Practical Guide to Conservation Agriculture in West Asia and North Africa

Rachid MRABET[a] & Patrick WALL[b]

[a] Research Leader, INRA Morocco, La Victoire Avenue, Rabat 10000 Morocco
[b] Independent International Consultant, La Cañada 177, Sector O, Bahias de Huatulco, Oaxaca 70989, Mexico

ICARDA
Science for Better Livelihoods in Dry Areas

IFAD
INTERNATIONAL FUND FOR AGRICULTURAL DEVELOPMENT

European Union

2015

International Center for Agricultural Research in the Dry Areas (ICARDA), PO Box 114/5055, Beirut, Lebanon

Contents

Objectives and beneficiaries of this guide

Conservation agriculture (CA) is a new method of agricultural production that is more productive and environmentally friendly than the common form of agriculture based on plowing and intensive soil tillage. However, adopting CA is not an easy process and involves a change not only in the way we think of agriculture, but also in agricultural policy and the institutions that support agricultural production, including input and output markets, credit, and research and extension systems.

This manual serves as an introduction to CA, a guide to the benefits and difficulties associated with its adoption, and an introduction to the practical application of CA, together with some scientific background as to why the system works. As such, the guide aims to help farmers, extension specialists, researchers, and all stakeholders involved in agricultural production understand the principles and practices of CA, and why changing to the new system is necessary. Furthermore, the guide sets out the steps necessary for successful adaptation, adoption, and implementation of CA, and describes the practices and equipment necessary for success. However, there is no recipe for a successful CA system, and adaptation to local conditions and farmer needs is always required. Those interested in CA are advised to contact farmers and technicians with experience in the system before embarking on the journey to sustainable agricultural production. The experience of these practitioners can help avoid the same mistakes being repeated and can be an invaluable aid in answering queries and overcoming doubts related to CA.

Why do we need a change?

Soil and land degradation are serious and widespread in the West Asia and North Africa (WANA) region (and in many other parts of the world). Although official figures (IAASTD, 2008) show that most of this degradation is due to wind and water erosion, there are other underlying factors which make the land more susceptible to erosion. Tillage leads to the breakdown of soil structure, leaving pulverized soil that is highly susceptible to erosion, compaction, and crusting. At the same time tillage leads to a reduction in soil organic matter – the key to soil fertility and soil health. Removal of all or most of the crop residues by grazing reduces the return of organic matter to the soil and exacerbates the effects of tillage in reducing soil organic matter. Soil fauna and flora depend on a continuous supply of organic material for their existence; and in bare soils depleted of plant material, biological activity is drastically reduced to the point where the soil is little more than an inert structureless medium.

As a result of soil degradation, and largely due to the reduction in soil organic matter, soil fertility declines, and because less water enters the soil, and less of the water that does enter the soil can be retained because of the lack of pore space, crop yields decline. Farmers can get over some of the effects of soil degradation by adding more nutrients, either as organic or inorganic amendments, and/or by irrigation, but these are expensive practices and so the profitability of agriculture is reduced.

This downward spiral of soil fertility, crop yields, and profitability is clearly not sustainable. New agricultural methods that allow for profitable and productive farms are required to ensure the food security not only of the present generation but also of future generations.

What are CA and no-tillage systems?

In the second half of the twentieth century, farmers, researchers, and extension personnel in various parts of the world became alarmed about the levels of land and soil degradation, and began to look for new ways of conducting agriculture that did not damage the soil and the environment. Most of the solutions focused on doing away with soil tillage, and replacing this with direct seeding of crops into untilled soil. The systems were known as direct seeding, no-tillage, or zero tillage (and their equivalents in various languages). However, it soon became obvious to early researchers (e.g. Derpsch et al., 1991) that doing away with the tillage component of conventional agriculture was not the only change needed, permanent soil cover with living crops and crop residues was also required, as well as crop rotation, especially for overcoming problems of crop diseases. For this reason a new name for the system was sought that conveyed the idea of a complete agricultural system and, in the 1990s, practitioners began to use the term 'Conservation Agriculture'. The term was formalized by FAO (2002) as a system based on minimizing soil movement, permanent ground cover, and crop rotation that allowed for the management of agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the natural resource base and the environment.

CA is often confused with the term 'conservation tillage'. This latter term was developed in the USA to describe reduced tillage systems developed after the Dust Bowl era of the 1930s. Conservation tillage (CT) is defined as any system that leaves at least 30% of the soil surface covered with crop residues after crop sowing. While the ground cover aspect is consistent with CA, CT systems often include considerable soil movement with vertical tine implements which is not consistent with CA. CT also focuses on the tillage part of the system, whereas CA describes the whole agricultural system.

As stated above, CA describes farming systems that embrace three principles (Figure 1):

- Minimum soil disturbance without soil inversion, achieved with direct seeding using specialized equipment that allows crop seeds (and fertilizer) to be placed into untilled soil through the surface residues;
- Permanent soil cover with living crops or crop residues. Residues can be both standing stubble or loose (flat) residues;
- Crop rotations to reduce crop diseases and increase diversity, resilience, and soil health.

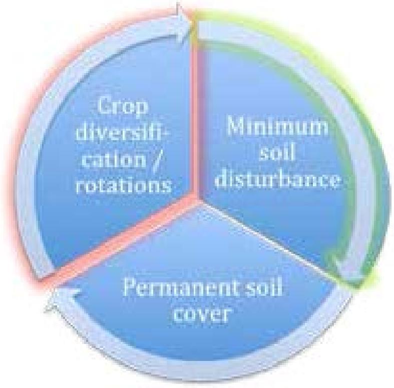

Figure 1. The three key principles underlying CA

It is important to understand that these are principles (not fixed technologies), and that the way these principles are applied will vary from place to place depending on climate, cropping patterns, farmer assets, and many other conditions. For instance, large farmers in the Americas, Australia, and Kazakhstan practice CA using large mechanized (tractor mounted) seeders and sprayers whereas small farmers in southern Africa also practice CA systems, but using hand hoes or dibble sticks and backpack sprayers or manual weeding. In South Asia, CA systems, often using two wheel tractors, may incorporate manual seeding of relay crops into another standing crop to increase cropping intensity. Although the CA principles are universal, the way they are applied in a particular situation needs to be tailored to local needs and conditions. This is as true in the WANA region as anywhere else.

Generally farmers do not adopt all of the principles of CA at the same time. Commonly direct seeding is the first component adopted, often without the retention of many crop residues, as has happened in Iraq and Syria. Keeping more surface residues may be the second component adopted, and the adoption of crop rotations may come later. However, this again depends on local situations and in North Africa we have seen instances where farmers adopt a new crop rotation before they manage to maintain crop residues.

CA is not a technology or a group of technologies but rather a new form of agriculture that involves the whole farming system (Figure 2). Another way of looking at CA is that it is a type of agriculture that removes the negative, unsustainable components from productive, conventionally tilled systems (the plowing, lack of crop residue retention, and monoculture are removed from conventional systems) but all other components of productive systems such as timely sowing, high yielding and disease-resistant varieties, adequate plant populations, correct fertilization, weed control, and pest and disease management still need to be followed (Figure 2). However, it is also true that once the soil is not tilled and residues are left on the soil surface for several years, the optimal management of many of these other factors changes, and so there are multiple changes in the production system. The addition of new crops in the rotation adds another component to these already complex changes.

Farmers, extension personnel, and scientists who are accustomed to soil tillage (that is often thought of as the key component of agriculture) may have difficulty in believing that crops can be grown without tillage. However, plowing is not a part of natural systems – there is no plowing of forests and natural pastures – and yet these systems are very productive. In these natural systems, leaves from a diverse set of plants fall, and cover the soil surface forming a mulch. CA tries to make agriculture emulate as far as possible natural vegetation systems.

Because it involves a change in the whole farming system, a switch to CA is not an easy process. The farmer needs to obtain and manage much new knowledge, and extension specialists and researchers play a major role in helping farmers obtain this knowledge.

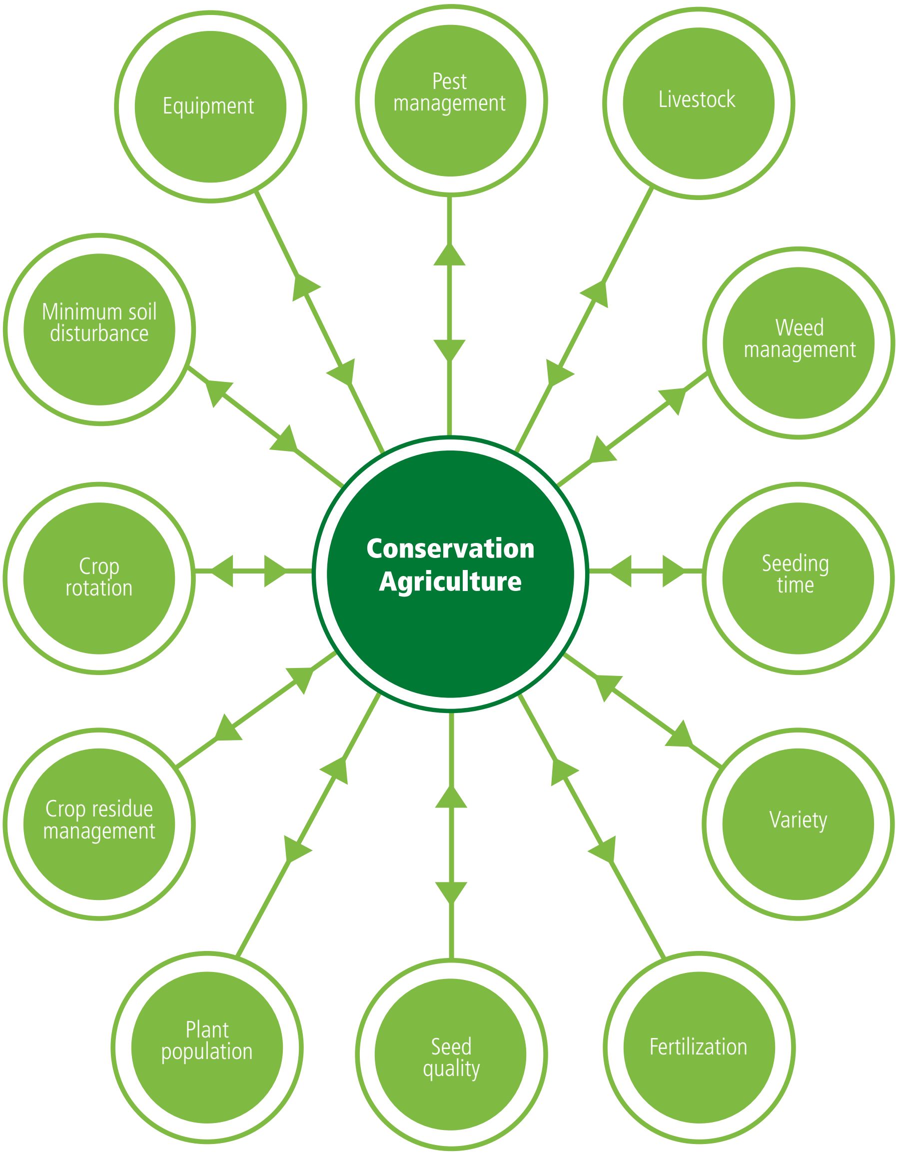

Figure 2. CA requires a system approach

The benefits of CA systems

Because of the reduction in tillage and the increase in residue retention, there are numerous benefits that can be expected from CA systems. Many of these are on the farm itself, while others occur at the watershed and community level – and some benefit the global community as a whole (Table 1).

