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Adaptation and Constraints of Conservation Agriculture

Addis Tadesse Tekle
Ethiopian Institute of Biodiversity, P.O. Box 30726 Addis Ababa, Ethiopia

Abstract
This paper is intended to revise those works in the area of conservation agriculture (CA) and its benefit specifically, in regards of it adoption and constraints for better service of humans as well as the Ecosystem in general. The immediate goals of CA include increasing the productivity of land, water, labor and capital to meet human needs, while preserving the integrity of the natural ecosystems on which all life depends. Specifically, CA aims to conserve and enhance the quality of natural and human resources, while achieving greater profitability of agriculture for producers, assured supply and better-quality food for consumers, a greater and sustainable livelihood opportunities to raise standards of living broadly and equitably. 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 behavior of all concerned stakeholders. Generally the objective of this paper is to indicate those points in regards to adoption and constraint of conservation Agriculture thought reviewing different papers in this area of current research.
Keywords: conservation agriculture, crop rotation, minimum tillage, cover crop

Introduction

Conservation agriculture (CA) refers to the simultaneous use of three main principles: (i) less disturbance of the soil, i.e. reduced tillage (RT) or no-tillage (NT) and direct seeding; (ii) soil cover, i.e. crop residue, cover crops, relay crops or intercrops to mitigate soil erosion and to improve soil fertility and soil functions and; (iii) crop rotation to control weeds, pests and diseases (Derpsch, 2001). Other terms such as conservation tillage, zero-tillage and direct drilling apply to CA. CA emerged historically as a response to soil erosion crises in USA, Brazil, Argentina and Australia where currently it spans over million hectares (Ribeiro et al., 2007). The most famous success story is that of Brazil, where conservation agriculture has been initiated by farmers. Afterwards, research, policy, NGOs, public and private sectors joined their efforts to farmers and farmers' societies and networks which led to effective and dynamic innovation systems that have strongly contributed to disseminate the technology.

Although the universally accepted practice of tillage was queried in the 1940s , the practical application of minimum tillage on a large scale did not occur until two decades later. This was prompted by increasing concerns of soil erosion exacerbated by traditional practices of regular and thorough tillage (Thomas et al., 2007). It became feasible by the development of low-cost herbicides such as Roundup containing the active ingredient glyphosate (N-(phosphono-methyl) glycine) manufactured by Monsanto in 1974. With the advent of chemical weed management one of the reasons for tillage became redundant. Experimentation with minimum tillage began in North America and the UK because this is where herbicides first became widely available. It then spread to commercial farming in South America and Australia, particularly targeted to large land holdings offering economies of scale in reducing tillage requirements. If tillage was to be minimized or foregone it became necessary to develop implements for effective placement of seed and fertilizer into undisturbed soils; these required more robust tine and disc systems. This was done for the increasingly powerful tractors becoming available from the 1960s, especially considering the additional traction requirements necessitated by seed and fertilizer delivery into undisturbed soil. The research and development process encouraged, and indeed resulted in, close interaction between researchers, engineers, mechanics and farmers due to the multiplicity of differing requirements of soils and cropping systems and the need for ongoing trial and error modification of delivery systems. With development of techniques of chemical weed management and effective seed and fertilizer delivery systems with minimal soil disturbance, the other aspects of CA, increased soil coverage with crop residue or cover crops and more diverse crop rotations, became more feasible. In southern Africa, no-tillage direct seeding systems appeared in the mid-1980s when specific machinery design and manufacturing started for the commercial farming sector. The main trigger for increased interest in direct seeding technologies in the region was large-scale soil degradation and fuel shortages, which increased the need for planting systems with a lower energy requirement. By 1998, it was estimated that about 30% of the commercial farmers in Zimbabwe had adopted CA (Nyagumbo, 1998). However, the spread of CA in large-scale commercial farming was based on high power traction, well beyond the means of most small holder farmers. Thus alternative pathways for introduction of CA among small holder farmers were required. Interestingly some of the Zimbabwean prototypes were later exported to India and Bangladesh were local manufacturers adapted them to small-scale farmer's conditions.

Research results

Full implementation of the principles of CA involves a radical change in many farm operations. A new knowledge base is needed by farmers to establish crops, manage weeds, manage crop residues, respond to newly emerging diseases and insect pests, and manage diverse crops. Clearly, farmers who make the change are driven by an expectation of substantial benefits. These generally are the promise of cost or labour savings or productivity increases (Pieri *et al*., 2002).

Although many efforts initially focused on the large-scale commercial farms there have also been initiatives to develop machinery for small-scale farmers interested in practicing CA especially in the States of Parana, Santa Catarina and Rio Grande do Suale. Current reports indicate, there is an estimated 200,000 ha managed by small-scale farmers under CA in Brazil (Wall, 2007). Machinery systems for small-scale farmers were mainly focused on manual and animal traction seeding systems such as the manual jab-planter and animal traction direct planters. The Brazilian machines had spillover effects to southern Africa where new machinery is now developed and tested. By contrast with development in Brazil, in southern Africa farmers were not the main driver for change to CA but donor-driven initiatives. In Zimbabwe, a GTZ/BMZ funded project on "conservation tillage" (CONTILL) operated from 1988 to 1998 (Hagmann, 1998). The major focus of this project was developing and extending small-scale farmer CA systems like mulch ripping and other resource-conserving seeding systems. However, the approaches were mainly developed on research stations with little farmer interaction. Therefore the adoption of new CA systems was generally limited. In Zambia, a World Bank funded project initiated the large-scale extension of CA in 1996 based on manually dug planting basins and later rip-line seeding systems (Haggblade and Tembo, 2003).

