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Key Lessons from International Experiences about Conservation Agriculture and Considerations for its Implementation in Dry Areas

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Abstract

Land scarcity and soil degradation in dry areas are increasingly recognized and being documented. Their impact on the livelihood of people and the resilience of ecosystems is a source of growing concern. Alternative land management practices and strategies are needed to mitigate/reverse current negative trends. Conservation agriculture (CA) may contribute to this goal. Indeed, CA emerged historically in response to soil erosion crises and their negative economic consequences.

The adaptation of CA in diverse situations, including small-scale farming, of rainfed and irrigated agriculture has given way to developing various CA systems spanning a wide array of practices ranging from reduced tillage (RT) to no-tillage (NT) with varying degrees and means of soil cover.

CA is perceived as a powerful tool of land management in dry areas. It allows farmers to improve their productivity and profitability especially in dry years while conserving and even improving the natural resource base and the environment. However, CA adaptation in drylands faces critical challenges linked to water scarcity and drought hazard, low biomass production and acute competition between conflicting uses including soil cover, animal fodder, cooking/heating fuel, raw material for habitat etc. Poverty and vulnerability of many smallholders that rely more on livestock than on green production are other key factors.

This paper builds on selected lessons from a wealth of international experiences with the development, fine-tuning and dissemination of CA-based systems, their known drivers, constraints and impacts, to address the potential and challenges of CA in dry areas. It suggests ways and means that may help in designing and shaping alternative programs, tools and strategies aimed at sustainable land management in dry areas.

Key words: Conservation agriculture, biomass, soil cover, dry areas, land management, innovation systems, livelihood, crop-livestock competition, sustainability, production costs, soil erosion, adoption.

1. Introduction

The current concept of Conservation Agriculture (CA) has been mainly shaped in the subtropical Brazilian large-scale market oriented farming conditions. While different authors have proposed different definitions, a definition largely used is that proposed by FAO(1) :

"CA is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. CA is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes".

From this definition, one can infer that conservation agriculture is not an actual technology; rather, it refers to a wide array of specific technologies that are based on applying one or more of what are widely regarded as the three main conservation agriculture "principles" (IIRR and ACT, 2005):

- Reduce the soil tillage, or suppress it altogether;
- Cover the soil surface adequately—if possible completely and continuously throughout the year;
- Diversify crop rotations.

In the international literature, terms such as conservation tillage (CT), zero-tillage (ZT), direct drilling (DD), direct sowing/seeding (DS), and Resource Conserving Technologies (RCTs) are also common, and usually refer to technologies or technology packages that may constitute specific subtypes of CA systems or intermediate systems. One can mention that CA frontiers with other technologies such as agroforestry, or soil and water conservation practices (SWC) such as terraces, zaï, half moon and other water harvesting practices are still not precise.

Whatever the label actually used, there is growing evidence of large-scale adoption of CA systems worldwide (Derpsch, 2005). However, the type of actual CA practices used in diverse agro-ecological and socio-economic environments is highly variable, and frequently departs from the simultaneous and rigorous local application of the three generic CA principles. (Erenstein, 2003; Harrington and Erenstein, 2005; Lahmar et al., 2007b). Only in limited areas are such principles applied simultaneously and consistently over time: such cases that one may call 'full conservation agriculture' are common, yet not systematic, in southern Brazil (do Prado, 2004; Bolliger et al. 2006) and a few other Latin American countries (Scopel et al. 2004; Ribeiro et al. 2007).

Historically, CA practices and systems emerged as a response to soil erosion and profitability crises in USA, Brazil, Argentina and Australia (Coughenour, 2000; Scopel et al., 2004)(2) . Their development was allowed by the discovery and availability of herbicides, which for the first time gave farmers a practical and economic option to control weeds other than by agronomic and mechanical means. The transition from conventional plough-based agriculture to conservation agriculture was neither fast nor without hurdles: in most places, it took several decades of hard work and trial-and-error by a variety of actors(3) to get to the point where CA systems were profitable and adapted to the specific local conditions that each user had to face.