Table 1. *Benefits and impacts of CA (Pieri et al., 2002)*

Farm level	Community/watershed level	Global level
• Labor, time, and farm power savings through reduced cultivation and weeding requirements. • Lower costs due to reduced operations and external inputs. • Lower repair costs, longer life span of equipment, and less fuel consumption. • Better trafficability in the field, less drudgery. • More stable yields, particularly in dry years due to improved moisture and nutrient availability. • Labor savings provide opportunities for diversification (livestock, high-value crops, and agro-processing). • Increased profits (in some cases from the beginning, in all cases after a few years) due to increased efficiency of the production system.	• More constant water flow in rivers and streams, improved recharge of the water table with re-emergence of dried-up wells and water sources. • Cleaner water due to less erosion and reduced sedimentation of water bodies. • Less flooding due to increased infiltration; less damage from droughts and storms. • Improved sustainability of the production system and enhanced food security. • Increased environmental awareness and better stewardship of natural resources. • Lower municipal and urban water treatment costs. • Reduced rural road maintenance costs. • Increased farmer associative activities. • Improved rural livelihood and quality of life.	• Improved carbon balance through reduced carbon emissions, less fuel and energy consumption, and increased carbon sequestration in the soil organic matter. • Better biodiversity protection at the microflora and fauna levels (e.g. increased soil biological activity, bird nests in CA fields, and fish in streams and ponds). • Improved hydrological cycle at the river basin and continental levels. • Reduced desertification and land degradation, through lower risks of soil erosion and enhanced soil regeneration. • Recharge of aquifers through the capture and infiltration of rain water. • Recognition of the role of rural dwellers and farming activities in providing key environmental services to the society at large.

Soil quality

Maintaining and developing soil quality and soil health is essential not only for current crop production and agricultural sustainability, but also for environmental stewardship. CA systems have an important influence on soil physical, chemical, and biological properties. Soil structure itself depends on small crumbs of soil called aggregates, in which particles of sand, silt, and clay are held together largely by soil organic matter. These aggregates contain pore spaces that hold water. In a structurally strong and healthy soil there are more, stronger (organic matter rich) aggregates, there is more biological activity, more water is held in the soil, and the soil better resists the passage of machines and animals that would otherwise cause compaction. Over time, soil organic matter increases in most CA situations and this, together with the associated increase in soil aggregation, is the major soil quality change associated with CA implementation.

Research in the WANA region has shown that soil bulk density is reduced and water infiltration and retention are increased in CA systems through reductions in tillage and stubble retention. In semi-arid Morocco, researchers have shown that under CA systems the amount of large pores in the soil decreased, and the number and amount of small pores increased in comparison to conventional tillage. The small pores are important for storing moisture whereas the large pores drain quickly and hold little water. The increased porosity is especially important for crop growth since it has a direct effect on soil water and aeration, and enhances root growth.

Agronomic impacts

In a recent review, Kassam et al. (2012) stated that CA enables farmers to reverse crop yield decline. The most important and primary benefit generated by adopting CA in the relatively dry WANA region, with its variable climate and frequent drought stress, is increased and more stable crop yields. Reported yield differences between CA systems and tillage-based systems in the WANA region are in the range of 20–120%, largely due to improved soil moisture and nutrient availability (Mrabet, 2008; 2011).

Economic benefits

The economic advantages of CA are also numerous, but the time it takes to achieve them are farm and situation specific. Over time, CA permits important cost savings, as less labor, machinery, and fuel are required. In other terms, CA permits higher efficiency in crop production (more output for a lower input). Reduced labor use with CA systems permits the development of other complementary agricultural and non-agricultural activities, such as value-adding activities or off-farm work. Hence CA increases the profitability and competitiveness of both small and large farming systems.

There are three major changes in the costs of production in the early stages of adoption of CA: equipment costs, a reduction in tillage costs, and often an increase in the cost of weed control. Adequate equipment for seeding directly into untilled soil is a pre-requisite for successful implementation of a CA system. While there are many no-till drill choices and options, one thing is common among models – they are generally more expensive than conventional-till drills: the prices of effective no-till grain drills are 2–5 times those of conventional drills. However, the greater cost associated with purchase of a no-till drill may be offset by decreased total equipment costs. Furthermore, with the exception of the initial purchase of a no-till seed drill, CA reduces investment in agricultural machinery and extends tractor life due to lower draught requirements and cleaner working conditions (less dust). It also reduces labor requirements and simplifies labor management.

Generally costs of production in CA are lower than those in conventional agriculture because of the reduction in the cost of land preparation. However, in some instances where weeds are a major problem and weed control is difficult, the increase in the cost of weed control may offset some or all of the savings on tillage. In WANA, however, if the crop is seeded with the first rains, an extra application of herbicide may be unnecessary and the cost of post-emergence weed control is the same as in conventional agriculture. Under these conditions the savings in the cost of production are immediate.

In studies in Syria, famer profitability was shown to have improved by US$220/ha, while in Iraq profitability was $US355/ha higher (Piggin and Devlin, 2012). These benefits came from reduced costs in fuel, labor, and seed as well as from increased yields resulting from the greater water use efficiency.

While the economic benefits of CA at the field level may be clear, as evidenced by information in the preceding paragraphs, the profitability of farming overall depends on adequate markets for inputs, outputs, and services – important bottlenecks in the early stages of adoption of a technology or system that involves changes in equipment, inputs, and/or crops. A key factor, therefore, in extending the use of CA is ensuring that market limitations for key inputs and outputs, especially the produce from new crops, are removed or reduced.

Food security issues

CA provides the best opportunity we have today for halting soil degradation and restoring and improving soil productivity, all of which directly affect food security. Research in WANA has shown that crop yields (mainly cereals) under CA systems tend to increase over the years with yield variations decreasing. Through increased grain and straw production, CA offers higher food and feed availability, as well as greater income, and therefore access to non-farm food and feed items – equally important for food security. Due to the more stable yields, CA systems are more secure, particularly in dry areas and/or dry years as a harvestable crop can normally be obtained, even in the toughest seasons.

Social and societal benefits of CA systems

WANA farmers are artists in surviving the severe and diverse environmental and economic threats associated with conventional agriculture. By shifting to CA systems, farm families will become even more resilient as a result of the increased productivity and reduced risk. Drought is the most common environmental risk in the region, and the increased efficiency of use of rainfall under CA underpins the reduction of risk in CA systems.

As shown by experiences around the world, CA holds benefits not only for large farmers, but also for small- and medium-sized farms. Whereas fuel and machinery savings may be the biggest benefit on large mechanized farms, labor savings and reduced drudgery are often the major benefit reported by smallholder farmers. However, smallholder farmers may need more support in terms of research, extension, information, and services than their larger (and more resource-secure) counterparts. Because of the multiple benefits of CA systems, they are associated with the sustainability of rural livelihoods, social equity, and rural development, and therefore merit policies that support the adoption of these more sustainable agricultural systems.

CA and environmental stewardship

CA farmers contribute to the conservation of environmental public goods (Table 1), especially of water, air, soils, and soil biodiversity. The CA system is one of few agricultural practices that can deliver ecological services (Table 1) that benefit farmers, society, and the environment, including benefits such as reduced erosion and downstream sedimentation, improved aquifer recharge, carbon sequestration, and energy conservation, as well as cleaner surface water and air (Piggin and Devlin, 2012). Because of these environmental services there are ongoing discussions in many regions as to how society should compensate CA farmers for these services.

CA and climate change

Problems of land degradation, desertification, declining soil quality, reduced soil fertility, and low agricultural production levels may be irreversible if appropriate measures are not taken soon. These problems are exacerbated by climate change, which is predicted to not only lead to drier conditions in WANA but also to greater variability in weather conditions and a higher frequency of extreme events. It is predicted that the entire WANA region will face severe and extreme drought and floods: predictions are that by the end of the century there will be a 10–30% reduction in precipitation, with both greater spatial variability (from site to site) and temporal variability (among seasons). In this hotspot of climate change, it is important to develop technical, policy, market, and investment conditions that facilitate sustainable agricultural development and food security in the face of climate change. This will involve three main pillars:

1. Sustainably increasing agricultural productivity and incomes;

2. Adapting and building resilience to climate change, where resilience refers to the capacity of the farmer, the community, and the country to recover from extreme climatic shocks;
3. Mitigating further climate change by reducing, or preferably stopping, greenhouse gas (GHG) emissions.

There is no single avenue to achieving these goals, but building these three pillars will involve the adoption of appropriate, sustainable, highly productive, low risk, and low GHG emission practices; building social and physical systems to help overcome the effects of extreme climatic events; and developing policies and institutions to enable these changes.

In previous sections we discussed how CA can increase agricultural productivity and incomes. CA is the best opportunity we have at the moment to achieve the needed technological changes in areas of field crop production, and policy-makers in the WANA region should consider CA systems as the best option for both adaptation to climate change and mitigation of the causes of climate change, while at the same time halting and reversing desertification. Concerns over global warming and rising food prices are growing in WANA, and this should increase social and political support for CA to help mitigate these effects.