Conservation agriculture is generally defined as any tillage sequence that minimizes or reduces the loss of soil and water; and operationally is tillage or tillage and planting combination, which leaves at least 30% or more mulch or crop residue cover on the surface (SSSA 1986IIR and ACT 2005). According to (Ribeiro *et al*., 2007) and Rabah Lahmar (2007) CA emerged historically as a response to soil erosion crises in USA, Brazil, Argentina and Australia where currently it spans over million hectares.

The most famous success story is that of Brazil, where conservation agriculture has been initiated by farmers. Afterwards, research, policy, NGOs, public and private sectors joined their efforts to farmers and farmers' societies and networks which led to effective and dynamic innovation systems that have strongly contributed to disseminate the technology. In the drylands of southern Africa, CA has been loosely applied to any tillage system that conserves or reduces soil, water and nutrient loss, or reduces draft power (human, animal and mechanical) input requirements for crop production. With the cropping period in most semi-arid regions being relatively short, the timing of field operations is critical (Twomlow *et al.,* 2006)

1. Adoption of conservation agriculture worldwide

Although much of the CA development to date has been associated with rain-fed arable crops, farmers can apply the same principles to increase the sustainability of irrigated systems, including those in semi-arid areas. CA systems can also be tailored for orchard and vine crops with the direct sowing of field crops, cover crops and pastures beneath or between rows, giving permanent cover and improved soil aeration and biodiversity. The common constraint, according to farmers, to practicing this latter type of intercropping is competition for soil water between trees and crops. However, careful selection of deep-rooting tree species and shallow-rooting annuals resolves this. Functional CA systems do not replace but should be integrated with current good land husbandry practices (Shaxson, 2006). Because of the benefits that CA systems generate min terms of yield, sustainability of land use, incomes, timeliness of cropping practices, ease of farming and ecosystem services, the area under CA systems has been growing rapidly, largely as a result of the initiative of farmers and their organizations. It is estimated that, worldwide, there are now some 106 million ha of arable crops grown each year without tillage in CA systems. Table 1 provides information on country-specific arable and permanent cropland area under CA, and as percentage of total arable and permanent cropland area. A useful overview of the adoption of CA in individual countries is given by Derpsch and Friedrich (2009). Except in a few countries (USA, Canada, Australia, Brazil, Argentina, Paraguay, Uruguay, Kazakhstan, China, Kenya, Tanzania, Lesotho, Malawi, South Africa), these approaches to sustainable farming have not been 'mainstreamed' in agricultural development program or backed by suitable policies and institutional support. Consequently, the total area under CA is still small (about 7 per cent) relative to areas farmed using tillage. Nonetheless, the rate of increase globally since 1990 has been at the rate of some 5.3 million ha per annum, mainly in North and South America and in Australia and New Zealand.

Conservation agriculture is a system approaches to sustainable agriculture indeed according to the points listed above. Yet, most of the conservation agriculture is presently done in USA, Brazil, Argentina, Canada, Australia, and other developed countries. As it has been well described by Kassam *et al*. (2009), briefly, it is estimated that, worldwide, there are now some 106 million ha of arable crops grown each year in conservation agriculture systems. According to FAO AQUASTAT (2008), Currently, South America has the largest area under conservation agriculture with 49586 900 ha (46.6% of total global area under conservation agriculture) followed by North America (39 981 000 ha, 37.5%). Australia and New Zealand have 12 162 000 ha (11.4%), Asia 2 630 000 ha (2.3%), Europe 1 536 100 ha (1.4%), and Africa 470 100 ha (0.4%). USA ranked the first (26,500, 000 ha) among different countries.

Except in a few countries (USA, Canada, Australia, Brazil, Argentina, Paraguay, Uruguay, etc.), these approaches to sustainable agriculture have not been ‘mainstreamed’ in agricultural development program or backed by suitable policies and institutional support. Consequently, the total area under conservation agriculture is still small (about 7%) relative to areas farmed using tillage. Nonetheless, the rate of increase globally since 1990 has been at the rate of some 5.3 million ha per annum, mainly in North and South America and in Australia and New Zealand. Reasons for slow adoption are many, traditions of intensive cultivation is the first one. Nevertheless, conservation agriculture is knowledge-intensive and a complex system to learn and implement. It cannot be reduced to a simple standard technology and thus pioneers and early adopters’ face many hurdles before the full benefits of conservation agriculture can be reaped (Derpsch, 2008). Also, it is appeared that in most countries, conservation agriculture is as yet a relatively unknown concept (Kassam, 2009). Indeed, conservation agriculture is not an easily transferable single component technology; the appropriateness of conservation agriculture depends on both biophysical and socioeconomic factors and their interactions. The conservation agriculture knowledge base developed in the USA, Canada, and Australia is not directly transferable to developing countries, thus, there is a great need for research into conservation agriculture in developing countries.