Today, CA in its many forms covers about 100 million ha worldwide (Derpsch, 2005), versus 60 million in 2000 (Derpsch, 2001). This swift increase in acreage touches continents and countries very differently: CA occupies a large share of areas devoted to annual crops in the USA, Australia, Brazil and Argentina, but remains marginal in Europe (de Tourdonnet et al., 2007) and in Africa

(1) FAO conservation agriculture website: *http://www.fao.org/ag/ca/index.html*
(2) This paper does not with traditional/indigenous CA systems such as the Slash-and-Mulch systems practiced by smallholders throughout tropical America, even though they offer many interesting insights and lessons: see for example Thurston, 1997 or Triomphe and Sain, 2004.
(3) farmers-innovators, extension agents, researchers and input manufacturers were among the key ones.

(Harrington and Erenstein, 2005). In Asia, a swift increase of CA surfaces is occurring in the Indo-Gangetic plains (Gupta et al., 2007). In China and Central Asia, current CA acreage is expected to increase rapidly due to the growing interest in CA, existing favorable institutional and policy conditions, the involvement of machinery manufactures and national and international research institutions (Harrington and Erenstein, 2005). In most cases, farmers who have adopted CA until now are motorized and practice large-scale commercial, high-input, market-oriented agriculture on hundreds or even thousands of hectares. They usually have access to strong support services, including research, extension, input supply and credit. Furthermore, much of the adoption has occurred under favorable agroclimatic conditions: deep soils, humid or sub-humid climates in particular. Conversely, adoption of CA by smallholders in unfavorable areas has been the exception. Such differential adoption rates raise a number of questions, be it relative to the universal validity of the CA principles, or relative to the factors and conditions involved in the adaptation and adoption process.

The objective of this paper is to identify the potential benefits and challenges related to the application of CA experiences for the dry areas of the Arab region. It will also address a number of questions by drawing on recent international experiences with CA in diverse environments.

As for the main sources used for this paper, there is increasing evidence available worldwide about the many past and on-going experiences with CA, as reported for example during the first three World Congresses on Conservation Agriculture, held respectively in Madrid-Spain in 2001 (Garcia-Torres et al., 2001), in Foz de Iguassu-Brazil in 2003, and in Nairobi- Kenya in 2005. Yet little of this evidence has been systematized, and hence it is difficult to draw synthetic lessons. Also, the latest results of many on-going experiences have not been reported to the worldwide CA community[(4)].

Fortunately, the results of the EU-sponsored KASSA project (Knowledge Assessment and Sharing on Sustainable Agriculture[(5)]) are now available: it had the specific objective of synthesizing the validated scientific knowledge generated on CA in a number of regions: Northern and Eastern Europe, the Mediterranean, Latin America and Asia (Lahmar et al., 2007a). Other key sources for this paper are the results of a series of case studies conducted within the framework of collaboration between FAO and CIRAD (Triomphe et al., 2007a; Boahen et al., 2007, Baudron et al., 2007, Nyende et al., 2007; Kaumbutho and Kienzle, 2007, Shetto and Owenya, 2007). In addition, a number of reviews and syntheses about CA have also become recently available, such as West and Post (2002), do Prado (2004), Scopel et al. (2004), IIRR (2005), ACT (2005), and Bolliger et al. (2006). Finally, first-hand knowledge and contacts with many on-going CA projects were also extensively used to complete the picture whenever necessary.

2. Productivity and profitability of CA

CA is widely heralded for its effect on crop productivity. Yet they are far from uniform.

In Latin America, crop yield increases at the farm level when comparing NT systems to conventional plough-based systems were extensively reported (Ribeiro et al., 2007a). Conversely, in Northern Europe and the Mediterranean, CA does not appear to drastically change yields (de Tourdonnet et al., 2007a, Arrúe et al., 2007a). On average, yields in Northern Europe on poor and medium fertile soils do not change (+/- 10%) under CA; they actually decrease slightly on very fertile soils with a high intensive level of production. In the Mediterranean countries, most of the

(4) There have been many regional and national workshops and publications on CA over the world. As example three Mediterranean workshops on no-till took place respectively in Morocco in 2001, in Tunisia in 2004 and in Spain in 2006. See also Conservation agriculture status and prospects. Abrol, I.P. et al. eds, 2005.

(5) KASSA results are publicly available at http://kassa.cirad.fr/

studies carried out in Spain and in Morocco concluded that yields are generally 10-15% higher under no-tillage, especially in dry years. Similar observations have been reported in Latin America (Ribeiro et al., 2007b): yield effect tends to be stronger during relatively dry years, while productivity among contrasting management systems remains similar under normal climatic conditions. This makes CA a more interesting option in dry areas where drought is a continual hazard. The effect of CA practices on productivity is not uniform however, as different annual grain crops respond differently to different soil / tillage systems: the crop rotation increases and stabilizes yield more than continuous cropping.