Adaptation to climate change

CA will help farmers in the WANA region adapt to the warmer and drier conditions provoked by climate change through improved soil quality and improved soil–water dynamics (increased infiltration rates, soil moisture storage, and crop water availability; and reduced evaporation, runoff, and erosion). Generally, CA has been shown to give better resistance to dry spells and droughts and increased agro-ecosystem resilience and stability (Figure 3). As mentioned above, crop yields are higher under CA, especially under dry conditions, and less variable across years. This implies that farm families will have more resilience to climate risks.

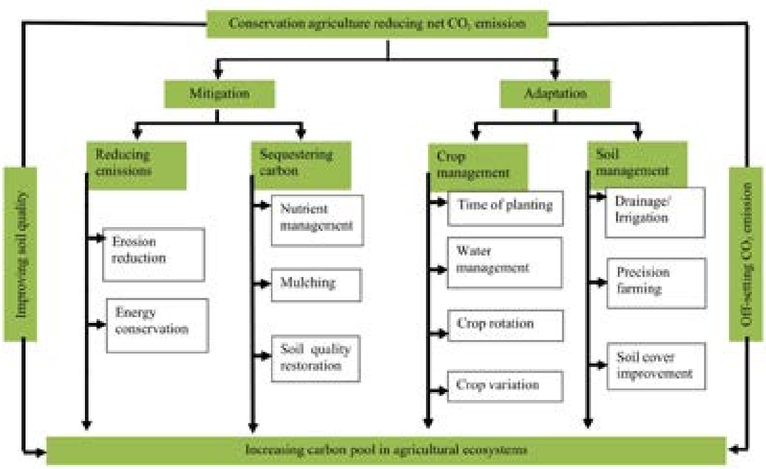

Figure 3. *CA and climate change, adaptation, and mitigation features*

Mitigation of climate change

GHG emissions are one of the principal causes of climate change, and carbon dioxide (CO2) is one of the three principal GHGs. Plants capture CO2 from the air in photosynthesis and convert it into plant tissue. When the plant dies, the tissue is converted into soil organic matter. By increasing the levels of organic matter in the soil, CA manages to 'sequester' CO2 from the atmosphere and store it in the soil, thus reducing the greenhouse effect and climate change. Research in semi-arid Morocco has shown that CA considerably reduced CO2 emissions compared to conventional tillage practices (Moussadek et al., 2011). The amount of extra carbon stored in the soil is dependent on climate regime (aridity), cropping intensity, biomass production levels, crop residue return, and soil nutrient balance, as well as micro-meteorological properties at the soil–plant interface. Most of these factors respond positively to CA systems.

In CA, fuel use is substantially reduced when tillage operations are eliminated, thus reducing emissions of GHGs and other pollutants. Commonly, fuel use in CA systems is 50–70% lower than in conventionally tilled systems.

Nitrogen oxides (especially nitrous oxide) are very potent GHGs and if nitrogen is badly managed, nitrous oxide emissions can offset all of the benefits of CA in increasing carbon sequestration and reducing fuel use and emissions. It is therefore very important to ensure that nitrogen is managed correctly and efficiently. Nitrogen fertilizers should not be broadcast on the soil surface, but should rather be placed in a band below the surface.

Difficulties with CA

The multiple benefits of CA were outlined in the sections above. However, there are also costs associated with the adoption of CA (Table 2). The first of these is the cost of learning about the new system and its management. Secondly, CA requires good and precise management, and is more complicated to manage than a continuous cereal–fallow system with tillage.

Successful implementation of CA farming demands proper preparation, as well as attention to detail and high-level management skills (Table 2). The farmer (and the researcher and extension personnel) must acquire new knowledge, and be prepared to adapt the system to their particular needs. It should be obvious that one cannot compare a package of CA practices imported from elsewhere with the conventional practices that have been developed, adapted, and adjusted over decades and expect the new package to outperform the conventional practice without first adjusting and adapting the new practice.

Many of the benefits of CA only develop in the longer term, whereas farmers need short-term benefits – farmers cannot afford to make short-term investments only for the promise of long-term gain. It is important therefore to ensure that there are short-term benefits to the adoption of CA. This may need some incentives for adoption. As noted above, many of the benefits of CA are also public goods (e.g. environmental conservation) as they benefit other sections of society. This raises the question for policy-makers of whether the farmer alone should bear all of the costs associated with the conversion to CA.

Table 2. *The two sides of CA systems*

Benefits	Trade-offs
• Reduced fuel costs • Reduced labor requirements • Reduced horsepower requirements • Reduced equipment needs • Increased crop yields under dry conditions • Increased profitability • Reduced soil erosion • Increased water conservation and water use efficiency • Improved soil quality and soil health • Carbon sequestration • More sustainable agriculture • Greater food security • Climate change adaptation and mitigation • Other environmental services	• Higher knowledge and managerial requirements – difficult shift from conventional agriculture • Competition for residues and balancing soil quality with livestock feeding • Costly necessary equipment • Often a heavier reliance on herbicides • Probable shifts in weed, pest and disease populations and intensity • Often higher nitrogen fertilizer requirements in the first years • Difficult in soils with poor drainage and excess water

Competition for crop residues will be discussed later in this guide. However, balancing the needs of the soil and the need for livestock feed is a major difficulty in CA, especially in the early stages of adoption. The fact that farmers currently use the crop residues means that there is a cost associated with leaving some of the residues on the soil surface and this cost must be taken into account in analyzing the benefits of the system.

Weeds are a major problem in any agricultural system, but tillage is an effective method of weed control in conventional systems. Once tillage is stopped, weed control becomes more difficult and, especially in the early years of CA, farmers may need to rely more heavily on herbicides for early-season weed control. Also, as the change to CA involves a change in the whole production system, it is likely that the change will benefit some weeds, pests, and diseases more than others, and there will be a shift in populations of these organisms. Keeping ahead of these changes requires good management – including monitoring of pest populations (including weeds, diseases, and insect pests), acquiring information on their control, and initiating an effective integrated pest management (IPM) scheme on the farm.

There is a cost associated with the increase in soil organic matter and soil fertility under CA systems – in the initial stages of CA some more nitrogen often needs to be added to the system. This is because the crop residues (including roots) break down more slowly in untilled situations and therefore also liberate the nitrogen they contain more slowly. However, as pointed out later, this cost should be considered an investment – it is often covered by yield benefits in the short term in drier areas, and is more than covered by the long-term benefits of increased soil fertility.

As mentioned previously in this guide, CA provides many benefits with respect to water conservation and use. For this reason it is difficult to manage CA where soil drainage and excess moisture are a problem and areas with poor drainage should be avoided. There are methods that enable the successful management of CA under these conditions, including raised permanent beds, but again management of these systems is more demanding and needs to be adapted and adjusted locally.

The principles of CA

The importance of not disturbing the soil

Only a few years ago all textbooks on agricultural production stressed that the aim of land preparation was to prepare a seedbed that had a fine tilth. This tillage involved turning the soil and breaking down aggregates and soil clods into loose, pulverized soil into which it was very easy to seed.

Today we know that breaking down soil aggregates by tillage damages soil structure, oxidizes soil organic matter (the organic matter that holds the aggregates together), and ultimately leads to soil degradation.

After some years of tillage, soil organic matter levels in tilled soils are well below those of untilled soils, and as organic matter is the most important component of soil fertility and soil health, soils become far less fertile and require higher levels of fertilizer for crop production. When roots and crop residues are mixed into the soil by tillage they come in contact with oxygen and moisture and are broken down quickly. In an untilled soil, however, oxygen enters the soil through the pores but is not as readily available to organisms as in a recently tilled soil, and the rate of soil organic matter breakdown is slower.

Tillage destroys root channels and other pores, and although it leaves considerable pore spaces in the tilled soils, pores are not continuous and water does not flow through them. In an untilled soil, channels from old roots, earthworms, and insect burrows provide continuous pores that allow water and oxygen to enter the soil easily, and which also facilitate root growth and exploration.

Tilling the soil also opens up the profile and facilitates the evaporation of water from moist soil. The amount of moisture loss depends on environmental conditions and soil moisture, but as much as 25 mm of moisture can be lost by conventional land preparation practices, whether these are with soil inversion or using a chisel plow.

As tractors plow the soil with a moldboard or disc plow, one wheel of the tractor is at the bottom of the furrow and compacts the soil. Soil is also compacted by the tillage implements themselves, forming plow pans at the depth where tillage is performed, and restricting root growth and water percolation. In CA systems all wheel traffic is on the soil surface and there are no implements to cause compaction, except for seeding tines and discs. Biological activity is increased because of the lack of tillage and also by the availability of crop residues (see below), and the increased biological activity (especially of earthworms, insects, and similar organisms) helps restructure the soil and break down any compaction formed by surface traffic and seeders. A healthy, well-structured soil is also able to resist compaction far better than a degraded soil. However, it is important to restrict traffic (including animal hooves) on CA fields when they are wet – soil structure is weaker in wet soils.

Generally land preparation in conventional agriculture is carried out as soon as there is some moisture from the first rains, and then the crop is sown after the next rains when there is sufficient soil moisture. In CA conditions, the crop can be sown straight after the first rains, giving a longer growing season and higher yields as long as frost is not a problem. If spring frosts limit early seeding of current varieties, longer season varieties (usually higher yielding) which flower after the frosts can be grown. In a study using crop models, Sommer et al. (2012) found that under rainfed semi-arid Mediterranean conditions there was a yield benefit from earlier seeding in 25 out of 30 years.

The importance of crop residues

The retention of crop residues is a key component of CA systems, and many of the benefits of CA come from the residues. Because crop residues are commonly used as animal feed, farmers are often reluctant to leave residues on the soil surface. However, it is important to understand and demonstrate the benefits of the residues (Figure 4) so that the best balance between the needs for soil fertility and for animal feed can be obtained. In some cases there may be benefits to no-tillage even in the absence of appreciable residue retention, as has been shown in the drier areas of Morocco (Oussama El Gharras, personal communication), Iraq, and Syria (Haddad et al., 2014). However, it is likely that there will be more benefits to the system and to crop productivity if residues are left, and it is unlikely that systems without residue retention will be sustainable.