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).

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).

Country	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**

Conservation Agriculture area in 1,000 [ha], Area under Conservation Agriculture in industrialized countries.

No-till agriculture in the modern sense originated in the USA in the 1950s, and from then until 2007 the USA had the largest area under no-till worldwide. In the USA, no-till currently accounts for some 25.5 per cent of all cropland.

Conventional agriculture with tillage remains in the majority even if CA is a valid option for farmers, as compared with southern Latin America where no-till has become the majority agricultural system with 60 per cent of the cropland area. According to CTIC (2005), only half of the total area under no-till in the USA is being permanently not tilled, some 26.5 million ha, corresponding to 15.3 per cent of total arable and permanent cropland. 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 who practice rotational tillage (plough or till their soils occasionally) will not experience the full benefits of the system (Derpsch, 2005).

In Canada, CA is now practiced on some 13.5 million ha (25.9 per cent of arable and permanent crop area), although the no-till technology is used over a much larger area, 46.1 per cent of cropland (Derpsch & Friedrich, 2009). In Australia, CA has been widely embraced by farmers (12 million ha). It has improved weed control, time of sowing, given drought tolerance and has enabled dry regions to use water most efficiently. But inappropriate seeding machines which move the mulch too much and sheep that graze crop residues are leading to an insufficient soil cover.

New Zealand has about 160,000 ha under CA, which corresponds to 17 per cent of all cropland area. New Zealand farmers were among the first to use and develop the no-till technology: in the 1970s, pasture renovation without tillage was tried and practiced successfully. Later, annual crops were seeded with the no-till. However, the majority of the increase in CA area has occurred since 2000. CA is not widespread in Europe (Lahmar, 2009): no-till systems do not exceed 2 per cent of the agricultural cropland. Since 1999 ECAF (European Conservation Agriculture Federation) has been promoting CA in Europe, and adoption is visible in Spain, France, Germany, Ukraine and Finland, with some farmers at 'proof of concept' stage in the UK, Ireland, Portugal, Switzerland and Italy.

2. Area under Conservation Agriculture in developing countries

Brazil has the longest experience in CA, and now has 25.5 million ha under various forms of CA. Since its first appearance in 1972, many useful lessons have originated from Brazil and from neighboring Argentina and Paraguay, which now respectively 19.7 and 2.4 million have ha of CA. They have also set important precedents for the engagement of farmers as principal actors in the development and adaptation of new technologies.

Brazil took the initiative when herbicides (paraquat and diquat) and direct-drilling equipment became available in the USA, 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. Common interest groups were then formed among large-scale farmers and then by 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 still is 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 per cent), greatly reduced surface runoff and soil erosion, and cut tractor use, resulting in big savings in fuel and production costs. Such benefits explain why today, Latin American farmers practice zero-tillage CA on a continuous basis on some 50 million ha. Paraguay has experienced a continuous and steady growth of CA adoption, almost all of it over the past 10 years. Tillage practices have disappeared almost completely. In tractor mechanized farming systems, about 90 per cent (2.4 million ha in 2008) of all crop area is under CA (Derpsch & Friedrich, 2009). Similarly, in small farmer production systems with animal traction or manual systems, no-till practices have\ increased to about 30,000 ha covering 22,000 small farmers. The increased interest in small farmer CA systems has been a result of government support that provides grants for buying no-till equipment.

Among the most encouraging research experiences has been the CA work developed in the dry Mediterranean environments of North Africa in Morocco (Ben Hammouda et al., 2007) where highly innovative adaptations have been made to the low and unpredictable rainfall. In sub-Saharan Africa, innovative participatory approaches are being used to develop supply chains for producing CA equipment targeted at smallholders. Similarly, participatory learning approaches such as those based on the principles of farmer field schools (FFS) are being encouraged to strengthen farmers' understanding of the principles underlying CA and how these can be adapted to local situations. The corresponding program recognize the need to adapt systems to the very varied agro-ecosystems of the regions, to the extreme shortage of land faced by many farmers and to the competing demands for crop residues for livestock and fuel – problems that are particularly pronounced amongst small-scale farmers in Africa in the semi-arid tropical and Mediterranean regions. CA is now beginning to spread to the sub-Saharan Africa region, particularly in eastern and southern Africa, where it is being promoted by FAO, CIRAD, the African Conservation Tillage Network, ICRAF, CIMMYT, ICRISAT, IITA (Ernstein et al.,2008). Building on indigenous and scientific knowledge and equipment design from Latin America, farmers in at least 14 African countries are now using CA (in Kenya, Uganda, Tanzania, Sudan, Swaziland, Lesotho, Malawi, Madagascar, Mozambique, South Africa, Zambia, Zimbabwe, Ghana and Burkina Faso).

fig 2. Shows Manual CA planting systems in Mozambique

CA has also been incorporated into the regional agricultural policies by NEPAD (New Partnership for Africa's Development) and more recently by AGRA (Alliance for a Green Revolution in Africa). In the specific context of Africa (where the majority of farmers are resource-poor and rely on less than 1 ha), CA systems are relevant for addressing the old as well as new challenges of climate change, high energy costs, environmental degradation and labour shortages. In Africa CA is expected to increase food production while reducing negative effects on the environment and energy costs, and result in the development of locally adapted technologies consistent with CA principles (FAO, 2008).