In terms of profitability, large-scale farmers in Latin America and Europe gain significantly from using CA, due mostly to lower mechanization / motorization costs, including reduction in labor, fuel, lubricants, and maintenance and depreciation costs of agricultural machinery. A tractor lasts three to four years longer in NT systems than when used for hard tasks such as ploughing in conventional cropping systems. Savings allow increasing crop area and more efficient use of machinery and labor force. Small-farmers who depend on use or access to a tractor also benefit directly or indirectly from reduced machinery costs, and also from more autonomy from hired machinery entrepreneurs (Scopel et al., 2005). In Asia, savings ranging from US$ 70 to 140 per hectare accrue from a combination of less needs for irrigation (from 15-20% or even more under bed planting), and increased yields of 200-500 kg/ha.

While cost reductions are most common with the use of CA, savings may be offset by additional costs incurred for chemical weed and pest control. It is reasonably arguable that the rise of the cost of pesticides and/or heavy infestations of weeds, pests and diseases may affect farmers' decision with respect to the use of CA.

In small-scale farming throughout Latin America and Africa, CA reduces drudgery, especially for farmers depending on animal draught or human labor. Reduction in total labor use ranges from 11% to 46% depending on the crops grown. Reduction in labor peaks throughout the agricultural year is also an important aspect. Labor reduction allows farmers to increase their cultivated area or to undertake other activities generating additional incomes, or even to provide help for their neighbors, which is also socially relevant (Ribeiro et al., 2007b).

The short term socio-economic benefits that CA provides through the reduction of costs of production, the need to improve farms' competitiveness, the current trend of increase of the farm size, market globalization and the steady increase of fuel cost are seen likely sufficient to boost CA systems within Europe and possibly overcome farmers and societal reluctance due to socio-cultural barriers or environmental considerations. In many European regions the shift from conventional agriculture to CA is likely already ongoing (Lahmar et al., 2006).

Long-term socio-economic benefits are supposed to come about with the improvement of soil physical, chemical, and biological properties and soil fertility (Gupta et al., 2007a-b) which may also increase the profitability and attractiveness of CA. However, a recent study (Deen et al., 2006) showed that a change in yields occurs in the early years of NT adoption; the length of time under NT had a minimal impact on crop yield response to the NT system.

Taken together, these results show clearly that RT and especially NT greatly cut production costs in basically all types of agroecosystems. The increased global and regional competition will certainly urge more farmers to seek a reduction of their production costs and an increase of their productivity and profitability. CA has proven to be an effective means to achieve these goals. However, the magnitude of the increased profitability depends on many factors including soil, crop, rotation, machinery, cropping and farming systems, etc. Unfortunately, reliable long-term data related to input costs, and to socio-economic aspects of CA, remain scarce and do not allow drawing a comprehensive picture and a realistic comparison among countries, cropping systems, and farming conditions (Lahmar et al., 2006).

3. Potential of CA for soil and water conservation in dry areas

Changes induced by CA practices in soil properties related to soil water, fertility and erosion, and the erosion processes as affected by CA practices have been researched in many dry areas. Most of the studies were conducted at research stations, on a limited number of soil types and only few studies refer to long-term experiments or to on-farm designs. Number of properties have been investigated (soil structure and porosity; aggregates stability; soil infiltration and hydraulic conductivity; soil compaction; earthworm population; soil organic matter (SOM) and carbon (SOC)) but the studies rarely addressed all the properties simultaneously. This makes it difficult to understand the functioning of CA systems and to build a comprehensive knowledge base regarding the long-term impact of CA systems on soil and water in dryland agroecosystems. In this section we will focus mainly on research results obtained in the Mediterranean drylands (Arrúe et al., 2007b).