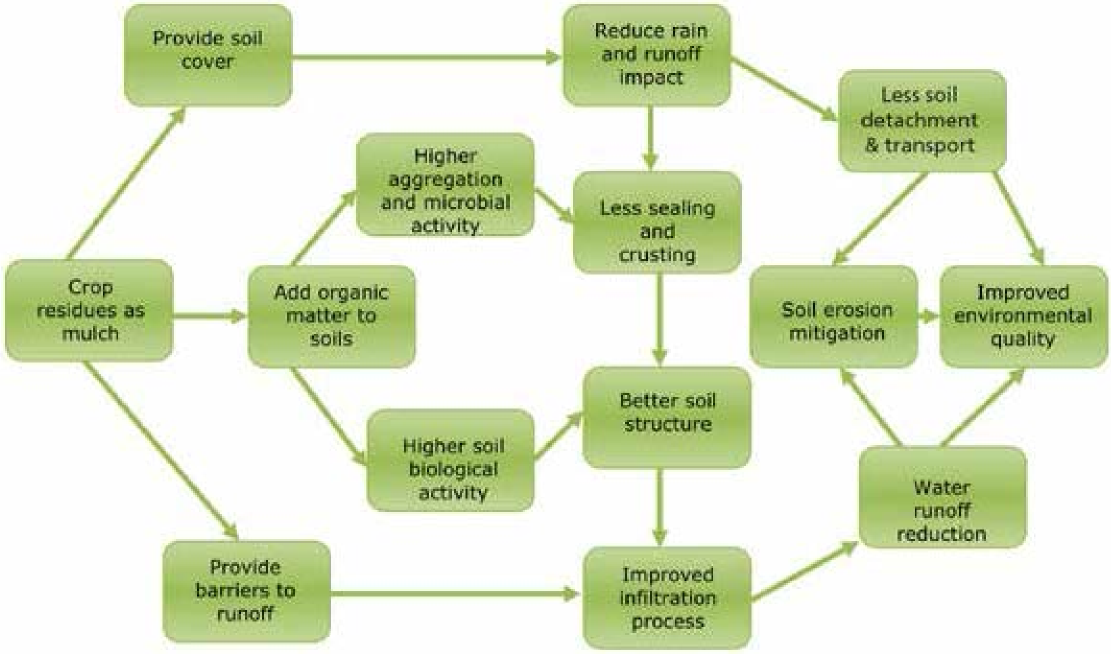

Figure 4. *Soil conservation effects of crop residues under CA*

Increased water infiltration

Raindrops falling on bare soil break down surface aggregates, especially when these have been pulverized and weakened by constant tillage over the years, and the loosened soil particles run with the water and block the small pores that carry water down into the soil. The surface layer of fine soil particles that is formed restricts the infiltration of water into the soil, and forms a crust when it dries that can impede crop germination and require reseeding. Covering the soil surface, however, with crop residues protects the soil surface from the explosive impact of the raindrops, so that surface pores remain open and water infiltration is maintained. This is an effect that can be observed in the first year of a CA system, provided sufficient residues are left on the soil surface. Obviously only the water that manages to enter the soil will be available for the crop roots, and the rest of the water runs off the field causing soil erosion and flooding.

Apart from the main effect of surface residues on water infiltration through protecting the soil surface from the effect of raindrops, the residues also slow the flow of water across the soil surface as it runs off the field, giving more time for the water to infiltrate into the soil. Slowing down the water also means that water does not erode the soil as much, again reducing soil erosion.

In regions such as WANA where grazing of crop residues is the normal practice, it is extremely difficult to maintain any crop residues on the soil surface, let alone achieve complete soil cover. However, it is very important to leave some straw on the soil surface both to protect it as much as possible from rainfall splash and to retain as much moisture as possible from rainfall and run-on (water that runs onto the field from upper slopes). It is important to continue to demonstrate the beneficial effects of crop residues and work with farmers and livestock owners to identify avenues toward maintenance of some residues to enable system sustainability.

Reduced soil erosion

Soil erosion is caused by two natural forces – wind and water. Soil losses due to water erosion in the WANA region are among the highest in the world, while wind erosion is the major desertification process in the region. Reducing erosion, one of the principal benefits of CA, is therefore critical.

The soil that is lost to erosion is from the surface – the most fertile part of the soil profile. It is also the soil where seeds and fertilizers are placed, and with severe water erosion these can be lost with early-season rains, requiring parts of the crop to be reseeded and resulting in problems of soil fertility. Stopping, or greatly reducing, soil erosion with CA halts the loss of fertile soil and over time reduces the amount of fertilizer that needs to be applied to maintain soil fertility.

Crop residues and water erosion mitigation

Because surface residues increase water infiltration into the soil, and slow the flow of water across the soil surface, they greatly reduce soil erosion. Many studies have shown that keeping approximately 30% of the surface covered with crop residues reduces water erosion by about 80%. Full surface cover, which is extremely difficult to obtain, generally stops water erosion completely.

CA allows the cultivation of steeper slopes than is possible under tillage-based systems, but permanent contour bunds should still be maintained on these slopes to protect against heavy rainfall events.

Crop residues and wind erosion reduction

Methods for preventing wind erosion from agricultural fields are limited to reducing the wind speed. Crop residues can again help in reducing wind speed over the soil surface and so reduce wind erosion. However, for best protection against wind erosion, the residues should be left standing as stubble. The higher the stubble is cut at harvest, the more effective it is in reducing wind erosion – for instance wheat straw cut at 30 cm height will give twice as much protection against wind erosion as stubble cut at 5 cm height. Although all methods of controlling wind erosion have their merits, including trees planted as wind breaks, by far the most effective is leaving standing stubble on the field. Again, wind erosion is also reduced by doing away with tillage – loose, tilled soils are easily eroded by wind.

Crop residues, evaporation, and soil temperature

Crop residues on the soil surface protect the soil from the sun's radiation, and therefore reduce the evaporation of water from the soil. This can often be easily observed by moving some of the residue cover in a CA field – under the residues the soil is moist, whereas the soil is dry where there is no ground cover.

Because the soil surface under crop residues is protected from radiation, it also remains cooler, which is a benefit not only for the germinating seeds and crop roots, but also for the growth and diversity of the soil fauna and flora. However, soils may remain colder longer into the spring in regions with cold winters, possibly delaying seeding and early development of some crops.

Crop residues and water storage

As the residues increase water infiltration and reduce evaporation there is more water available for the crop in CA systems. This reduces the frequency and severity of drought situations and results in higher yields in dry seasons and less risk of crop loss. Also, over time, as soil organic matter increases, the amount of water that can be held in the soil increases, reducing further the risks of dry periods. Large improvements in the water storage in the soil profile have been found in semi-arid WANA regions under CA systems.

Crop residues and the soil fauna and flora

Soil organisms are crucial to soil structure as they break the crop residues down into humus which glues soil particles together, forming soil aggregates – the key to soil porosity, water-holding capacity, and soil quality in general. These organisms, including bacteria, fungi, insects, and earthworms depend on crop residues (both aboveground residues and roots) for sustenance and survival. Under tilled systems where the residues (including the roots) are mixed with moist, aerated soil during tillage, they are broken down very rapidly by soil organisms, which then die off giving the common 'flush' of nitrogen 1–2 months after tillage. However, in CA systems where crop residues are left on the soil surface, they are broken down much more slowly – generally only the portion of the residues in contact with the soil surface are moist and 'fed on' by fauna and flora. Under CA situations there is not the large flush of nitrogen seen in tilled situations (much of which is often lost) but a slow, regular supply of nitrogen, and the residues provide a constant source of food for soil organisms. Due to the presence of a constant food source from the residues, it is common to find earthworms in a CA field after only a few years of a change to the new system – a good indication that soil biological activity and soil health are improving.

Crop residues and soil organic matter

As discussed above, tillage breaks down soil organic matter and reduces soil fertility. In a CA system, soil organic matter breakdown is much slower, and if enough residues are left on the soil surface to complement the organic matter left by the roots, then soil organic matter forms faster than it is broken down and organic matter levels increase over time. This is the basis of the increase in soil fertility and productivity under CA: soil organic matter is the key to soil structure (aggregation), chemical fertility (as it holds nutrients in a form available to plants), and water relations.

The importance of crop rotation

One of the main reasons that crop rotation is especially important in CA systems is to break the cycle of diseases that can survive on the residues of particular crops. How often a break is needed in the disease cycle depends on many factors including the environment, the resistance level of the crop variety, how much residue remains, how fast it decomposes under local conditions, and the characteristics of the particular disease. In many cases it is possible to grow, for instance, a cereal crop for two or three consecutive years before the levels of diseases harbored on the residues result in appreciable and economic yield losses. Then it becomes important to break the disease cycle before seeding a cereal crop into the residues. Often a break of one season will reduce the disease levels sufficiently, but if the residues break down very slowly, then a break of more than one season may be necessary.

Apart from the effect on diseases, crop rotation can also give many other benefits, some of which are still not fully understood. Incorporating a legume into a cereal system can improve nitrogen nutrition, especially if the grain is not harvested (as legume grain contains large amounts of nitrogen). There are other possible benefits, including breaking the life cycle of insects that attack a particular crop, helping bring nutrients from depth and deposit them in the residues at the soil surface by incorporating a deep-rooted crop in the rotation, and regulating ground cover by alternating crops with durable residues (such as cereals) with crops whose residues break down rapidly (such as legumes). Many crops also exude organic compounds from the roots that help build soil structure and may also make some nutrients more available – for instance some varieties of lupins can increase phosphorus availability in the soil.

In order to understand all of the effects of crop rotations, it is important to test different options and observe the effects. However, markets need to be available for the crops in the rotation, and the lack of markets can hamper the adoption of new crops in the rotation.

Practical aspects of CA

Equipment for seeding into untilled soil.

CA requires different types of equipment from conventional agriculture. The farmer no longer needs moldboard plows, chisels, disks, and harrows, but one basic requirement to establish a CA system is to be able to seed directly into untilled soil through the crop residues. Although CA can be managed with different types of equipment, including manual and animal-traction equipment, we will concentrate here on tractor-drawn or -mounted equipment, as this is the most common equipment in the WANA region.

Worldwide there have been many improvements in the design and durability of no-till drills, and there is now considerable knowledge on the key requirements for a suitable and versatile no-till seeder/planter.

Uniform and precise seed placement is a requisite for high crop yields. In CA this is more difficult than in conventionally tilled fields because the soil is harder and the crop residues can cause an uneven surface and, depending on conditions, may be difficult to cut or penetrate. Also conditions are more variable than in conventionally tilled situations because of residue distribution that affects the degree of soil hardness. For precision placement of seed (and fertilizer) the residues must be uniformly spread to allow the opening devices to cut through the plant material and place the seed at a uniform depth. Therefore, if appreciable amounts of straw are to be left on the field, the combine harvester needs to be fitted with a straw spreader.