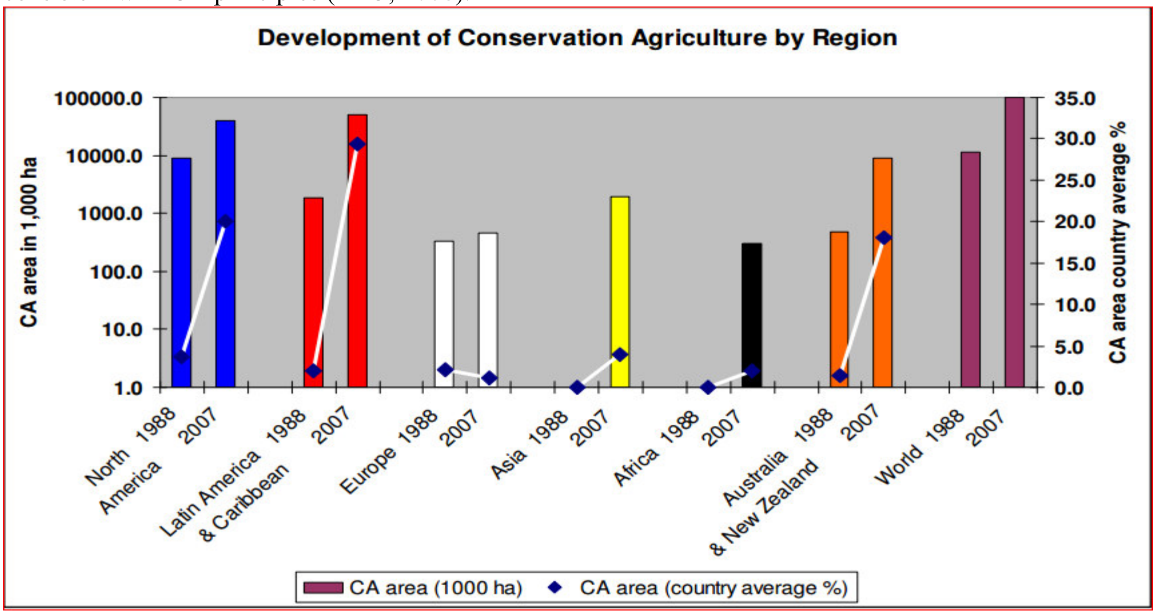

Figure 1: Development of Conservation Agriculture over the last 20 years by world region in total area (ha) and as average percentage across the adopting countries of the respective region(from FAO, 2008).

3. Effects of conservation agriculture on soil and water conservation

3.1 Conserving soil water

Effects of conservation agriculture on soil water conservation have been observed in almost all of the research on it because of the inherent relationship between water and soil conservations as well as crop productivity in the rain fed areas. In conservation agriculture, the presence of a crop residue at the soil-atmosphere interface alters the entire soil ecology. Huang *et al*. (2008b) showed that no-till with stubble retention increased surface soil water content significantly. Retaining residues on the soil surface can provide cover to reduce evaporation, provide barriers against runoff, and improve precipitation infiltration. In addition, the crop residues can also reduce the rate of evaporation by isolating the soil from sun heating and ambient air temperature, and increasing resistance to water vapour flux by reducing wind speed. Some crops do not produce sufficient residue to intercept the raindrops (Baumhardt and Lascano, 1996).

In summary, previous research shows that conservation agriculture with no-till and crop residues retained on the soil surface can reduce evaporation, and improve infiltration of precipitation. Soil and water erosion can be reduced by adopting conservation agriculture.

3.2 Improving soil quality

Soil quality is a subject that is receiving increasing attention. Soil quality is usually considered to have three main aspects: physical, chemical, and biological. It is considered to be important for the assessment of extent of land degradation or amelioration, and for identifying management practices for sustainable land use. Physical quality (soil structure) has big effects on chemical and biological process in the soil; therefore, it plays a central role in studies of soil quality (Dexter 2004). It is well-known that additions of above crop residues or increases in soil organic matter can improve soil properties. Therefore, conservation agriculture practices should be able to improve soil quality because of crop residues retained on the soil surface. No-till and/or minimum till reduces soil compaction and prevent soil structure decline.