3.1. Soil physics and related water properties

Soil structure and porosity change when soil management shifts from tillage to RT or NT and soil cover. However, the magnitude and the significance of the changes seem to vary depending on soil texture, the climate, and the CA practice, i.e., RT or NT and the soil cover management. In many situations CA practices led to compaction of the topsoil (Gómez et al., 1999; Hernanz et al., 2002) and a decrease of soil porosity (Lampurlanés and Cantero-Martínez, 2006). As consequence, the hydraulic conductivity decreases (Lampurlanés and Cantero-Martínez, 2006; Moret and Arrúe, 2007). The negative effect of NT on infiltration can be counteracted by the presence of residues on the soil surface, resulting in lower evapotranspiration and greater water storage in the upper soil layer (Josa and Hereter, 2005; Lampurlanés and Cantero-Martínez, 2006), or by the increase in the population of earthworms, resulting in a greater number of vertical paths created by continuous worm burrows that maintain or increase hydraulic conductivity (Moreno et al., 1997). However, in the Mediterranean context, soil moisture as influenced by climatic conditions of the year is a determinant factor for the number of the earthworms during and between years (Ojeda et al., 1997).

3.2. Soil organic matter and aggregate stability

Changes in SOM and SOC under CA are intensively reported in the international literature. SOC generally increases, and the increase rate depends on the CA practices and the crop rotations (West and Post, 2002).

NT systems always accumulate more organic matter on the soil surface than RT systems. One particular feature of CA is that SOC accumulates near the surface of the topsoil which leads to a vertical stratification of the carbon (Hernanz et al., 2002; Moreno et al., 2006; Mrabet, 2002; Álvaro-Fuentes et al., 2007). This distribution of SOM and SOC improves the biological activity, enhances the physical properties of the topsoil, and reduces erosion risk.

Soil surface crusting is very common in dry areas. It plays a key role in runoff and erosion. Low aggregate stability favours soil surface sealing and erosion (Lahmar and Ruellan, 2007). CA practices seem to improve aggregate stability (Mrabet et al., 2001): the improvement is higher in NT systems compared to RT systems (Hernanz et al., 2002). The increase of aggregate stability is correlated to the increase of SOC (Hernanz et al., 2002). Nevertheless, soil sealing is a complex process involving many factors and in regions where crusting is a significant problem, soil cover plays a key role in preventing crust formation (Usón and Poch, 2000).

3.3. Erosion mitigation

Research focused on both water and wind erosion. Water erosion has been studied in annual crops in Spain (De Alba et al., 2001) and in perennial crops in Spain, Italy and Greece (olive orchards) (Gómez et al., 1999, 2005). Wind erosion has been studied in semiarid Spanish cereal/fallow lands (López et al., 2001; López and Arrúe, 2005). In Andalusia several studies focused on the development of simulation models and expert systems to predict the effect of tillage systems on water erosion under different climatic conditions and to design site-specific agricultural implements (Simota et al., 2005; De la Rosa et al., 2005). As results, in dryland olive crops, reduced tillage and soil cover seem to be effective in reducing water erosion (De la Rosa et al., 2005). In cereal/fallow lands, reduced tillage, with chiselling as primary tillage, could be a viable alternative to mouldboard ploughing for wind erosion control (López et al., 1998, 2000).

From these results, it is very clear that the combination of soil cover and NT or RT plays a key role in controlling water runoff. However, it is not yet clear to what extent CA systems can mitigate soil erosion under the aggressive Mediterranean climate. Empirical observations and actual measurements of the drastic reduction of soil erosion by NT practices in Brazil led to the general thought that NT systems by themselves were strong enough to control erosion. Consequently, farmers neglected complementary conservation practices and eliminated terracing systems. Recent results showed that the protection of soil surface by crop residues in NT systems is not always followed by a reduction of runoff. In addition to leaching of nutrients and pesticides, sheet and rill erosion developed even on sites where NT systems have been used for along time. A new conservation technique, called "vertical mulching" (Denardin et al., 2005) is being developed in southern Brazil in NT systems. The combination of NT, terraces and tree plantations in northern Catalonia-Spain seem to be the best way to preserve soil, water and the landscapes.

4. Development, adaptation and dissemination of CA

As already highlighted, the shift to CA practices has historically largely been driven by economic considerations such as decreasing production costs, and especially the cost savings associated with the reduced use of machinery. This has been the case in Europe, in the U.S., and recently in the Indo-Gangetic Plains (Soane and Ball, 1998; Coughenour, 2000; Gupta et al., 2007b). Other factors which also relate broadly with economic factors include decreasing work load especially during seasonal peaks. To a large extent, ecological crises are a driver for CA adoption. Examples are the extreme erosion affecting Southern Brazil, and the complex agro-environmental sustainability crisis affecting the dominant intensive rice-wheat irrigated cropping systems of the Indo-Gangetic Plains. These were perceived and acted upon mostly because of their direct economic consequences in terms of the threat they posed to farmers' livelihoods, even though of late, environmental concerns and the perceived role of CA in achieving a more harmonious relationship with nature have become more prominent.