No-till planters/drills are heavier than conventional planters to enable them to penetrate untilled soil. They must be able to cut through and/or move the residues, penetrate the soil to a depth suitable for proper rooting and growth, establish good seed-to-soil contact and close the seeding furrow without gathering crop residues. Keeping these five points in mind, and the relative importance of each under the particular conditions of the farm, a farmer can evaluate the strengths or weaknesses of any piece of planting equipment, decide on the best model for his/her conditions and make any adjustments or changes necessary to make no-till seeding successful.

Many different soil conditions can be present at the time of planting. Moist soils covered with residues, which may also be wet, can dominate during late fall and early spring. In contrast, hard and dry conditions may also prevail. Although cutting residues is easier during dry conditions, it is more difficult to penetrate the hard, dry soils. Proper timing, equipment selection and adjustment, and management can overcome these difficult issues. The following paragraphs introduce the different types of equipment to achieve these ends.

The major features of no-till drills (shown in Figure 5) are:

- Soil and residue cutting devices (coulters – A);
- Furrow opening devices for depositing seed and fertilizer (openers – B);
- Soil-firming devices to ensure seed–soil contact (press wheels – C).

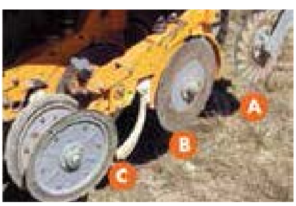

Figure 5. *No-tillage seed drill components*

Coulters are used to cut through surface residues and loosen some soil. They can broadly be classified on the basis of their diameter and the profile of their cutting edge. There are five types of disk coulters: smooth (plain), notched, ripple, bubble, and wavy or fluted (Figure 6). Within this last group there are many configurations depending on the number of waves and the width of the track. The first four types of disks create straight and narrow slots without much disturbance, whereas fluted coulters create a wavy or sinusoidal slot with greater disturbance. The amount of soil movement caused by a particular coulter will depend on the planting speed. Fluted coulters, especially those with relatively few large 'waves', also require more weight.

Coulters are equipped with adjustable down-pressure springs to aid penetration and cutting through the residues. The spring pressure is adjustable to allow the desired degree of penetration to be obtained. Coulters should be adjusted so that they penetrate 1–2 cm less than the seed openers.

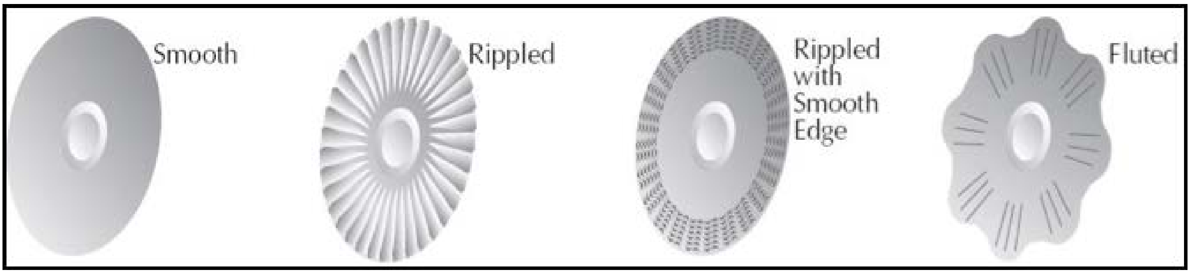

Figure 6. *Major types of coulters*

Drills equipped with coulters have less hair-pinning (forcing of uncut straw or chaff into the opener furrow) than drills with double disk openers alone because residue is cut (and possibly mixed with soil depending on the type of coulter and the amount of soil movement) ahead of the opener.

Furrow openers are used to open a slot in the soil and place the seed and the fertilizer. According to the kind of opener used, no-tillage seeders can modify soil physical properties to different degrees depending on soil and climate conditions, thus potentially affecting crop emergence and early growth (Table 3).

Table 3. Advantages and disadvantages of openers (based on Mrabet, 2001)

Opener type (Figure 8)	Advantages (strengths)	Disadvantages (weaknesses)
V-shaped slot openers:(1 & 2 in Figure 8) Openers can be double disk (generally offset and/or of unequal size), triple disk or cross-slot	• Low maintenance • Good residue handling • Good depth control	• Compaction and smearing of soil in wet conditions • Tend to 'tuck' residues into the slot (hair-pinning) when residues are moist or the soil surface is soft • Seed implantation into hair-pinned residues • Tend to concentrate seed and fertilizer at the base of the slot if applied in the same furrow • High penetration force needed • Difficulty in soil covering • Wet and loose residues tend to pile up in front of disks causing the drill to block
U-shaped slot Single disk	• Simple and robust • Compact (often used for small grain seed drills) • Good residue handling	• High penetration force required • Considerable soil movement (depending on the angle)
U-shaped slot or furrow openers Hoe or shank type (3 in Figure 8)	• Low cost • Better soil penetration requiring less weight of the implement • Deep penetration to moist horizons • Do not tuck residues into the slot, but 'brush' them sideways • Do not create smear surfaces at the sides of moist planting furrows, creating a better seedbed	• Problems with rocks and other obstacles • Poor residue handling, bunching, and increased residue covering • Require a good cutting disk (coulter) for long residues • Considerable soil movement depending on shape and width • High wear rates • Smearing in wet soils • Inadequate depth control

Soil-firming press wheels are devices used to close the seed furrow and firm the seed-bed. Many sizes and configurations are available for most drills, from a narrow, single press wheel to two wheels in a V-configuration (Figure 7).

In developing countries, CA equipment can be hard to find, expensive, and/or not suited to local conditions. Where possible, a farmer should first try out different machines, or closely observe the functioning of different seeders used by other farmers, and preferably only purchase or procure a no-till planter after testing the CA system and acquiring a good knowledge of all components of the system.

Figure 7. Types of press wheels for no-tillage drills

The conformation of the most cost-effective and efficient drill may change over time. For instance in WANA, if only small amounts of residues will remain on the field, hoe or shank type openers, even without a coulter to cut the residues, may be very efficient, and cheaper than drills with disk openers. However, if the farmer later begins to leave more residues, coulters or even disk openers may be more viable options.

For a long time, the major barrier to CA adoption in WANA was the availability and suitability of direct-seeding equipment. In Morocco, Syria and Tunisia, research has developed local, lower cost no-till seeders for small grain crops. However, more no-till direct drill equipment adapted to local soil and crop conditions is still needed.

Crop management

It is important to remember that, to attain the potential from a CA system, all agronomic factors (e.g. plant populations, seeding date, fertilizer practices, and varietal choice) must be well managed, just as they need to be well managed in conventionally tilled systems. In fact, other agronomic factors generally become even more important under CA because the increased availability of moisture for the crop permits higher yields, which therefore demand better management.

Cropping systems

Farmers generally have multiple goals aimed at maximizing the total economic productivity of the farm as a whole. Food, forage, and livestock production are all important. These objectives remain the same when a CA system is introduced, but may be more complicated due to the different rotational crops that the farmer will manage on the farm, together with the pest, disease, and weed control issues that these imply. Farmers who start a CA system also need to maintain and manage the residues.

Crop rotation can itself bring management difficulties to the farm, as the farmer must learn how to manage, and importantly market, new crops. Until new markets can be developed it is often very difficult to increase the diversity of the cropping system.

However, where possible, CA cropping systems should include food legume, forage, deep-rooted, and high-residue crops, as these will maximize the benefits of crop rotation. Avoiding monocropping (continuous cropping of the same crop) is essential for achieving the agronomic and biophysical benefits of CA. One of the early changes in the conversion to a CA system in parts of the WANA region is to replace the common weedy fallow with a productive forage crop – generally a cereal and legume mixture. This gives the farmer more forage of a much higher quality than the commonly-practiced weedy fallow, and also begins the cycle of integrated weed management in the system. However, it is also important to remember that managing rotations properly requires more skills than continuous cropping.

Figure 8. *Examples of some opener types shown in Table 3*

Sustainable weed management in CA

One of the main reasons for tilling the soil is to kill germinated weeds. As there is no tillage in CA systems, different methods of weed control are needed. Achieving adequate weed control is often the biggest problem when a farmer starts a CA system and he/she may need to use herbicides to replace the tillage – normally desiccant herbicides that kill all germinated weeds but do not affect the crop seeds before they are sown or germinate. These herbicides, for instance glyphosate (the active ingredient of RoundUp) and paraquat, behave almost like tillage – they clean the land of weeds letting the crop emerge in weed-free conditions. However, in the semi-arid rainfed areas of WANA, often there are very few or no weeds present when the first rains fall and desiccant herbicide applications are generally not needed in these cases, as experienced with CA on farms in Iraq and Syria (Haddad et al., 2014). Just as in conventional (tillage-based) agriculture, weeds that germinate with or after the crop have to be controlled by other methods – either chemical or mechanical.

However, chemicals are not the only way to control weeds in CA systems, and it is important that the farmer approaches weed management in an integrated manner, employing several different methods of weed control. This is especially true because continued use of the same chemical or family of chemicals can lead to populations of weeds that are resistant to the herbicides and therefore are far more difficult to control. The following paragraphs summarize the major components of integrated weed management.

Two of the major components of integrated weed management – lack of tillage and continuous ground cover – are also two of the pillars of CA. Tillage incorporates seed into the soil, and then brings it up to near the surface the next season. However, in CA systems any weed seed produced (and this should be very little in a well-managed system) stays on the soil surface where it may rot, be eaten by birds and insects, or fail to germinate due to unfavorable moisture conditions. In the CA system, seed that remains deeper in the soil profile (incorporated by previous tillage and no longer brought to the surface by more tillage) loses its viability over time and rots. At the same time the crop residues or living plants shade the soil surface and inhibit seed germination – complete cover with a forage or green manure cover crop can drastically reduce weed populations.

Crop rotation is another pillar of CA systems, and is also one of the components of integrated weed management. This is largely because of the different selective herbicides that are used in different crops, but also sometimes due to the heavy ground cover of some crops in the rotation. One should remember that it is easier (and usually cheaper) to control broadleaf weeds in a cereal crop and grass weeds in a broadleaf crop. There is also the possibility of allelopathic effects (where exudates from the crop or the crop residues inhibit the germination and/or growth of other plants).