3.3 Increase soil organic carbon and organic matter

Soil organic matter sustains many key soil functions by providing the energy, substrates, and biological diversity to support biological activity, which affects soil aggregation and water infiltration. The degree of soil organic matter stratification with depth has been suggested as an indicator of soil quality, because surface organic matter is essential to erosion control, water infiltration, and conservation of nutrients. Conservation agriculture is promoted, in part, for its beneficial effects on carbon retention that occur with time (Zibilske *et al.*, 2002). Organic carbon levels were significantly higher with direct drilling, compared to conventional cultivation. The contents of organic carbon in soil can also be improved by conservation agriculture by keeping crop residues containing carbon and nutrients at the soil surface layer. Another mechanism by which soil organic carbon and organic matter is retained in conservation-tillage systems may be due to reduced oxygen availability below the surface of no-till systems, which affects decomposition rates (Wershaw, 1993) and the distribution of aerobic and anaerobic microbes and microbial processes.

3.4 Improving hydraulic conductivity and infiltration

Infiltration and evaporation are the most significant processes determining soil water storage. Infiltration is also an important soil feature that controls leaching, runoff, and crop water availability. The impact of different tillage systems on infiltration has been well investigated using rainfall simulators and ponded or tension infiltrometers (Luo *et al*. 2005). In general, infiltration is greater under no-tillage (NT) than in tilled soils due to the larger number of macro pores as a result of increased fauna activity, and accumulated organic matter forming a litter of residues (Arshad *et al.* 1999). Disruption of macro pore continuity by tillage can reduce infiltration and hydraulic conductivity.

However, a few researchers, for example, found that infiltration and/or hydraulic conductivity was lower under NT than inversion tillage as NT increased bulk density (small porosity) whereas tillage increased porosity, particularly large pores (Tebrugge and During 1999). The use of crop residues in conservation agriculture protect the soil from raindrop impact reduce slaking of surface aggregates and prevent pore sealing and crust formation, residues left over the soil also slow the flow of surface runoff, thus increase the opportunity for water to infiltrate. The combination of these beneficial effects of residues can increase water infiltration. Hydraulic conductivity and infiltration can be improved and evaporation can be decreased by no-tillage and crop residue cover in conservation agriculture in general, this will, in turn, decrease runoff and soil erosion.

3.5 Improving soil stability and aggregation

Soil stability refers to the susceptibility of soil to change under natural or anthropogenic perturbations. Soil aggregate stability has been recognized as a relevant factor in the control of water erosion because erodibility of soils is directly related to aggregate stability. There is medium to high aggregate correlation between aggregate stability in water, aggregate size, and total organic carbon content (Castro Filho *et al*. 2002).

The favorable effect of conservation agriculture systems on soil aggregation has been reported in different soil types and climates. In contrast, conventional tillage promotes loss of soil organic matter, which leads to disruption of soil aggregates contributing to erosion. Conservation agriculture systems that leave more crop residues on the soil surface generally allow improvements in soil aggregation and aggregate stability

(Madari *et al.* 2005). Application of crop residue also results in erosion control because it protects surface aggregates against the effects of raindrops. Research on conservation agriculture showed that no till with stubble retained treatment had more water stable aggregation.

In summary, conservation agriculture characterized by no-tillage and crop residues retention is helpful for soil aggregating and the aggregate stability, thus, in turn, will help to control or reduce soil erosion.

3.6 Reducing soil and water erosion

Runoff and soil loss are problems common to most cropland in the world, especially those with unstable aggregates in the surface horizon both from the standpoint of sustainability and offsite environmental damage (Rhoton *et al*. 2002), so it has been, and continues to be, a very important research area.

Conservation agriculture, with crop residue mulch can provide soil cover to reduce rain impact and provide barriers against runoff, this will help to increase moisture infiltration and decrease soil detachment. Moreover, retaining crop residues on the soil surface lead to an increase of soil organic carbon which gives rise to improved soil aggregate stability and the return of biological diversity to the soil particularly, earthworms. It results in a increase in moisture infiltration too. Research on the Western Loess Plateau of China showed that under a wheat-pea rotation system, runoff was alleviated and runoff intensity was reduced with no-till with stubble retention, soil loss from erosion was reduced by62.4% (Zhao *et al.* 2007).

fig 3. Shows manual CA planting using Animal traction systems

4. Constraints to conservation agriculture adoption

Farmers in a country or region, where CA is not practiced, face a number of problems which make adoption difficult. These problems are of diverse nature, such as intellectual, social, biophysical and technical, financial, infrastructural and policy. Most farmers are facing , several of these problems, if not all, at the same time to the effect that only very few bold pioneer farmers adopt CA. Farmers are not in the position to start with a blank sheet and to weigh objectively the merits and disadvantages of CA against conventional tillage farming. In all cases CA is the new unknown concept, according to IVth World Congress on Conservation Agriculture, (2009) the default condition for more than 90% of the world's farmers is the conventional tillage-based practice which has worked for them so far.