But the road to CA adoption is not straightforward. In many places, unforeseen technical problems drove many initial adopters back to conventional farming. This has, for example, been the case in Europe and the Mediterranean because of problems with weeds, pests, and crop residue management (Rasmussen, 1999; Arrúe et al., 2007b), or to excessive topsoil compaction (Munkholm et al., 2003). Lack of knowledge and technical advice (or access to them) has also discouraged farmers from adopting CA in many cases. Changes in economic circumstances have also had a large influence on adoption. In France, for example, the attractiveness of CA to farmers has been highly dependent on the types and amounts of subsidies in place under the Common Agricultural Policy which have fluctuated over time. In the Indo-Gangetic Plains, the retention of soil cover is still difficult because of the demand for crop residue for cooking fuel and animal feed is high in the region and many farmers are use to burning rice residue in the field to enable timely sowing a wheat crop. More generally, the use of a cover crop and diversified crop rotations is still hardly practiced in many places due to climate and soil limitations, lack of adapted cover crop varieties, difficult management of crop residue in wet and dry conditions, competition for crop residue, and general market conditions. In turn, the difficulty of introducing cover crops means that farmers are often left to opt for chemical control under CA as the only alternative to ploughing if they do not have the labor resources necessary to control aggressive weed growth. This is especially true in manual agriculture in Africa (Boahen, 2007; Baudron et al., 2007).

Such difficulties may explain why some farmers around the world return partly or entirely to ploughing after years of practicing CA, even though they perceive the effectiveness of CA practices in increasing soil organic matter, enhancing earthworm activity, reducing soil erosion, and improving water infiltration and productivity under dry conditions. In the absence of systematic, unbiased monitoring of actual CA practices, and notwithstanding available estimates, the true current extent and type of CA adoption remain unclear. It seems, however, that RT is more common than NT in many places, and that areas listed as NT may correspond to fields managed in NT only for a part of the rotation, whereas the other crops of the rotation are managed using RT or ploughing. Such is, for example, the case of CA adoption in the Indo-Gangetic Plains (Gupta et al., 2007a), or in many areas across Europe (de Tourdonnet et al., 2007). Said differently, diverse tillage practices may follow one another in time and may coexist within the same farmland, as illustrated by the situation of small farmers in Southern Brazil, who while claiming to practice NT, resort periodically to tillage to handle difficult situations with respect to weed infestations, soil compaction or simply to incorporate lime (Ribeiro et al., 2005, Bolliger et al., 2006, Triomphe et al., 2007b).

5. Drivers and constraints for CA adoption

Process-wise, adoption seems to depend a lot on who is involved in the adaptation and dissemination process, and especially the role played by farmers and their organizations in leading multiple stakeholder consortia. Southern Brazil is well known for the fact that large-scale farmers and their associations have been at the forefront of CA adaptation and diffusion (through farmers' groups such as the Clubes da Minhoca, or Earthworms clubs) since the 1970s, taking advantage initially of experiences and NT equipment imported from the U.S. in the 1970s (Ekboir, 2003). The adoption process was catalyzed by a close interaction and collaboration among a number of stakeholders, including farmers, input and equipment manufacturers, local governments, and to a lesser degree, research and extension services. Many of the same dynamics are true for the large-scale farmers of Argentina, under the leadership of AAPRESID(6), a farmer-led society. In their case, CA adoption was strongly facilitated by the seemingly perfect fit between CA and the introduction of genetically-modified crops highly suited to management under NT, such as the "Round-up ready" soybean varieties.