Stopping new weed seed from entering the field is an important part of integrated weed management. Practices for reducing or stopping new weed seeds from entering the field include:

- Attention to detail, especially in the first years, and spot-spraying and/or hand-pulling weeds that have escaped control before they set seed. There is an old saying from European farmers of the Middle Ages that goes "One year's seeding means seven years weeding": if the weeds are allowed to set seed it takes a long time (and a lot of expense) to rid the field of weeds again!
- Keeping the edges of the field clear of weeds either by grazing, cutting, or using herbicides so that they do not set seed that can enter the field again.
- Taking care with grazing animals. Animals that have been grazing in weedy areas can introduce a considerable amount of weed seeds into the field. If possible try to feed the animals on clean feed (hay from clean fields) for 4–5 days before they enter the CA fields. Bedding and droppings from animals fed on weedy areas should be composted to make sure the weed seed is killed before using it in the CA field.
- Making sure that equipment entering the field is clean and does not contain weed seeds. Good cleaning of seeders and any other equipment will reduce new infestations of weeds.
- Finally, and very importantly, use good seed that is guaranteed to be free of weeds.

Using all of the components of integrated weed management will reduce weed pressure over time – how fast this happens will depend on the type of weeds, the environment, and how well the weeds are controlled and managed.

In summary the important components of integrated weed management in CA systems include:

- Not incorporating weed seeds into the soil with tillage.
- Smothering germinating weeds with residues and/or crops, especially forage crops or green manure cover crops.
- Chemical weed control (herbicides) that may involve desiccant herbicides to kill weeds that have germinated before seeding and/or selective herbicides to control weeds that germinate with or after the crop.
- Crop rotation with crops of different types so that herbicides are also different and rotated.
- Spot-spraying or hand-pulling weeds when populations are low so that they do not set seed.
- Stopping new weed seeds from entering the field through:
  - Use of clean seeds;
  - Use of clean equipment;
  - Eliminating weed seed set in field edges;
  - Ensuring animals do not introduce weed seeds to CA fields.

Efficient application of herbicides

Achieving successful, economic, efficient, and environmentally friendly chemical weed control is not easy and requires considerable knowledge. Some important aspects of efficient chemical weed control are:

- Choice of the right equipment (especially sprayers and spray nozzles) and their maintenance.
- Calibration and correct management (spacing and height of application) of sprayers.
- Choice of herbicides taking into account the crop, residual effects, and crop rotation; type, species, and age of weeds to be controlled; and herbicide families and their rotation to limit the possibility of the development of herbicide-resistant weeds.
- Amounts and quality of water for different herbicides.
- Correct use of surfactants.
- Weather conditions for application, especially wind speed, relative humidity, and air temperature, as well as soil moisture conditions. This knowledge is important both to obtain efficient weed control and to limit damage to nearby crops through spray drift and herbicide volatilization.

The importance and need for different herbicides and types of herbicides (Table 4) is likely to vary over time, depending on seasonal climatic conditions and shifts in weed populations. In the semi-arid areas of WANA, and especially in cereal-based rotations, post-emergence herbicides may be necessary to clean up weeds that escape the pre-emergence desiccant herbicide. However, as reported by researchers from Syria and Iraq, pre-emergence weed control can be sufficient to control early-season weeds and significantly reduce weed infestations and pressure in CA. It is worth stressing that it is important to invest time and effort in weed control in the early years of adoption of a CA system to ensure that the weeds do not set seed.

Table 4. *Herbicide application methods in CA systems: advantages and disadvantages*

Application times and products	Advantages (strengths)	Disadvantages (weaknesses)
Pre-seeding/pre-emergence (of the crop), non-selective desiccants – only emerged weeds are controlled	• Only required when weeds germinate prior to seeding – burn-down (desiccant) treatments at planting are not required in many cases. • Consistent weed control if properly done. • Spraying at non-peak work periods. • No carryover effects (except on exceptionally sandy soils). • Low carrier volumes (glyphosate).	• Weed control can be reduced by rain within a few hours of application. • Herbicide investment is made early in the growing season. • Potential for late-season weed pressure in wet years although narrow crop rows reduce this risk. • Water quality important (glyphosate).
Pre-plant/pre-emergence (of the crop), selective herbicides with residual effects	• Consistent weed control if properly done. • Less time-sensitive (a larger application window) than post-emergence programs. • Less sensitive to short periods of adverse weather. • Broad-spectrum control available for some crops. • Reduced risk of carryover associated with long residual compounds.	• Some herbicides with long residual effects may not be desirable on land overlying shallow aquifers. • Herbicide investment is made early in the growing season. • Weed species that will be present must be predicted in advance. • A risk of carryover to subsequent crops in drier years (depending on compound and crop sequence). • Potential for late-season weed pressure in years much wetter than normal, although split applications and narrow crop rows reduce this risk. • High carrier volumes. • May not be effective where seeding equipment causes substantial soil disturbance.
Post-emergence (of the crop), selective herbicides with or without residual effects	• Spraying decisions can be made after weed pressure is known. • Many post-emergence herbicides have little or no soil residual effects. • Can be used where residue spreading has been less than ideal. • Many compounds can be sprayed with low rates of carrier. • Active even where seeding equipment causes substantial surface disturbance.	• Burn-down treatment is usually required at planting time with later seeded crops. • Very timing sensitive (a narrow application window). • Performance is sensitive to adverse environmental conditions at or near spray time. • Crop injury or poor control may result from inadequate environmental conditions. • Increased chance of cutworm problems due to early-season weed growth in fields. • Sequential treatments (two separate sprayings) may be required to obtain broad-spectrum control. • If failure occurs, few viable rescue alternatives are available. • Yield loss to weed competition may occur prior to spraying.

Integrated pest (disease and insect) management (IPM)

Plant diseases can be divided into two main groups depending on the type of plant tissue they can infect: some diseases can only infect living plant tissue (often of a particular species of plant or a group of similar species) and others can infect dead plant tissue, and which often infect tissue from a wider range of species. Leaf and stem rust of wheat are two examples of the former – they are called obligate parasitic diseases as they can only infect living tissue of wheat. Some other diseases such as Septoria spp. or Alternaria spp. can infect living tissue, but they also survive on dead plant tissue – the crop residues. CA has no effect on the intensity of diseases of the first group but, as one of the components of CA is leaving crop residues on the soil surface, it does affect the prevalence and intensity of diseases that survive on these residues. Some of these diseases such as the leaf spotting diseases (tan spot and Septoria) and head scab can cause problems in cereal systems with a switch to CA because of the carryover of the diseases on the residues.

The best way to overcome disease problems is to use varieties that are resistant to the common diseases. In most cases, including results from the WANA region (Piggin et al., 2011), varieties that are good under conventional agriculture also perform well under CA. However, this will depend on their resistance to diseases that survive on crop residues – sufficient resistance to these diseases may be a requisite for varieties to be used in CA.

Populations of most insects that are harmful to crops are not affected either directly or indirectly by tillage method. Almost all insect problems blamed on the maintenance of residues can be traced to failures in sanitation or rotation practices. However, the residue cover on CA fields appears to attract fewer aphids, which may then translate into a lower incidence of barley yellow dwarf virus, which affects barley, wheat and oats.

Just as with weeds, IPM programs can, and should, be implemented to successfully manage insects and diseases in any cropping system – not just in CA. The principal components of IPM are:

- Crop rotation - the most important component of IPM in CA systems. Rotation with a non-host crop is the single most valuable approach in helping to limit disease and pest infestation in CA systems. Continuous cropping encourages infestation and dominance of certain diseases and insects. Planting different crops breaks disease and insect life-cycles and prevents them multiplying.
- Varieties with disease resistance.
- Correct planting dates to avoid or reduce disease incidence.
- Proper inter-crop and in-crop management to break disease and insect cycles, for instance by controlling weeds to reduce insect populations.
- Finally, when absolutely necessary, the application of fungicides and insecticides.

Soil fertility management

Soil fertility management is a key component of efficient and profitable crop production. Under a CA system the new dynamics of moisture and organic matter result in changes in nutrient availability and therefore require changes in the way nutrients and fertilizers are managed. Soils generally contain abundant levels of many nutrients but only small portions of these are in a form available to plants. Many nutrients (especially the micronutrients) are more available (are liberated more readily into the soil solution) when associated with soil organic matter than in their inorganic form, and so the increases in soil organic matter under CA enhance nutrient availability over time. Also plants can only absorb nutrients in solution, and so absorption of nutrients requires soil moisture, which is increased in CA systems as seen above.

If phosphorus is deficient, farmers should apply and incorporate adequate amounts of phosphorus fertilizer before the switch to a CA system. Banding of phosphorus fertilizer is more efficient than broadcasting in a CA system, just as it is in conventionally tilled systems. In fact, banding may be even more advantageous in CA because phosphorus movement in the soil is very slow and, as the soil is no longer plowed, a zone of high phosphorus concentration is formed in the layer where fertilizer is applied.

CA also affects nitrogen management. Because of the increased surface moisture under residues, maintaining crop residues can increase nitrogen losses due to volatilization if fertilizers are broadcast. However, placing nitrogen fertilizer just below the soil surface with a coulter can effectively reduce volatilization losses and increase nitrogen use efficiency.

Building organic matter requires nitrogen as well as carbon. The organisms that break down the crop residues (e.g. earthworms, microbes, and fungi, which comprise the soil fauna and flora) need nitrogen as well as the carbon from crop residues and roots. In turn they break down the residues into soil organic matter, make nutrients available to plants, and build soil structure. Nitrogen may be temporarily tied-up by microorganisms as they decompose crop residues. Therefore, during the early phases of CA adoption, when soil organic matter levels are increasing, more nitrogen may be required than the crop uses. In most situations 10–20% more nitrogen should be applied during the first 3–5 years of the establishment of a CA system. Over time, the amount of nitrogen needed for CA should be similar to or even lower than that for conventional tillage systems. The cost of this additional nitrogen should be considered as an investment as it results in restored/increased soil fertility in the future, and is normally more than offset by cost savings in tillage.

After several years of CA, the soil becomes more fertile and has higher levels of nitrogen, available phosphorus, potassium and many micronutrients. In many cases after the establishment of a good CA system, crop yields increase and fertilizer requirements go down.