4.1 Intellectual Constraints to Adoption

New technologies that lead to immediate fast adoption often show obvious advantages resulting in fast acceptance and enthusiasm. In many cases this enthusiasm cools down, once the new technology is known and the downsides become visible. With CA it is just the opposite way: it contradicts so much of the knowledge a farmer has learned and been told that the benefits offered by CA are not obvious in the beginning. However, once the step-wise adoption begins, CA improves its performance over time. The more experience producers have with CA, the more convinced and positive is their opinion about it. The less practical experience people have with CA, the more critical and negative is their attitude towards it. A study carried out with European and American no-till farmers and agricultural experts came to similar conclusions. It was found that the experts, mostly without practical experience in CA, anticipated many problems for its adoption. In their perception actually the problems exceeded the benefits leading to an overall negative attitude. Farmers, however, who were actually practicing CA and had experience with the system, had an overall positive perception with the benefits clearly dominating and the problems being manageable (Tebrugge and Bohrnsen 2000). CA has actually two intellectual barriers to overcome: the first is that CA concept and principals are counterintuitive and contradict the common tillage-based farming experience, which has worked for generations and which often has created cultural values and rural traditions; the second is the lack of experiential knowledge about CA and the mechanism to acquire it. Soil tillage, and particularly the plough, has in most countries become part of the culture of crop production. Ploughing, cultivation and tillage are often synonyms for growing a crop.

Cropland is called "arable" land which is Latin for "ploughable" land. The plough has been part of the very early developments of agriculture and has the character of a brand symbol for what is 'correct'. It is therefore difficult for people to accept that all of a sudden the plough is dangerous and that a crop can grow without tilling the land. Overcoming this "mental compaction" is often much more difficult than actually physically starting with no-till farming (Landers 2001). Unless a person has seen it happen, it is very difficult to imagine a soil becoming softer and better structured without being tilled. The second intellectual impediment to adoption is simply the lack of sufficient experiential knowledge about it at all and the means of acquiring it. Globally some 7% of the agricultural land is under CA. The adoption is concentrated in some few countries, eventually reaching adoption levels beyond 50%, while in the rest of the world the adoption is at levels below 2%. This explains that most people have never seen a CA system in practice. Since it is also not yet represented in any labels or certification schemes or has any direct relevance to consumers, CA hardly appears in the media. CA is also not included in university curricula even in good agricultural universities. This explains that, despite having an adoption level more than twice that of organic farming, the public knowledge about CA is much lower than about organic farming. Even most agricultural professionals and many farmers have never heard about CA, and if they have, they have only vague ideas. Permanent no-tillage farming and CA are often simply not known and therefore not on the screen as an option for farmers. For actual adoption of CA the farmer would not only need to know about CA elements in general, she/he would need to know the details on how to implement CA elements under the specific conditions of an individual farm. This knowledge is generally not available as a standard technology package off-the-shelf. Worse, CA is a complex and management intensive farming concept in which crop management has to be planned ahead and is mostly proactive and not reactive, as in the standard tillage-based systems. Problems of soil compaction or uneven surface in tillage-based systems are corrected with tillage, in no-till systems they have to be prevented from occurring from the start. Weed and pest management in conventional tillage systems is often based on chemical or mechanical control as response to the incidence, while in CA the incidence of weeds and other pests is reduced by forward planning of crop rotations. This increased complexity requires a degree of experience and knowledge, which has to be acquired and learned. For early adopters this learning process and experiential knowledge has therefore involved a lot of trial and error until sufficient local experience and knowledge is accumulated to make the adoption easier. However, the solutions to these practical problems are best developed by the farmers themselves and not by scientists. Usually farmer's own adaptive "research and development" process leads to quicker and more applicable results than the so called 'Green Revolution' approach of leaving the development of a standard technology package "ready for adoption" to the scientific community.

To effectively cope with the diverse agro-ecological and socio-economic conditions of farming environments when considering system level alternatives and changes, flexible approaches to on-farm testing and dissemination are required. This is particularly so when knowledge-intensive, integrated practices involving the simultaneous management of several elements are being introduced as is the case with CA, and the elements concerned cannot be reduced to standardized technology package intended for wide applicability (Stoop et al.2008). The same accounts for other complex and management intensive concepts, such as integrated pest management (IPM), which has been successfully introduced by FAO through a network of Farmer Field Schools (FFS) first in Asia. An den Berg and Jiggins (2007) and more recently in Africa. Another more recent example is the System of Rice Intensification (SRI) with similar levels of complexity and need for local adaptation paired with the problem of being counterintuitive (Stoop *et al*., 2008).

Thus, a relatively large variation in the implementation and performance of CA practices in farmers' fields is an obvious and logical consequence of this dissemination approach, partly also because the new balances and equilibria as well as full benefits that such practices are expected to offer take time to establish. Therefore, economic assessments and adoption studies based on aggregated results over relatively short periods of time will further contribute to biased and/or pre-mature, generalized conclusions with regards to production potentials, agronomic feasibility and future prospects.