Similar dynamics are at play at a more modest scale in the CA adoption processes observed elsewhere. In the Indo Gangetic Plains (Gupta et al., 2007), researchers and their partners developed and

(6) AAPRESID: Asociación Argentina de Productores en Siembra Directa. http://www.aapresid.org.ar/

disseminated in a participatory manner a wide basket of Resources Conserving Technologies[7] (RTCs), as a result of the emergence and consolidation over 2 decades of continuous efforts of an effective and dynamic innovation system assembling efforts of public and private sectors, national and international research institutions, extension services and innovative farmers. In France, farmers, initially discouraged by the lack of interest of formal research, created their own associations, such as BASE[8] and FNACS[9] to exchange, develop and promote CA practices suited to their conditions (Triomphe et al., 2007b). Today, many more stakeholders and formal institutions have joined the on-going efforts, including research. Spain is the country with the longest experience with CA around the Mediterranean. The true development of CA practices began in earnest in the 1980s with the involvement of technical advisers from agricultural services, farmers' cooperatives and multinational and national companies and scientists, many years after the initial efforts to introduce CA were made. Nowadays, across Spain there are many research groups on CA organized within the Spanish conservation tillage research network, collaborating with many farmers' societies and consortia and developing basic and applied research linked to farmers' concerns including long-term experiments to develop and assess CA-based systems. It is worth mentioning that the first world congress on CA took place in Madrid in 2001 (García-Torres et al., 2001) and the third Mediterranean meeting on no-tillage took place in Zaragoza in 2006 (Arrúe and Cantero-Martínez, 2006). In Italy, no-tillage trials started in 1968, but CA expansion began only in the 1990s. It was driven by the need to reduce cropping costs and the availability on the Italian market of sowing equipment and adequate herbicides (De Vita et al., 2006). In Tunisia adoption has increased markedly, as a result of collaboration between mostly educated large-scale farmers, a Tunisian high education and research school, the Tunisian Technical Center for Cereals (CTC), equipment manufacturers and providers under the auspices of an externally-funded project (Ben-Salem et al., 2006). Conversely, in Morocco, despite more than 20 years of successful CA research (Mrabet, 2007), farmers' adoption of CA practices remains still incipient, most probably due to the fact that the CA agenda has for the most part remained a research agenda, with no or weak linkages with farmers and other stakeholders.

While large-scale farmers, easily able to take risks in investing resources and to enroll allies, have adopted CA relatively swiftly to the point where conventional farming has almost disappeared. Adoption by small-scale farmers has been a much more tedious and delayed process. When it occurred, it was the result of systematic, well-funded, wide-ranging public efforts aiming at CA development. Such has been the case in Southern Brazil, within the context of the well-funded micro-watershed projects implemented in Paraña and Santa Catarina States (do Prado, 2004; Bolliger et al., 2006). Research has been pivotal in the development of animal-drawn and manual CA equipment (Ribeiro et al., 2007a), a condition which was also key in the Andean valleys of Bolivia (Wall et al., 2003), and has recently been observed throughout Eastern and Southern Africa (Shetto and Owenya, 2007; Baudron et al., 2007). Developing or making CA equipment available to farmers is indeed critical, as availability of jab planters, NT drills, herbicide sprayers and "knife-rollers" induce huge reductions in labor requirements and drudgery, constituting major driving forces for CA adoption by small-scale farmers, despite the constraints such farmers face with weed control.

Overall, the dynamics of CA adaptation and adoption varies from country to country and from region to region within a country; as well as with time, depending on the specific circumstances farmers face. Table 1 offers a list of some of the key factors acting as drivers to CA adoption both

(7) Resource-Conserving technologies constitute a diverse set of practices including zero and reduced tillage, surface seeding, bed planting, real time N management using leaf colour chart, residue management, paired row planting, single deep placement of fertilizers, laser levelling, controlled traffic. They can be applied simultaneously, but also as single components, or as part of a step-wise adoption process.

(8) BASE Bretagne Agriculture Sol et Environnement.

(9) FNACS Fondation Nationale pour une Agriculture de Conservation des Sols.

at the farm and regional levels. Most of these factors are reversible: drivers can become constraints and vice versa. While not all factors are necessary for CA adoption to take place, Table 1 makes it clear that CA does not have the same probability of being a suitable option in all agroecosystems and socioeconomic contexts.

Indeed, the development of CA systems and their socio-economic and ecological sustainability are highly site specific. The fine tuning of CA systems requires a continuous adjustment which calls for permanent knowledge generation and sharing among the stakeholders. The success in the shifting process requires: (i)- substantial research efforts on CA systems to generate knowledge needed to develop, adapt, and improve site specific attractive CA technologies and options, and to assess/anticipate their long-term impacts; (ii)- creating favorable conditions allowing a significant involvement of leader farmers and farmers organizations, private companies and extension services in the shifting process and the improvement of their knowledge and management skills; (iii)-a favorable institutional and policy environment allowing all the stakeholders to interact within an effective innovation system able to generate, improve and disseminate knowledge (Lahmar et al., 2007b).