Management of the crop residue cover

Because of all of their benefits described above it is important that some crop residues remain in the field in CA systems. However, crop residues are also a vital source of animal feed. Finding the balance between sustaining livestock and maintaining soil fertility and productivity is something that each farmer will have to do. Initially it may be difficult to keep much residue on the soil surface, but over time as crop productivity (including straw production) increases, especially in drier areas, it should be possible to leave more residues in the field. It is also important that the farmer does not convert his or her whole farm to CA in one step – but should start with a small part of the farm, get to know the system and find out how to manage it properly under local conditions, before gradually expanding to cover the whole farm. This strategy also ensures that the impact of the introduction of CA on the availability of livestock feed is minimized. Research in dry areas has shown that after a few years of CA, because of the increased yields (of both grain and straw) under the CA system, as much feed can be removed from CA fields as before (when they were tilled) but still leaving enough on the soil surface to provide the benefits of CA.

Crop residue must be properly managed year-round to provide the benefits without interfering with crop production. However, residue management is especially important during harvest and seeding operations. At harvest the crop should be cut high enough to leave standing stubble to control wind erosion, and the cut straw spread evenly to ensure good soil cover and to allow efficient seeding – windrows of straw left behind a combine harvester without a straw spreader make seeding very difficult and the crop stand very variable the next season.

The residues from different crops break down (or, more correctly, are broken down by soil fauna and flora) at different rates. This is associated with the requirements of the fauna and flora for nitrogen as well as carbon – residues that are rich in nitrogen allow the soil organisms to break them down faster than residues that have little nitrogen. Cereal straw has little nitrogen (it has a high carbon:nitrogen (C:N) ratio – commonly 80:1 to 120:1) compared to legume residues which have a C:N ratio of approximately 20:1, and so cereal residues break down much slower than legume residues, which are broken down very fast. Therefore it is important to include in the rotation crops that have durable residues, such as cereal crops, with legume crops, whose residues decompose rapidly.

Livestock in CA systems

As mentioned earlier, the adoption of CA involves a trade-off between using crop residues as animal feed and keeping them on the soil surface for water and fertility management. Livestock are generally an important part of the farming system and so the need for feed cannot be disregarded. At the same time it is important to realize that crop residues, especially the most common residues – those from cereal crops – have low nutritional quality for livestock.

In the WANA countries, the integration of livestock and crops is not only a common practice but is also a cultural and social norm, and it is important to respect traditional rules governing livestock grazing in the region. Crop residues, and in particular cereal stover, provide highly valued fodder for livestock. Changing social norms requires negotiation and the involvement of all stakeholders, including local policy-makers, and is one of the prime topics for discussion and resolution by the local innovation platform that will be discussed later in this guide.

At the same time, ground cover holds the key not only to successful CA systems but also to sustainable agriculture – systems where organic matter decline and soil erosion continue unabated are not sustainable, and so, even though the trade-off between livestock feed and ground cover will be difficult to resolve, it is necessary to achieve sustainable farming systems. Several options to facilitate the co-evolution of CA and livestock are outlined below, but the particular options and mix of options that are feasible will depend on local conditions and the particular farmer's needs. These options include (Mrabet, 2008):

- Replacement of the (weedy) fallow with fodder crops to produce a greater quantity of higher quality feed for livestock;
- Introduction of forage legumes (i.e. vetch and sulla) and cereal/legume mixes (e.g. vetch/oats or pea/triticale) in the cropping systems. Legumes are an important source of high-quality feed for animals, for nitrogen cycling, and as a weed and disease break in cereal monoculture;
- Partial removal of crop residues, ensuring that enough residues are left for soil protection and enrichment;
- Flexible seasonal controlled grazing on stubble with appropriate stocking rates;
- Establishment of perennial forages for direct grazing and for cut-and-carry (use of fodder trees, shrubs, and cactus);
- Introduction of row crops (cash crops) for generating higher returns to guarantee feed purchase, especially if supplementary irrigation is possible;
- Use of silage and feed blocks to give more efficient use of a wide range of agro-industrial by-products;
- Temporary displacement of animals to pastures; soil physical condition of degraded lands may recover faster under CA conditions when animals are excluded for a period;
- Increasing crop biomass yields and soil quality through integrated soil fertility management and best management practices. Combined with the partial removal of crop residues this can increase straw availability for livestock while safeguarding soil quality;
- Production of better quality (more nutritious) straw through genetic improvements.

In other regions of the world, integrated crop/livestock farming is successfully managed under a CA system and so there is no reason why this cannot be achieved in the WANA region. However, it will not be easy because cultural norms are deeply ingrained, and only with education and understanding of the perils of unsustainable agricultural practices and the involvement of all stakeholders will sustainable solutions be developed.

Top ten practical factors for CA adoption

It can be difficult to fully switch to CA. Farmers should first identify and experiment with CA in situations where it is likely to have the highest impact and hence acceptability. For CA to be widely accepted and for farmers to be successful in their adoption of CA farming systems, each one of the following ten points (based on Derpsch, 2008) must be addressed through careful planning prior to starting with the CA system. The farmer should:

1) Improve his/her knowledge of the system – especially concerning weed control – and plan for the change to permanent CA at least one year in advance.
2) Analyze the soil and aim for a balanced nutrient status and adequate pH.
3) Avoid soils with poor drainage.
4) Eliminate soil compaction (plow pans) before starting with the CA system.
5) Flatten out irregularities in the soil surface to enable uniform seeding.
6) Produce the largest possible amount of mulch cover.
7) Obtain the use of a no-till seeding machine.
8) Start small: start on 10% of the farm.
9) Use crop rotation, possibly including green manure cover crops.
10) Be prepared to learn constantly and watch for new developments.

CA: lessons learned from other countries

CA systems have been developed and adopted in many countries around the world over the last half-century. Lessons learned from a wide range of diverse agricultural systems, soil types, climatic conditions (including tropical, sub-tropical, and temperate climates), and farm sizes provide a wealth of information to help in developing CA systems in new areas. CA systems are practiced by at least some farmers in most countries around the world, and the system has been adopted on over 125 million hectares worldwide, equivalent to 9% of the world's cropped lands. The countries with the greatest areas of CA are the USA (26.5 million hectares), Brazil (25.5 million hectares), Argentina (25.6 million hectares), Australia (17.0 million hectares) and Canada (13.5 million hectares) (Kassam et al., 2012). Recently there has been a large expansion of the CA area in Kazakhstan, China, and several countries in eastern and southern Africa. Although zero-tillage wheat production has expanded rapidly in South Asia over the last 15 years, the wheat crop is generally alternated with an intensively tilled rice crop and therefore cannot be regarded as a true CA system. However, recent advances in direct seeding or direct transplanting of rice into untilled soil suggest that a CA revolution is likely in South Asia over the next decade.

In general the spread of CA in the Americas and Australia has been farmer-driven, with different degrees of support from research and extension systems. Soil erosion, soil degradation, the need for efficient use of water, especially rainfall, and rising costs of production have been the major drivers behind the expansion of CA. Many of these experiences are relevant to the WANA region.

CA has spread most rapidly where agriculture is not subsidized by the government; in Latin America the area under CA has increased from only a few thousand hectares in 1990 to over 50 million hectares in 2008 (Derpsch and Friedrich, 2011; Kassam et al., 2012). Although most of this area is on relatively large, mechanized farms, there are also thousands of smallholder farmers practicing CA using animal traction and/or manual equipment. Results from China and sub-Saharan Africa (as well as for wheat in South Asia) have also shown that CA systems can be profitable for smallholder and resource-poor farmers.

In Europe, CA has progressed relatively slowly, possibly due to the level of subsidies. Today CA is found mainly in Russia (3.1 million hectares) and Spain (0.6 million hectares). It is promoted in France, Finland, Ireland, Italy, Portugal, and the UK. It is however important to note that CA is progressing more rapidly under perennial than annual crops in Spain, France, and Italy. The EU experience in applying CA systems in fruit orchards, vineyards, and olive plantations could be useful in the WANA region where olive and fruit value-chains require improved quality for greater competitiveness. In studies in Lebanon, savings due to CA over a three-year period in olive plantations were US$2000/ha (Jouni and Adada, 2010).

It is interesting to note that 72 million hectares of CA are located in Mediterranean-type climates (i.e. South and North America, Australia, and South Africa). The climate of Australia, with its pronounced aridity and frequent drought, is especially relevant to most WANA countries. Reduced soil disturbance through no-till and conservation farming methods have led to large increases in profitability and sustainability in the Australian cropping belt. The adoption of CA by farmers in Australia varies from 24% in northern New South Wales to 42% in South Australia and over 90% in Western Australia.

Ekboir (2002) studied the adoption of no-tillage and CA in six countries (Brazil, Paraguay, Bolivia, Mexico, India, and Ghana) and found that "although the development of no-till packages and their adoption by small-scale farmers followed different paths than for large-scale farmers, the paths shared one important common feature: all successful programs resulted from networks that worked with participatory research approaches".

State of CA in WANA

CA is applied on roughly 39,000 hectares in West Asia (Table 5) where spontaneous adoption of CA has been catalyzed by fuel shortages and two Australian-funded projects, which resulted in increased availability of locally produced affordable no-till seeders – now being exported to other WANA countries (e.g. Maghreb countries) (Haddad et al., 2014). Although CA research started in the early 1980s, adoption of CA in the Maghreb countries, where CA offers multiple benefits to farmers, is still lagging behind other regions (Boulal et al., 2014).

Table 5. *Area of CA systems in selected WANA countries in 2011. Data from Haddad et al. (2014), Kassam et al. (2012) and Boulal et al. (2014)*

Country	Area (ha)
Algeria	5,500
Iraq	7,800
Lebanon	1,500
Morocco	4,000
Syria Arab Republic	30,000
Tunisia	12,000
Total	60,800

For a durable, continuous shift from conventional agriculture to CA in WANA, the change in paradigms needs commitment and changes in behavior of all concerned stakeholders. In fact, CA researchers, extension agents, and farmers need to motivate policy-makers, institutional leaders, politicians, donors, and international agencies to assist in removing external constraints and creating an environment in which CA systems can flourish. In many cases it is not a case of creating subsidies to promote CA, but rather removing policies that hinder the adoption of sustainable practices – for instance subsidies on tillage equipment.

Improving the quality of information exchange among farmers, research institutions, universities, agribusinesses, and government agencies will no doubt go a long way toward overcoming obstacles and trade-offs (Table 6). Farmer-to-farmer information and knowledge exchange has been shown to be the most effective route for technology adoption and it is important that extension systems support and facilitate farmer knowledge communication. Field days in which farmers are the presenters and protagonists are far more effective in convincing other farmers that a technology is worthwhile than presentations by researchers and extension agents.