4.2 Social Constraints to Adoption

Farming communities in the developing regions are mostly conservative and risk averse. Any farmer doing something fundamentally different from the others will therefore risk being excluded from the community. Only very strong and individually minded characters would take that step, which leads to social isolation and sometimes even to mocking. Even if those individuals have visible success, the aversion created in the community and the peer pressure can result in other farmers not following. The pressure can be so bad that the community gets jealous of the success and instead of also adopting it, it leads to boycott including using 'black magic' and placing bad spells on the fields. For adoption of CA it is therefore not enough to find any progressive farmer who will prove the concept to work, but the farmer must have a socially important role, and be respected and integrated in the community. Ideally the community should be involved from the very beginning to avoid this kind of antagonism. Other problems can be traditional land tenure systems, where there is no individual ownership of land, which lowers the incentives of farmers to invest in the long term improvement of soil health and productivity. Also communal grazing rights, which often include the right to graze on crop residues or cover crops after the harvest of the main crop, create conflicts which make it difficult for the uptake of CA practices. These problems can be real impediments to the adoption of CA and conflicts arising, for example, from alternative uses of crop residues as mulch or animal feed cannot be solved by orders or directives. Even physical protective structures such as fences might not be the optimal solution, if they work against the traditional social values of the respective cultures. Much more important in the process is that the entire community first understands the issues and the changes and benefits involved in adopting CA and jointly looks for solutions.

4.3 Input Constraints

Access to equipment, seeds, fertilizers, and herbicides is a significant constraint to scaling up CA in Africa. CA does not necessarily require more equipment than conventional agriculture, but some of the equipment is different and is not always available. The most significant differences tend to be in land preparation and seeding. In silty or clayey soils, the soil surface is penetrated only in precisely targeted lines or pits that will be seeded. Seeds are then deposited into these areas or inserted directly into the ground through the mulch or ground cover layer. Some conventional agriculture tools can also be used for CA (e.g., certain weeding tools), while other can be modified for CA (e.g., hand hoes can be made narrower to dig CA planting basins or rows). For non-mechanized CA involving simple hand tools, equipment costs are relatively low (if the requisite equipment is available at all). Costs increase significantly when using animal- or tractor-powered implements (IIRR, 2005).

Limited access to (or affordability of) inorganic fertilizers, pesticides, and herbicides may also represent a constraint to practicing CA in a maximally productive manner. However, one of the chief advantages of CA is that it can increase yields in contexts where agrochemicals are not available or not affordable, by fostering biological processes and management practices that enhance soil fertility, pest control, and weed control. Nitrogen-fixing plants are an integral part of most CA systems, and can include shrubs, annual herbaceous plants, or trees such as Faidherbia albida. Intercropping with these species improves yields, soil health, and soil chemical and biological properties while reducing weed and pest problems. Despite these benefits, however, spontaneous adoption of cover crops for soil fertility enhancement alone is uncommon; rather, the plants must offer some direct benefit, such as human food or animal fodder (Baudron *et al*., 2009).

4.4 Biophysical and Technical Constraints to Adoption

Although the concept of CA is universally applicable, this does not mean that the techniques and practices for every condition are readily available. In most cases the actual CA practice has to be developed locally, depending on the specific farming situation and agro-ecological conditions. Especially the crop rotations, selections of cover crops, issues of integration of crop and livestock have to be discovered and decided upon by the farmers in each location. A diversity of problems arises, very often around weed management, residue management, equipment handling and settings, planting parameters like timing and depth, which all have to be discovered new. This creates the problem that extension agents and advisors in the beginning, when CA is newly introduced in a region, cannot give specific advice on practices, but have to develop these practices together with the farmers. On the other side such an approach, if correctly applied, is much quicker and more sustainable than the development of specific practices by scientists, since it uses the immense pool of experience and innovation potential of the farmers' community. In this way some cover crops have been developed from weeds, or practices such as growing paddy rice or potatoes under no-till in CA have been developed by farmers without the scientists even thinking of proposing such innovations.

CA with higher levels of fertilizer than conventional maize production has the potential to raise yields, but cash constraints are a barrier to widespread fertilizer use (regardless of tillage method). Most farmers in Mozambique grow maize without fertilizer (Bias & Donovan, 2003). The benefits from fertilizer use depend on soil conditions. Fertilizer use in Africa is generally low because of both demand side and supply side factors. Demand is often weak because of "the low -levels and high variability of crop yields on the one hand and the high level of fertilizer prices relative to crop prices on the other." (Morris *et al*. 2007).

Another technical constraint is the simple unavailability of certain technologies or inputs, apart from the financial or other constraints. In many countries where farmers start with CA there are no seeds available for cover crops. Also the availability of equipment, especially notill direct seeding equipment, often is a problem. By now there are technologies available for most situations, somewhere in the world. However, in a specific location farmers might not be aware of these technologies or they simply have no way to access them. This is where usually external support such as knowledge sharing or eventually even the introduction of specific technologies, such as direct seeding equipment, is required.

4.5 Financial Constraints to Adoption

Although the profitability of CA is usually higher than for conventional farming practice there are still financial hurdles to adoption, depending of the availability of capital to invest into this change of production system. These constraints exist at all farm size levels, though obviously to different degrees and for different purposes. Changing a production system to CA is a long term investment. In many cases the rationale for the change is the degradation of the natural resources, especially of soil and water, as a result of the previous tillage-based agriculture. In order to start with CA and to successfully create favorable conditions for the soil life and health to return, some initial investment into the land might be necessary, such as breaking existing compactions by ripping, correction of soil pH or extreme nutrient deficiencies, leveling and shaping of the soil surface for the cropping system foreseen under CA. Especially for small subsistence farmers the capital for this kind of investment is not available. In addition to this, the farmer needs new equipment, while most of the existing equipment is becoming obsolete and will most likely not find an attractive second hand market for.. The larger the farmer, the more important is this hurdle, since a no-till seed drill for example is considerably more expensive than a conventional one. This conflict between the potential improved profit margin on one side and the very concrete and actual investment requirements on the other side often leads to the fact that farmers decide not to change to CA, even though they are convinced about the benefits.