6. Drivers and constraints for CA development in Arab region dry areas

In dryland areas of the Arab region[10], CA development faces specific challenges. Evidence abounds in the semi-arid Mediterranean about the ability of CA to improve water productivity and soil protection against degradation and erosion. However, there are many obstacles that prevent farmers from applying CA. They include water scarcity, unreliable precipitation, and drought that result in low biomass production. The acute competition that omnipresent livestock provide for available biomass, not to mention the high incidence of poverty among rural smallholders that exposes farmers, mainly smallholders, to risks of crop and livestock failures during the transition period is a further constraint. Hence, it is important to ponder what might make CA a viable option for this region.

Almost the whole Arab region territory is arid. Furthermore, the per capita arable land is among the lowest of the world (0.19 ha/person) (FAO, 2006a) and it will decline even further given the steady increase of the population. Livestock is ubiquitous; it is considered as a major economic activity in the Mediterranean cereal zones (Cantero-Martinez and Gabiña, 2004). The Arab region is suffering from a number of interrelated problems including poverty and undernourishment (FAO, 2006b), extensive soil degradation caused partly by agricultural land mismanagement (overgrazing, excessive/non-adapted soil tillage, bad management of irrigation and drainage) (Lahmar and Ruellan, 2007), and significant loss of agricultural land due to the expansion of urban areas (ACSAD, CARME and UNEP, 2004). These problems must also be considered in context of a growing population that is expected to double from its current 315 million by 2050 (FAO, 2006b). Consequently, the livelihoods of rural people and ecosystems' resilience are under growing threat in the region as a whole. This assessment is far from new. Indeed, the debate on the impact of ploughing on land degradation began in the 1950s. Several attempts were made to mitigate this situation, such as introduction of the Australian-born ley farming, and the early introduction of a series of mechanical measures to control soil erosion. However, neither of these interventions was very successful (Chatterton and Chatterton, 1996, Roose and de Noni, 1998; Lavee et al., 2004).

Hence the need for alternatives agricultural practices to sustain Mediterranean dry areas farming systems is increasingly evident. The development of CA practices has been suggested, and in some cases, worked on by a number of researchers (Pala et al., 2000; Dixon et al., 2001; Mrabet, 2001; Cantero-Martínez and Gabiña, 2004; Lahmar and Ruellan, 2007).

10-Refers in this text to the 22 countries of the league of Arab States.

CA is promoted in the Mediterranean region mostly because it is perceived as a powerful production and protection land management tool. However, CA adaptation in dry areas faces specific challenges (Mrabet, 2001; Pratap Narain and Praveen Kumar, 2005; Wani et al., 2005), including water scarcity and, rain unreliability and drought hazard; low biomass production and the acute competition for its use as soil cover, animal fodder, cooking/heating fuel, row material for habitat etc., and, the poverty and vulnerability of many smallholders that rely more on livestock than on green production. Success of CA in these conditions remains weak in absence of substantial institutional, financial, research and learning support.

7. Discussion

In the absence of specific enabling policies and other material incentives, farmers' adoption of CA remains mainly driven by economic considerations; i.e., the short-term reduction of production costs it provides. This explains why the large-scale farms are always the pioneers in CA adoption. Environmental considerations or natural resources degradation do not seem critical in the farmers' decision whether or not to shift towards CA, except probably when they are economically threatened by acute environmental crises. Overall, owing to current CA experiences, practices and knowledge, CA can hardly be considered as a stabilized set of components, but rather as a basket of technical and managerial options to be used in a flexible way, according to specific targeted objectives and correlative constraints and opportunities.