Table 6. Risks in CA systems

Type of risk	Cause	Explanation
Biological	Pests	Switching to CA may cause a shift in the makeup of pest populations. A few harmful insects are indirectly affected by tillage in terms of how it impacts the habitat they need for survival. Undisturbed residue may provide a better habitat for the over-wintering/over-summering life stages to survive (e.g. Hessian fly). However they also provide a habitat for beneficial insects and pest predators.
	Diseases	Usually an increase in disease incidence and/or severity of some diseases may occur because a greater quantity of inoculum of the pathogen is present on the residues left above the soil surface, especially when an adequate crop rotation is not employed.
	Toxins	Allelopathic exudates from decaying residues within the seed slot reduce early seedling vigor and may kill them. This can sometimes explain no-tillage failure with double-disk type drills.
	Nutrient stress	Nitrogen may be temporarily tied-up by microorganisms as they decompose crop residue with a high C:N ratio. Placement of fertilizers should be far enough from seeds to avoid toxicity problems.
	Physiological stress	In no-till conditions in wetter areas, moist soils with high mulch levels may cause waterlogging and/or reduce soil temperatures, prejudicing germination and early crop growth.
Physical	Weather	No-tillage systems favor crop productivity under more extreme and variable weather events than conventional tillage systems. However, CA is riskier in soils with limited drainage in periods of excessive rainfall.
	Machine function	Poor calibration and/or malfunction of seeders are major risks for successfully implementing CA (and conventional agriculture).
Chemical	Weed control	Ineffective herbicide weed control will increase the risk of impaired crop performance.
	Inefficient fertilizer placement	There are two risks from inappropriate fertilizer placement at sowing: a) If fertilizer is banded with seeds, there is a danger of damage or burning of the seeds; and b) if fertilizer is broadcast, the crop may suffer from uneven fertilizer distribution and nutrient losses.
Economic	Cost of initiating CA	Changing from conventional farming to CA requires investment in equipment, tools, and agro-chemicals, which is often a constraint for poor farmers. Initially input investments may not be compensated for by reduced tillage costs.
	Machine impacts on crop yields	To recover the cost of no-till machines requires an increase in crop yields and/or a reduction in costs of production.

Critical factors in promoting CA adoption in WANA

Adoption of CA requires solid local adaptive research, persistence in discovering the reasons behind failures, and belief in making the CA principles work. CA is a complex production system involving many components that must be adapted to local conditions and farmer needs. For this sort of technology the old linear model of agricultural knowledge flow – where researchers develop technologies and transfer these to extension agents who then transfer them to farmers – does not work. Farmer feedback and participation in the technology development and adaptation is vital.

Where possible, farmers should also take the lead in the extension process, with farmer-to-farmer exchange facilitated by both extension agents and researchers. However, as noted earlier, achieving widespread adoption of CA in WANA will require more than the development of viable technological options – it will also need considerable efforts to remove bottlenecks in the complete value chain, where bottlenecks are often more institutional (e.g. markets and policies) than technological. To address both the technical and institutional aspects of CA adoption, innovation platforms have been shown to be extremely important.

The innovation platform

The development of innovation platforms is one of the keys to the success of complex, multi-component technologies such as CA. An innovation platform involves a network of different agents and institutions working together and sharing information, to overcome bottlenecks in the production system. The platform will include farmers and as many of the key stakeholders in the principal local agricultural value-chains as possible: researchers, extension agents, machinery manufacturers, input and service providers, output market agents and intermediaries, credit providers, and policy-makers all participating in the development and testing of different aspects of the development process. It is important that all members of the platform stand to gain from increases in agricultural production and productivity. Some members of the platform will be doing the actual development, with others providing feedback on the performance of the innovation and its interaction with other components of the package. For example, machinery manufacturers or agrochemical company representatives can often provide solutions to equipment or weed problems that may not be evident to a network comprising only farmers and research and extension agronomists, and which would take limited networks considerable time to develop.

Small networks can generate valuable knowledge and technologies, but will be less efficient if important agents are absent. At the same time, if some important agents are not willing or able to participate, the network can still develop and function, although not as efficiently. It is more important to develop a functioning network of interested stakeholders than to expend considerable effort trying to incorporate uninterested partners.

Innovation platforms do not simply form by themselves. Normally it is difficult to get all the necessary players to talk to each other and become involved in trying to analyze and overcome bottlenecks to agricultural production and productivity (including, importantly, economic productivity). Energetic catalyzers who are convinced of the importance of CA and sustainable agricultural production systems are needed to push and encourage all of the different agents to participate in the innovation platform. Often, once platform members see the benefits they obtain from involvement they become far more enthusiastic about continued participation. In the past, catalyzers have come from local research and extension systems, international agencies, and even agrochemical companies. However, the role of leader, instigator, and catalyzer of the local innovation platforms is one that normally fits well with extension agents and researchers, and they should be encouraged and supported in efforts to develop and maintain local platforms.

The change from the linear model of information flow to that of an innovation platform implies important changes in the way researchers and extension agents function and interact with farmers. Extension agents need to be equipped with appropriate information for farmer empowerment and become, primarily, facilitators of farmer-to-farmer knowledge exchange instead of technology transfer agents. Researchers, however, should be involved in the innovation platform and learn from farmers of their needs and their perceptions of technology shortcomings. Researchers should concentrate on developing practical solutions to problems encountered with CA on farmers' fields rather than concentrating on comparing tillage systems.

To convert from conventional and traditional systems to CA is not a simple technical process, but rather one that requires a major simultaneous change in the mind-set of farmers, extension agents, researchers, technicians, and decision makers. It is therefore necessary to adopt a systems approach and get all stakeholders involved in an innovation platform focused on CA. In addition, joint resource mobilization is essential. Strengthened extension and focused and reliable subsidy programs will help CA progress in WANA. It should be obvious that these changes will not be easy, and there are likely to be many problems and pitfalls on the road to widespread adoption of CA in the region. However, the alternative of continuing along the present road of soil erosion, degradation, and unsustainability is socially unacceptable, and society owes it to future generations to leave the land and the environment in a better state than that which we inherited.

References

Boulal, H., M. El Mourid, H. Ketata and A. Nefzaoui. 2014. Conservation agriculture in North Africa. Pages 293–310 in Conservation Agriculture: Global Prospects and Challenges (R.A. Jat, K.L. Sahrawat and A.H. Kassam, ed.). CABI, Wallingford, UK.

Derpsch, R. 2008. Critical steps to no-till adoption. Pages 479–495. In: No-till farming systems, T. Goddard, M. Zoebisch, Y. Gan, W. Ellis, A. Watson, and S. Sombatpanit (ed.), Bangkok:World Association of Soil and Water Conservation (WASWC), p 479-495.

Derpsch, R., C.H. Roth, N. Sidiras and U. Köpke. 1991. Controle da erosão no Paraná, Brasil: Sistemas de cobertura do solo, plantio direto e preparo conservacionista do solo. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Eschborn, Germany.

Derpsch R. and T. Friedrich. 2011. CA Adoption Worldwide. FAO-CA website available online at: (http://www.fao.org/ag/ca/6c.html).

Ekboir J. 2002. Part 1. Developing no-till packages for small farmers. Pages 1–38 in CIMMYT 2000-2001 World Wheat Overview and Outlook: Developing No-Till Packages for Small-Scale Farmers (J. Ekboir ed.). CIMMYT, Mexico.

FAO. 2002. The Conservation Agriculture Working Group Activities 2000–2001. FAO, Rome.

Haddad, N., C. Piggin, A. Haddad and Y. Khalil. 2014. Conservation agriculture in West Asia. Pages 248–262 in Conservation Agriculture: Global Prospects and Challenges (R.A. Jat, K.L. Sahrawat and A.H. Kassam ed.). CABI, Wallingford, UK.

IAASTD (2008) Agriculture at a Crossroads: The Synthesis Report. Washington, DC, USA: International Assessment of Agricultural Knowledge, Science and Technology for Development. www.agassessment.org/Jouni, K. and F. Adada. 2010. Conservation agriculture in olive orchards in Lebanon. In Poster Presentation, 4th Mediterranean Meeting on Conservation Agriculture. Setif, Algeria. Options Méditerranéennes, A no. 96, IV Rencontres Méditerranéennes du Semis Direct.

Kassam, A., T. Friedrich, R. Derpsch, R. Lahmar, R. Mrabet, G. Basch, E.J. González-Sánchez and R. Serraj. 2012. Conservation agriculture in the dry Mediterranean climate. Field Crops Research 132: 7–17.

Moussadek, R., R. Mrabet, R. Dahan, A. Douaik, A. Verdoodt, E. Van Ranst and M. Corbeels. 2011. Effect of tillage practices on the soil carbon dioxide flux during fall and spring seasons in a Mediterranean Vertisol. Journal of Soil Science and Environmental Management 2(11): 362–369.

Mrabet, R. 2011. No-tillage agriculture in West Asia & North Africa. Pages 1015–1042 in Rainfed Farming Systems (P.G. Tow, I.M. Cooper, I. Partridge and C.J. Birch ed.). Springer, Dordrecht, Netherlands.

Mrabet, R. 2008. No-tillage systems for sustainable dryland agriculture in Morocco. INRA. Rabat, Morocco.

Mrabet, R. 2001. Le Semis Direct: Une technologie avancée pour une Agriculture durable au Maroc. Bulletin de Transfert de Technologie en Agriculture MADR-DERD. N° 76. http://agriculture.ovh.org.

Pieri, C., G. Evers, J. Landers, P. O'Connell and E. Terry. 2002. No-Till farming for sustainable rural development. Agriculture and Rural Development Working Paper. IBRD Rural Development Department, Washington.

Piggin, D.C C., A. Haddad and Y. Khalil. 2011. Development and promotion of zero tillage in Iraq and Syria. Pages 304–305 in Proceedings of the 5th World Congress on Conservation Agriculture, Australian Centre for International Agricultural Research, Brisbane, Australia. Available at: http://aciar.gov.au/WCCApapers (Powerpoint presentations used during the oral presentations and for workshops) (accessed November 12, 2014).

Piggin, D. C. and M. Devlin. 2012. Conservation agriculture: opportunities for intensifying farming and environmental conservation. Research to action: 2. ICARDA, Aleppo, Syria.

Sommer, R., C. Piggin, A. Haddad, A. Hajdibo, P. Hayek and Y. Khalil. 2012. Simulating the effects of zero tillage and crop residue retention on water relations and yield of wheat under rainfed semiarid Mediterranean conditions. Field Crops Research 132: 18–32.