CA is generally more profitable in the long-term than conventional farming. However, achieving these long-term benefits may require initial investment, which is often prohibitively expensive or risky for small farmers to undertake on their own. Vulnerable farmers are especially risk averse due to household food security concerns, and there is little room for error. In addition, while many farmers reap benefits in the first year of practicing CA, others do not realize increased yields or profitability for 3-7 years (Hobbs, 2007). During this time, farmers sometimes choose to abandon CA; thus, long-term adoption is more likely when CA provides significant benefits in the first or second year Such immediate benefit is more likely when CA is promoted in conjunction with good agronomic practices, improved seeds, and sometimes inorganic fertilizers.

The provision of credit facilities for these cases is one solution, but sometimes also the availability of contractor services or technical advice on how to adapt and modify existing equipment as a low cost intermediate solution to start can help. The modification of existing equipment has, for example in Brazil and in Kazakhstan, provided an entry point for some farmers to start with CA and then, after benefiting from the higher profitability, making the investment into proper equipment at a later stage. Especially for small farmers the home made solutions for simple CA farm tools are an important element for CA adoption in Paraguay (Lange and Meza, 2004).

4.6 Infrastructural Constraints to Adoption

As with any agricultural production system, CA also requires certain exogenous inputs to achieve intensive production levels. CA is capable of improving the soil and crop growth conditions for production and the efficiency of the natural resource and input use, but it is not a 'perpetual motion' process which would allow crop intensification from endogenous resources. If CA is therefore meant to sustainably intensify agricultural production, a suitable market and service infrastructure must be in place to provide inputs and to allow the processing and marketing of the produce. Without any external inputs, CA systems will still perform better than conventional tillage-based methods, but this will be at a much reduced level. Some of the inputs like the types of fertilizers will differ only marginally from the requirements of conventional tillage-based farming. Other inputs, however, such as herbicides, seeds for cover- and rotational crops and especially equipment for direct seeding, planting and residue management are often completely different to the traditionally used ones and have to be introduced to the markets. This requires not only a good input supply infrastructure, but also a proactive attitude of the supply sector, such as dealers and manufacturers. Otherwise a chicken-and-egg situation is created where the supply sector does not offer certain inputs because there is no market for them, but the farmers are also not demanding the items because they are not being offered. This deadlock often requires some external intervention mostly in stimulating the demand, but also in assisting the supply sector in making inputs commercially available. This includes, besides the collaboration with the farming sector, a close collaboration with the commercial input supply sector and some supportive policies.

4.7 Policy Constraints to Adoption

Adoption of CA can take place spontaneously, but it usually takes a very long time until it reaches significant levels. Adequate policies can shorten the adoption process considerably, mainly by removing the constraints mentioned previously. This can be through information and training campaigns, suitable legislations and regulatory frameworks, research and development, incentive and credit program. 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 program for sustainable agriculture. If those countries, with in the same Ministry of Agriculture, have then also a program to modernize and mechanize agriculture, it usually happens that the first items introduced under such a mechanization program 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. Even in countries where many farmers are practicing CA, there is often little awareness of CA among policy makers, and in some cases existing policies work against CA (Thiombiano & Meshack, 2009).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.

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

Summary and conclusion

Despite the obvious productivity, economic, environmental and social advantages and Benefits of CA, adoption does not happen spontaneously. There are good reasons for individual farmers not to adopt CA in her/his specific farm situation. The origin of the hurdles ranges from intellectual, social, financial, biophysical and technical, infrastructural to policy issues. Knowing the respective bottlenecks and problems allows developing strategies to overcome them. Crisis and emergency situations, which seem to become more frequent under a climate change scenario, and the political pressures for more sustainable use of natural resources and protection of the environment on the one hand and for improving and eventually reaching food security on the other provide opportunities to harness these pressures for supporting the adoption and spread of CA and for helping to overcome the existing hurdles to adoption. In this way, the increasing challenges faced around the world, from the recent sudden global crisis caused by soaring food prices, high energy and input costs, increasing environmental concerns to issues of climate change facilitate the justification for policy makers to introduce supportive policies and institutional services, even including direct payments to farmers for environmental services from agricultural land use, which could be linked to the introduction of sustainable farming methods such as CA. In this way the actual global challenges are providing at the same time opportunities to accelerate the adoption process of CA and to shorten the initial slow uptake phase. Conservation agriculture could decrease soil detachment and increase water infiltration that implies a decrease of water runoff; consequently, soil erosion would be reduced. Effects of conservation agriculture on reducing erosion were mainly caused by crop residues retained on the soil surface.

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