Lessons from the international experiences with the development, fine-tuning and dissemination of CA-based systems; their drivers, constraints and impacts may help in designing and shaping alternative programs, tools and strategies aiming at sustainable land management in dry areas. To avoid wasting precious resources, the following issues must be given due consideration:

i) - Development and sustainability of CA-based systems are highly site-specific. It is sensitive to, and dependent on, local biophysical, social, cultural, technological, institutional, market and policy environments. Thus, simply transferring a model from one to another place is not a viable option;

ii) - Shifting towards CA is not a simple matter of technical change. It is about an innovation process which calls for a thorough change in management and adequate knowledge and skills, from the field to the farm and beyond, allowing a continuous adjustment and integration of the new systems into local agriculture;

iii) - The process is knowledge consuming. It calls for a continuous generation and upgrading of knowledge, skills and capacities related to the development, functioning and performance of the systems. This requires the use of participatory, systemic and multidisciplinary research and development approaches, as well as significant investments in training and education;

iv) - Effective innovative learning processes depend heavily on the active sharing of the knowledge generated and experiences acquired, including successes and failures, between farmers and other stakeholders at the local, regional and international scales.

v)- The success of the whole process calls for setting up and maintaining dynamic and effective innovation systems over extended periods of time. Such systems allow multiple stakeholders to interact in real time and adapt, correct and improve the performance and sustainability of the suited CA-based/related systems. Farmers and their societies have to be prominent players in these systems. Other vital stakeholders include research; policy makers; service, input and implement manufacturers and providers. Ensuring effective coordination of such networks is essential to avoid the process aborting prematurely and to make sure the concerns and needs of the weakest stakeholders (usually the smallholders) are addressed.

Eventual success of CA projects in these conditions relies on the capacity to develop systems able to produce enough biomass (i.e., crop residue or cover crops that allow covering soil, feeding livestock and providing fuel and raw material for households), while simultaneously improving household livelihood in the short-term. This may also imply creating adequate enabling environments over sufficient periods of time to support the transition to CA and limit the associated risks.

8. Conclusions and perspectives

Land scarcity and soil degradation in the Arab region dry areas are increasingly recognized and being documented. Their impact on food production, environmental quality, people livelihood and ecosystems' resilience is a growing concern. CA may prove to be an alternative land management tool able to mitigate/reverse land degradation and to improve farmers' livelihood. Lessons from the international experience in CA tend to show that where it is suitable and when it is properly implemented, CA may fulfill these dual objectives. However, the development, the fine tuning and the dissemination of CA-based systems in the dry areas face many specific challenges; among them, especially low rainfall and drought hazard, low biomass production and competition for its uses from livestock and households, and rural poverty.

There is ample evidence that transition to CA-based farming is not a simple matter of technical change but rather a complex innovation process which calls for adequate enabling environments, values and attitudes favoring the involvement and capacity-building of the relevant stakeholders including small-scale/poor farmers and pastoralists/transhumants. Acceptability of future locally-adapted CA-based systems will depend on their ability to integrate harmoniously with livestock-related concerns and constraints and to contribute effectively to poverty alleviation over the short-term. Their long-term sustainability requires continuous technical and managerial adjustments that call for substantial participatory, systemic and multidisciplinary research and development efforts and effective education, training and dissemination strategies. More than a policy support, a paradigm shift is needed.

Table 1: Drivers and constraints for CA

Source: Lahmar et al., 2007b

Drivers/constraints for conservation agriculture (not ranked)	
Farm and market conditions	Reduced/ increased production costs
	More/ less flexibility and improved timeliness of operations
	More/ less diversification and enterprise selection
	Use/ lack of cover crops
	Use/ lack of suitable rotations for integrated pest, weed, disease control
	Suitable / scarcity or excess amounts of residues
	Strong/ weak crop-livestock interactions
	Reduced/ increased soil erosion and resource degradation
	Improved/ reduced water productivity (apply to water-scarce agroecosystems)
Biophysical conditions	Favourable/ unfavourable climate
	Favourable/ unfavourable soils
Social, cultural, technological, institutional, and policy environments	Presence/ absence of a crisis mentality
	Absence/ presence of socio-cultural barriers
	Leadership/ lack of leadership from farmers and farmer organisations
	Ready availability/ lack of conservation agriculture implements
	Presence/ absence of dynamic and effective innovation system
	Availability/ lack of knowledge regarding conservation agriculture
	Presence/ absence of policies for training, communication and support for farmers' initiatives
	Policies affecting farm size, agrarian structure and land tenure
	Appropriate/ inappropriate agricultural research policies
	Favourable/ unfavourable macroeconomic policies
	Favourable/ unfavourable agricultural sector policies
	Presence/ absence of suitable subsidies and credits to facilitate conservation agriculture
Impact of conservation agriculture on health and on the environment	Reduced/ increased pressure of weeds, pests and disease
	Reduced/ increased pollutions
	Impact of conservation agriculture on human health known/ not known

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