the moist savannas through the dissemination of proven technologies and good agriculture practices: going to scale in Burkina Faso. *Tropical Agriculture Association Newsletter*, 27(4): 21-25.

Landers, J. (2007). *Tropical Crop-Livestock Systems in Conservation Agriculture: The Brazilian Experience.* Integrated Crop Management, Vol. 5. Plant Production and Protection Division, FAO, Rome. 92 pp.

Lorenzatti, S. Begnis, A.S., Bianchini, A., Albertengo, J. and Rabasa, J. (2009). Certified agriculture: the sustinable production alternative. Invited paper at the VIIth International Conference on *Sustainable Agriculture Based on System Approach.* Dnipropetrovsk, Ukraine, 22-26 June 2009.

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, World Bank, Washington DC. 65 pp.

Rumley, R. and Ong, C. (2007). Wetting Africa's Appetite: Conservation Agriculture is Rainfall into Higher Crop Yields – and Catching On. *RELMA Review Series Conservation Agriculture in Africa*, Issue 3. (http://www.relma.org/PDFs%5CIssue%203%20%20Conservation%20Agriculture.pdf).

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

Shaxson, T. F., Kassam, A.H., Friedrich, T., Boddey, B. and Adekunle, A. (2008). Underpinning Conservation Agriculture's Benefits: The Roots of Soil Health and Function. Main background document for the Workshop on Investing in Sustainable Crop Intensification: The Case for Improving Soil Health, 22-24 July, FAO, Rome.

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.

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

Upadhyaya, M.K. and Blackshaw, R.E. (2007) (eds.). Non-Chemical Weed Management: Principles, Concepts and Technology. CABI, Wallingford.

Uphoff, N., Ball, A.S., Fernandes, E., Herren, H., Husson, O., Laing, M., Palm, C., Pretty, J., Sanchez, P., Sanginga, N., and Thies, J. (2006) (Eds.). *Biological Approaches to Sustainable Soil Systems.* CRC Press, Taylor & Francis Group. 764 pp.

Uri, N.D. (2000). An evaluation of the economic benefits and costs of conservation tillage. *Environmental Geology,* 39(3/4): 238-248.

Uri, N.D., Atwood, J.D. and Sanabria, J. (1999). The environmental benefits and costs of conservation tillage. *Environmental Geology,* 38(2): 111-125.